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# Expanded Use of Unmanned Systems to Non-Maritime Domain Awareness Missions

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**August 2016**

Homeland Security

# N O T I C E

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Technical Report Documentation Page

| 1. Report No. | 2. Government Accession Number | 3. Recipient's Catalog No. |
|---|---|---|

| 4. Title and Subtitle | 5. Report Date / 6. Performing Organization Code |
|---|---|
| Expanded Use of Unmanned Systems to Non-Maritime Domain Awareness Missions | 5. Report Date: August 2016<br>6. Performing Organization Code: Project No. 7202 |
| 7. Author(s): Dr. Andrew Niccolai, Bill Posage, LT Keely Higbie, Jason Story, Scot Tripp | 8. Performing Report No.: R&DC UDI #1532 |
| 9. Performing Organization Name and Address: U.S. Coast Guard<br>Research and Development Center<br>1 Chelsea Street<br>New London, CT 06320 | 10. Work Unit No. (TRAIS)<br>11. Contract or Grant No. |
| 12. Sponsoring Organization Name and Address: COMMANDANT (CG-711)<br>US COAST GUARD STOP 7331<br>2703 MARTIN LUTHER KING JR AVE SE<br>WASHINGTON, DC 20593 | 13. Type of Report & Period Covered: Final or Interim<br>14. Sponsoring Agency Code: Commandant (CG-711)<br>US Coast Guard Stop 7331<br>Washington, DC 20593 |

15. Supplementary Notes

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16. Abstract (MAXIMUM 200 WORDS)

For the last several years, the Coast Guard Research and Development Center (RDC) has explored the use of unmanned systems to facilitate the enormous task of maintaining Maritime Domain Awareness (MDA). While MDA is vital to Coast Guard mission success, there are several areas of opportunity for unmanned systems to enhance or automate certain Coast Guard tasks or missions, which have not been heavily explored. Recent advancements in robotics and the affordability of command and control systems have changed the cost benefit ratio in favor of integrating more unmanned systems into standard Coast Guard missions beyond MDA. The purpose of this project is to expand on the use of unmanned systems to enhance or automate the non-MDA tasks associated with these missions. This study identified opportunities to expand the use of unmanned assets to each of the Coast Guard's statutory missions. MDA components that have already been assessed for unmanned capabilities will be identified and recommendations on which unmanned systems can be implemented for each specific mission will be made.

| 17. Key Words | 18. Distribution Statement |
|---|---|
| Unmanned Systems, Maritime Domain Awareness | Distribution Statement A: Approved for public release; distribution is unlimited. |

| 19. Security Class (This Report) | 20. Security Class (This Page) | 21. No of Pages | 22. Price |
|---|---|---|---|
| UNCLAS//Public | UNCLAS//Public | 30 | |

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# EXECUTIVE SUMMARY

For the last several years, the Coast Guard Research and Development Center (RDC) has explored the use of unmanned systems to facilitate the enormous task of maintaining Maritime Domain Awareness (MDA). While MDA is vital to Coast Guard mission success, there are several areas of opportunity for unmanned systems to enhance or automate certain Coast Guard tasks or missions, which have not been heavily explored. Recent advancements in robotics and the affordability of command and control systems have changed the cost benefit ratio in favor of integrating more unmanned systems into standard Coast Guard missions beyond MDA. For the purposes of this study, MDA components of the capability opportunities explored will be those that require persistent, systematic observance. Non-MDA missions will be defined as short-term, task-oriented efforts outside the traditional role of surveillance and reconnaissance. Since the Coast Guard is a maritime service, this study will focus on systems operating in or near the maritime environment, specifically UAVs, USVs, UGVs, and UUVs.

The purpose of this project is to expand on the use of unmanned systems to enhance or automate the non-MDA tasks associated with these missions. This study identified opportunities to expand the use of unmanned assets to each of the Coast Guard's statutory missions. MDA components that have already been assessed for unmanned capabilities will be identified and recommendations on which unmanned systems can be implemented for each specific mission will be made.

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# LIST OF ACRONYMS, ABBREVIATIONS, AND SYMBOLS

| | |
|---|---|
| ATON | Aids to Navigation |
| AUV | Autonomous Underwater Vehicle |
| CONOP | Concept of Operations |
| CBRNE | Chemical, Biological, Radiological, Nuclear, Explosives |
| DoD | Department of Defense |
| EEX | Exclusive Economic Zone |
| FL | Flight Level |
| FSV | Fully Submersible Vessels |
| GAO | Government Accountability Office |
| GPS | Global Positioning System |
| HSDN | High Seas Drift Net |
| ISR | Intelligence, Surveillance, Reconnaissance |
| MDA | Maritime Domain Awareness |
| MOL | Military Outload |
| NSC | National Security Cutter |
| PWCS | Ports, Waterways, and Coastal Security |
| RAMPS | Robotic Aircraft for Maritime Public Safety |
| RDC | Research and Development Center |
| RFI | Request for Information |
| ROV | Remotely Operated Vehicle |
| SAR | Search and Rescue |
| SPSS | Self-Propelled Semi-Submersible |
| UAS | Unmanned Aerial System |
| UAV | Unmanned Aerial Vehicle |
| UGV | Unmanned Ground Vehicle |
| USCG | United States Coast Guard |
| USV | Unmanned Surface Vehicle |
| UUV | Unmanned Underwater Vehicle |
| VTOL | Vertical Take-Off and Landing |
| WHOI | Woods Hole Oceanographic Institute |

# 1. INTRODUCTION

## 1.1 Background

For the last several years, the Coast Guard Research and Development Center (RDC) has explored the use of unmanned systems to facilitate the enormous task of maintaining Maritime Domain Awareness (MDA). While MDA is vital to Coast Guard mission success, there are several areas of opportunity for unmanned systems to enhance or automate certain Coast Guard tasks or missions, which have not been heavily explored. Recent advancements in robotics and the affordability of command and control systems have changed the cost benefit ratio in favor of integrating more unmanned systems into standard Coast Guard missions beyond MDA. The Coast Guard is responsible for performing numerous tasks in support of its 11 statutory missions. Some of these tasks include inspection and servicing of Aids to Navigation (ATON), enforcing safety and security zones on our nation's waterways, and monitoring of those waterways.

Thus, the purpose of this project is to expand on the use of unmanned systems to enhance or automate the non-MDA tasks associated with these missions. For more information on the application of unmanned systems to MDA and other persistent missions please see USCG R&D Center referenced reports in Appendix A.

## 1.2 Objectives

- Identify capability needs for each Coast Guard statutory mission outside of MDA and possible areas of automation.
    - Areas where Coast Guard "developmental opportunities" exist.
    - Areas where Coast Guard is spending more money than desired.
    - "Dirty, dull, or dangerous" missions.
    - Time consuming tasks that if automated could free up the Coast Guard for more critical missions.
- Explore and identify unmanned platforms, sensors, and automation technology capability and limitations (through continued research, professional journal/publication readings, and conference attendance).
    - Develop/maintain unmanned systems professional library at RDC.
- Recommend key considerations for a Coast Guard Unmanned Systems Roadmap.
    - Business Case Analysis considerations for unmanned systems implementation.
    - Provide suggestions for potential follow-on Request for Information beyond traditional intelligence gathering for airborne, surface, subsurface and land systems.
    - Capabilities Demonstrations to assess performance characteristics.

## 1.3 Scope of Study

This study will identify opportunities to expand the use of unmanned assets to each of the Coast Guard's statutory missions. MDA components that have already been assessed for unmanned capabilities will be identified and recommendations on which unmanned systems can be implemented for each specific mission will be made.

The *National Strategy for Maritime Security: National Maritime Domain Awareness Plan*[1] defines MDA as "the effective understanding of anything associated with the maritime domain that could impact security, safety, economy, or environment in the United States." The military utilizes techniques like intelligence, surveillance, and reconnaissance (ISR), i.e. systematic observation techniques, to improve its effective understanding or awareness. These techniques are typically employed for an extended period of time, and may be performed over days, weeks, months, or even years. Thus, for the purposes of this study, MDA components of the capability opportunities explored will be those that require persistent, systematic observance. Non-MDA missions will be defined as short-term, task-oriented efforts outside the traditional role of surveillance and reconnaissance.

The National Institute of Standards and Technology[2] defines unmanned systems as “an electro-mechanical system, with no human operator aboard, that is about to exert its power to perform designed missions.” It continues, “may be mobile or stationary; includes unmanned ground vehicle (UGV), unmanned aerial vehicles (UAV), unmanned underwater vehicles (UUV), unmanned surface vehicle (USV), unattended munitions (UM), and unattended ground sensors (UGS).” Since the Coast Guard is a maritime service, this study will focus on systems operating in or near the maritime environment, specifically UAVs, USVs, UGVs, and UUVs.

# 2. BASIC INFORMATION ON UNMANNED SYSTEMS

## 2.1 Unmanned Aerial Vehicles (UAV)

The term UAV is indicative of the actual flight vehicle whereas the term Unmanned Aerial Systems(UAS) recognizes that often there is substantial equipment required that does not fly, e.g. ground control stations, launchers, directional antennas, etc. The Coast Guard organizes UAS using a grouping system defined by the Department of Defense (DoD).

Table 1. UAV Groups as defined by the DoD.

| | Maximum Weight (lbs) | Normal Operating Altitude (ft) | Speed (kts) | Representative UAS |
|---|---|---|---|---|
| Group 1 | 0 – 20 | <1200 AGL | 100 | WASP III, PUMA |
| Group 2 | 21 – 55 | <3500 AGL | < 250 | ScanEagle |
| Group 3 | < 1320 | < FL 180 | < 250 | Shadow |
| Group 4 | >1320 | < FL 180 | Any Airspeed | Fire Scout, Predator |
| Group 5 | >1320 | < FL 180 | Any Airspeed | Global Hawk |

The Coast Guard has been conducting evaluations of Group 1 UAVs and their applicability to maritime missions. In conjunction with DHS, the RDC is currently conducting the Robotic Aircraft for Maritime Public Safety (RAMPS) project to evaluate small UAVs and their ability to conduct various missions in a maritime environment. In the near term a Group 2 UAS will be hosted by the National Security Cutter (NSC). The NSC’s UAV will mainly be used for MDA missions but depending on the payload options of the systems selected it could be used for many of the other missions identified in this report. The Coast Guard also participates in Group 4 flight operations through DHS partnerships.

The FAA is the regulatory body overseeing UAV operations in the national airspace. The recent explosion in the recreational UAV market has resulted in additional scrutiny of unmanned aviation operations. Additionally, the Coast Guard maintains its own requirements for conducting flight operations. The process to acquire the necessary permissions to fly UAVs can be lengthy and resource intensive.


Figure 1. Group 1 UAV launched during a 2015 joint exercise with the Marines. (US Navy Photo)

#### 2.1.1 Capabilities

UAVs have the capability to provide real time aerial views of operations resulting in better situational awareness for decision making. The transiting speed of even the smallest UAV is considerably higher than most of their surface and subsurface counterparts. This high speed allows UAVs to get to operating areas faster and then to cover more area once they arrive on scene. UAV payloads often determine their applicability to specific missions. The basic payload for UAVs usually included advanced electro optical and/or infrared cameras that can aide in target identification.

#### 2.1.2 Limitations

Many of the most recent UAS developments have been focused on supporting ongoing conflicts in desert environments. This means many of the UAVs currently available are not marinized and unable to operate in a maritime environment. Many smaller UAS do not have transponders or sense and avoid capabilities. Often this means they are limited to conducting flights only in special use airspace. All UAS require a ground station consisting of command and communication equipment. Even for smaller Group 1 systems this equipment footprint can be hard to accommodate on Coast Guard boats where space is already limited. UASs are weight sensitive which can limit the payload they carry. This in turn limits what sensors can be used. Weight sensitivity is especially important for the smaller UAS.

### 2.2 Unmanned Surface Vehicles (USV)

The concept of operating surface vessels remotely has been explored for over a hundred and twenty years. One of the first examples of using radio frequencies to control vessels remotely was in 1898 when Nikola Tesla developed the TELEAUTOMATA. USVs were used by Germany in World War II to deliver explosives in attacks on allied shipping. The US Navy uses unmanned target vessels extensively as targets of live fire exercises. More recently the US Navy has developed a number of unmanned platforms mainly focused on Anti-Submarine Warfare and Mine Counter Measures. 4

Figure 2. Boat crew prepares to recover a USV during Arctic Technology Evaluation 2015. (USCG Photo)

The Coast Guard has participated in a number of joint demonstration using various types of UVS. The Coast Guard is the federal regulatory body responsible for unmanned vessel operations in navigable waters of the United States. The requirements for operating vessels, including unmanned vessels, are outlined in the Navigation Rules and Regulations. Currently there are no specific rules for unmanned operations, but unmanned operations must be conducted in a way that meets the requirements of the existing rules. One of the more challenging rules for unmanned operations is “Rule 5” that states a proper look out must be maintained at all times. It is the responsibility of the vessel owner/operator to ensure this requirement is capable of being met. As the popularity and capability of unmanned vessels increase, especially in the commercial and eventually in the recreational markets, the Coast Guard may need to further clarify the regulations pertaining to unmanned vessel operations.

### 2.2.1 Capabilities

When compared to other unmanned platforms in the maritime environment, unmanned surface vessels provide and increased payload and longer endurance. Large payloads can be accommodated by increasing the volume of the USV since it is supported on station by the vessel buoyancy. This same feature allows it to stay in the operational area for longer periods of time because it can conserve energy by drifting. New sensors and payloads that may be too heavy or too large to be flown on UAVs could be easily accommodated on USVs. A growing trend is to couple USVs with UUVs to provide increased capabilities of both systems.

### 2.2.2 Limitations

Communications with unmanned vessels can be difficult using direct line of sight communication options. The theoretical communication range is often limited by antenna height but practical experience indicates that reliable communications can be expected with 10 miles. Beyond line of sight communications, satellite communication is necessary resulting in increased complexity and cost of communication systems.

## 2.3 Unmanned Underwater Vehicles (UUV)

UUVs offer access to one of the last unexplored areas on earth. The level of autonomy in UUVs varies dramatically between platforms. There are two basic groups of UUVs, remotely operated vehicles (ROV) and Autonomous Underwater Vehicles (AUV). These two groupings are a result of the difficulty of long range communications underwater. Traditional electromagnetic communication methods are not capable of propagation through water. Some methods for wireless underwater communication are available, but they do not provided the bandwidth requirements required for constant vehicle control or video transmission.

ROVs use a tether back to the operator on the surface that relays command and control signals as well as live video feeds. ROV operations can be limited by the length of the tether and how efficiently it can relay the signals. The many newer ROVs use fiber optic cables that are smaller in size but provide more bandwidth over traditional cables.

Figure 3. A Coast Guard diver supervises the launch of an ROV. (USCG Photo)

Underwater vehicles that are not tethered are often designed to perform their mission autonomously because of the difficulties of underwater communications. The issue is even more challenging because AUV's do not receive GPS signals underwater and often must rely on inertial navigation systems to determine their location. AUV's are often programmed to conduct a specific mission before being launched and then are released to autonomously complete their mission without input from a human operator. Typically AUVs will either return to the operator or to the surface to transmit the data that has been collected. Some AUVs use changes in buoyancy to glide up and down through the water column. This form of propulsion can be very efficient and allow the AUV to perform long endurance missions. The application of AUVs to many of the mission scenarios in this report are limited due to the limited payload options for existing AUVs. Many of the AUVs are modular so they could receive different payloads if they were developed for these missions.

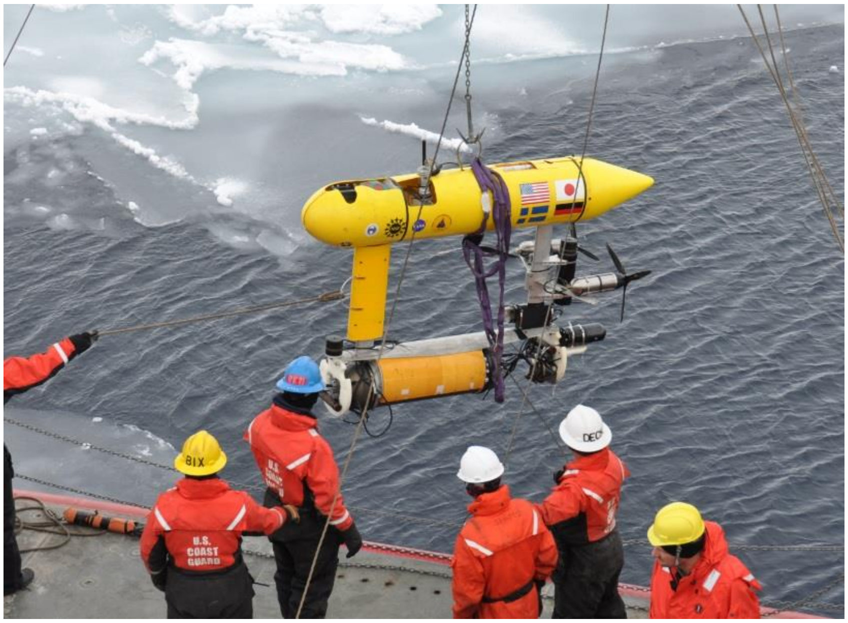

Figure 4. WHOI’s AUV being deployed during RDC’s Arctic Technology Evaluation 2013. (USCG Photo)

#### 2.3.1 Capabilities

UUVs provide the capability to grant access to the underwater environment cost effectively and without substantial risk to divers. UUVs can be quickly deployed and retrieved from extreme ocean depths that would require long decompressions times for divers. UUVs can also travel to depths well beyond those achievable to even the most skilled divers. UUVs provide this capability at a cost considerably less than manned submarines.

#### 2.3.2 Limitations

The biggest limitation for ROVs is the tether to the operator. Basic electrical principles dictate that as the tether gets longer it must get larger to provide effective communications between the operator and the vehicle. Larger cables result in more drag not only resisting the movement of the vehicle but also increase the impacts of currents acting against the tether in the water. ROV tethers can also get unintentionally tangled in underwater debris resulting in the loss of the vehicle.

Typical AUV speeds are less than five knots, limiting them for many Coast Guard applications. AUV operations are also limited by the availability of onboard power. AUV designers must manage the conflicting requirements of volume, drag, and power to ensure the vehicle will be able to execute its mission. AUVs are also limited in their ability to send and receive communications while operating underwater.

### 2.4 Unmanned Ground Vehicles (UGV)

UGVs have a long operational history with the military. Almost every major combatant in the World War II developed some type of remotely controlled armored or explosive laden ground vehicle. Since then there have been sporadic improvements in the command and control systems of UGVs. Advancements in robotics have resulted in most UGVs being capable of basic manipulation skills. In the wars in Iraq and Afghanistan the US military has deployed thousands of UGVs to disable explosive devices, provide situational awareness, and sweep for mines. Unmanned systems are great for these missions because they can remove personnel from these extremely dangerous tasks.

#### 2.4.1 Capabilities

One of the best applications of UGVs is to replace personnel in dangerous situations. Such jobs as bomb detection and detonation or nuclear reactor repair are common uses for UGVs. The Coast Guard has trained to use UGVs when responding to oil and other chemical spills on land.

#### 2.4.2 Limitations

UGVs biggest limitation is the difficulty in designing them for the terrain they will operate on. Many UGVs are designed for specific operating environments and their capabilities do not transfer well in to other environments. Many of the UGVs available today are restricted to line of sight operations and are not capable of long range communications. There have been some high profile autonomous UGV prototypes recently, but truly autonomous vehicle are yet to be commercially viable.

# 3. APPLICATION OF UNMANNED SYSTEMS TO COAST GUARD STATUTORY MISSIONS

## 3.1 Ports, Waterways, and Coastal Security (PWCS)

The PWCS mission entails the protection of the U.S. Maritime Domain and the U.S. Marine Transportation System (MTS) and those who live, work or recreate near them; the prevention and disruption of terrorist attacks, sabotage, espionage, or subversive acts; and response to and recovery from those that do occur. Conducting PWCS deters terrorists from using or exploiting the MTS as a means for attacks on U.S. territory, population centers, vessels, critical infrastructure, and key resources. PWCS includes the employment of awareness activities; counterterrorism, antiterrorism, preparedness and response operations; and the establishment and oversight of a maritime security regime. PWCS also includes the national defense role of protecting military loading operations. Unmanned systems could be integrated into PWCS in the following ways:

#### 3.1.1 Monitoring of Ports and Waterways

PWCS requires the monitoring of thousands of miles of the maritime environment. The RDC and other government agencies have been invested substantially in developing unmanned systems that provide MDA of Ports and Waterways. The non-MDA function of this mission includes creating moving security zones around protected assets or the temporary monitoring of locations for high profile events. Providing security to moving assets could be more effective if supported by unmanned vessels. Unmanned vessel could act as a force multiplier in conjunction with manned Coast Guard Boats that typically provide escorts and enforce security zones. UUVs have been used by the Coast Guard and other government agencies to conduct underwater security sweeps for high profile events. Their ability to provide this function will improve with advancement in underwater sensors.

### 3.1.2 Disaster Response

The Coast Guard is the federal first responder in the maritime environment in the event of a natural or man-made disaster. In the first moments of a disaster many of the risk are unknown. Unmanned assets are an excellent way to gain information on the scope of the disaster and the associated risk factors for the response without endangering personnel. UAVs provide are excellent platform for conducting the initial unmanned disaster response. They offer the ability to provide an overhead view of the extent of the damage. After a disaster waterways could be blocked preventing passage of USVs and UUVs. After the damage has been surveyed from the air, USV's in conjunction with UUV could be used to verify coastal navigation has not been effected by submerged hazards. Using unmanned vessels in this role would potentially allow manned asset to focus on other task such as evacuations.

## 3.2 Drug Interdiction

The Coast Guard is the lead federal agency for maritime drug interdiction and shares lead responsibility for air interdiction with the U.S. Customs Service. As such, it is a key player in combating the flow of illegal drugs to the United States. The Coast Guard's mission is to reduce the supply of drugs from the source by denying smugglers the use of air and maritime routes in the Transit Zone, a six million square mile area, including the Caribbean, Gulf of Mexico and Eastern Pacific. In meeting the challenge of patrolling this vast area, the Coast Guard coordinates closely with other federal agencies and countries within the region to disrupt and deter the flow of illegal drugs. Unmanned systems could be integrated into drug interdiction missions in the following ways:

### 3.2.1 Vessel Detection

Identification of vessel of interest for drug interdiction using unmanned systems has long been a goal of the Coast Guard. This has been identified as the main mission of many of the unmanned systems evaluated to date. Although predominately a MDA function, non-MDA function of this mission would include unmanned surge forces to saturate areas of high traffic. Unmanned systems could be used in conjunction with other manned systems to provide an overt presence to deter the transportation of illegal drugs. This mission could be fulfilled by any unmanned system; it only requires multiple, interoperable systems.

### 3.2.2 Vessel Marking and Tracking

After a vessel has been detected sometimes the mission needs require that it be marked and tracked before interdiction. This could be because the Coast Guard assets are busy with another interdiction or because there are no manned surface assets in the vicinity. USVs could provide the ability to mark and track a target vessel until manned asset can be vectored in. After detection UAVs could be launched and task with covertly tracking the target allowing time for the manned assets to arrive on scene. All unmanned CONOPS for drug interdiction should also be applicable to Self-Propelled Semi-Submersible (SPSS)/ Fully Submersible Vessels (FSV).

### 3.2.3 Non-Compliant Vessel Stopping

A constant issue for Coast Guard personnel is how to compel compliance with law enforcement instructions. Drug smugglers have gone to great extents in the past to prevent their capture after they have been instructed to stop their vessel. Often these situations escalate and put the Coast Guard personnel and the non-compliant vessel occupants in grave danger. Using unmanned systems to compel compliance would reduce the risk to Coast Guard boat crews and potentially de-escalate the situation. It is unlikely that in the near term UUVs will be able to operate over the range of speeds required to intercept non-compliant vessels. USVs would be the best option for vessel interdiction. Many of the non-lethal techniques currently employed by boat crews could easily be remotely deployed from an USV. There are some efforts to adapt UAVs for this purpose, but UAVs offer a limited payload capacity that cannot accommodate relatively heavy vessel stopping equipment.

### 3.2.4 Drug Detection

Drug detection offers one of the few applications of UGVs to Coast Guard missions. It has been demonstrated that UGVs can be deployed on large ships that would provide boarding teams advanced situational awareness of the environment onboard. Additional sensor suites on the UGV can take measurements and provide bulkhead penetrating imagery that could be used to reveal the location of illegal drugs in hidden compartments.

## 3.3 Aids to Navigation

Per 14 USC § 81, the Coast Guard's Aids to Navigation (ATON) mission includes establishing, maintaining, and operating visual and electronic navigational aids, navigation information, and vessel traffic management services for U. S. navigable waterways and ensuring that bridges and causeways allow for the safe passage of waterborne commerce and other marine traffic. Unmanned systems could be integrated into ATON missions in the following ways:

### 3.3.1 ATON Surveys

It is imperative that navigation buoys maintain their position in order to be reliable aids to mariners. Verifying the exact position of the various types of aids can be very time consuming. Unmanned systems have the potential to greatly increase the speed and efficiency of this task. UAVs could be used to quickly verify the exact location of buoys and other aids using their onboard GPS and other target tracking payloads. The RDC is currently planning a demonstration of this mission in the winter of 2016.

### 3.3.2 Post Storm and Waterway Surveys

After severe storms the Coast Guard and NOAA are responsible for ensuring safe passage of marine traffic through affected waterways. It is vital that the waterways are opened quickly after a storm so relief supplies can be delivered by water. Unmanned vessels outfitted with bathymetric payloads could be dispatched to determine if any hazards to navigation exist in the affected waterways. NOAA has already demonstrated the effectiveness of USVs conducting underwater surveys. The next advances will be in automating this task in order to deploy multiple assets to quickly re-open navigable waterways.

### 3.3.3 ATON Temporary Marker

Often there is a need for temporary ATONs for post storm notifications, obstructed channels, etc. A temporary ATON could act as a mobile notice to mariners displaying the most recent information pertinent to safe navigation. Given the need for stationary surface deployment, a USV is the preferred unmanned platform. Unmanned ATONs should be developed for this specific application keeping in mind the ATON location. Unmanned ATONs might require a deviation from the more traditional USV designs.

## 3.4 Search and Rescue (SAR)

Minimizing the loss of life, injury, property damage or loss by rendering aid to persons in distress and property in the maritime environment has always been a Coast Guard priority. The Coast Guard is recognized worldwide as a leader in the field of search and rescue. Under 14 USC § 88, "In order to render aid to distressed persons, vessels, and aircraft on and under the high seas and on and under the waters over which the United States has jurisdiction and in order to render aid to persons and property imperiled by flood, the Coast Guard may:

- Perform any and all acts necessary to rescue and aid persons and protect and save property;
- Take charge of and protect all property saved from marine or aircraft disasters, or floods, at which the Coast Guard is present, until such property is claimed by persons legally authorized to receive it or until otherwise disposed of in accordance with law or applicable regulations, and care for bodies of those who may have perished in such catastrophes;
- Furnish clothing, food, lodging, medicines, and other necessary supplies and services to persons succored by the Coast Guard; and
- Destroy or tow into port sunken or floating dangers to navigation."

Unmanned systems could be integrated into SAR missions in the following ways:

### 3.4.1 Shallow Water Rescue

One of the more challenging SAR scenarios can be shallow water rescues. Coast Guard boat crews cannot execute a rescue in water that is too shallow for their own vessels. Aviation assets are regularly required to assist in shallow water rescues if boat crews cannot reach them. USVs are often much smaller than existing Coast Guard boats and therefore can access shallower waters to deliver tow lines, communication equipment, or medical supplies. Depending on the carrying capacity, a UAV could be used in a similar manner.

### 3.4.2 Heavy Weather Rescue

Unmanned systems capable of operating in heavy weather could allow the Coast Guard to provide a response asset in the most extreme weather conditions. Despite using the best equipment and vessels available, there are still conditions that exceed the operating parameters of the Coast Guard response assets. Unmanned assets could be sent into the worst weather events with no concern of loss of life to Coast Guardsmen. The higher operating speeds of UAS make them a good option for heavy weather response. The UAS would likely need to be rather large to provide necessary power plant to achieve the speeds necessary to overcome high winds as well as the ability to deliver large rescue equipment like dewatering pumps and life rafts. Future developments in UUVs could make them a good heavy weather response platform because the effects of large breaking waves diminish as depth increases.

### 3.4.3 Ice Rescue

Unmanned systems have the ability to improving the efficiency of ice rescues. A typical ice rescue scenario involves a person falling through thin ice and not being able to get out from the hole they have fallen into. Rescuers that approach the person in the ice hole are at risk of becoming trapped in the ice themselves. Vertical Takeoff and Landing (VTOL) UAVs have been used to deliver line to the victim so they can be pulled out. This method is dependent on the size of the VTOL UAV and its ability to carry and/or drag a line the necessary distance to the victim. A USV type vehicle could be easily developed to assist with ice rescues. Usually ice rescues are conducted at short distances and COTS remote control components would suffice. Another benefit of a tethered vehicle would be if the tether could act as a rescue rope to pull the victim back to safety. The vessel could have a track system able to grip the ice as well as be buoyant enough to cross open water areas. The technology to construct and demonstrate a vehicle for this mission already is in existence in the UGV and USV markets.

### 3.4.4 Life Raft Delivery

Mass rescue scenarios are challenging SAR events. When there are a large number of people in the water following a casualty like a ferry or cruise ship sinking the quick delivery of life rafts can make the difference between life and death. One concept is to make the life rafts themselves unmanned systems that can be remotely controlled to ensure they get to where the most survivors are located. There have been numerous demonstrations of various concepts in the past.

## 3.5 Living Marine Resources Law Enforcement

Protecting the U.S. EEZ and key areas of the high seas is an important mission for the Coast Guard. The Coast Guard enforces fisheries laws at sea, as tasked by the Magnuson-Stevens Fisheries Conservation and Management Act (MSFCMA). Our fisheries priorities are, in order of importance, protecting the U.S. Exclusive Economic Zone from foreign encroachment, enforcing domestic fisheries law, and enforcing international fisheries agreements. Unmanned systems could be integrated into living marine resource law enforcement missions in the following ways:

### 3.5.1 Marine Mammal Alerts

Unmanned systems could be deployed to detect the presence of whales and alert shipping traffic in high collision risk areas. The current method of reducing the probability of a whale strike is to reduce the speed of ships that transit through areas know to be on the migration routes of marine mammals. Reducing the speed of marine traffic can result in additional costs to transiting ships. Unmanned systems could be used to monitor for marine mammals and alert ships to their presence, only requiring a reduction in speed when whales are in the vicinity. USVs and UUVs would be the preferred platform because that can be outfitted with acoustic payloads capable of passive detection of marine mammals.

### 3.5.2 Monitoring Closed Areas

The Coast Guard often needs to restrict the access to areas for a wide range of reasons. One specific need is to monitor Lower Mississippi River (LMR) closed areas for violations and to image the violators for enforcement action. Instead of dispatching a manned asset for this purpose, an unmanned system could be used thus freeing the manned asset for other missions. A USV or smart buoy would be best for this mission.

The USV would need to be capable of relatively long endurance or be able to autonomously anchor itself to maintain station in the river currents. Alternatively UAVs could be deployed from a boat to verify that no violators are present in the area. To accomplish this mission only an electro-optical sensor package would be required.

## 3.6 Marine Safety

The Coast Guard's Marine Safety mission includes enforcing safe and environmentally sound operation of U.S. flagged vessels throughout the world, asserting authority over foreign vessels operating in U.S. Port State Controlled waters to enforce safe, secure, and environmentally sound operations in U.S. waters, issuing licenses and documents to qualified mariners, and promoting competency through a combination of training courses, requisite experience, and examinations, conducting inspections of U.S. and foreign vessels, marine facilities, and review plans for vessel construction, alteration, equipment, and salvage, and developing and monitoring vessel construction and performance. Unmanned systems could be integrated into marine safety missions in the following ways:

### 3.6.1 Pollution Monitoring

Pollution monitoring is a very difficult mission because often the perpetrator is intentionally hiding their actions. UAVs can provide a covert way to monitor a suspected polluter. Many of the group 1 UAVs use electric motors and can be very difficult to hear and see from the surface. USVs could also be used to sample water around a vessel to verify it is not leaking any toxic substances. There are some specific cases where a UUV would be best suited for this mission. Some pollutants are denser that water and sink to the bottom making them difficult to detect from the surface.

## 3.7 Defense Readiness

The Defense Readiness mission supports the National Military Strategy and Department of Defense (DoD) operations by ensuring Coast Guard assets are capable and equipped to deploy and conduct joint operations in support the most critical needs of the combatant commanders in the following major national-defense missions:

1. Maritime interception/interdiction operations.
2. Military environmental response.
3. Port operations, security, and defense.
4. Theater security cooperation.
5. Coastal sea control operations.
6. Rotary-Wing Air Intercept (RWAI) operations.
7. Combating terrorism operations.
8. Maritime Operational Threat Response (MOTR) support.

These support the unified combatant commanders and require the Coast Guard to execute essential military operations in peacetime, crisis, and war. Unmanned systems could be integrated into defense readiness missions in the following ways:

### 3.7.1 Harbor Security and Defense

The Coast Guard is responsible for enforcing safety and security zones around Military Outload (MOL) activities. Unmanned systems could be used in a number of ways to compliment manned security details. USVs could be positioned between potential security threats and the MOL activity to provide an additional layer of defense. UAS could be deployed in order to provide better situational awareness and earlier target identification.

### 3.7.2 Security Zone Enforcement

Unmanned systems can be used to augment security provided by manned Coast Guard assets. Security zone enforcement missions could be accomplished by USVs outfitted with non-lethal weapons to deter potential attackers. There are a number of non-lethal technologies like malodorants, blunt impact munitions, and directed energy that could be installed on a USV for this purpose. The Navy as well as other foreign countries have a number of USV platforms that has been specifically developed for this purpose.

### 3.7.3 CBRN Attack Response and Recovery

If a Chemical, Biological, Radiological, or Nuclear (CBRN) attack is perpetrated in a maritime environment unmanned systems could be very beneficial to determine the severity of the attack and it potential risk to personnel. The CONOP would be to send in an UAV or USV to measure the air and its contaminants to determine if it is safe for personnel to be in the area. As the event transitions into a recovery, continued monitoring would be necessary and an unmanned platform could be used for this purpose freeing up manned assets for other tasks. Specific payloads would have to be developed for this mission. There exist the potential for some technology foraging using existing sensors to develop a payload that could detect and report back on a CBRN attack.

## 3.8 Migrant Interdiction

As the United States' primary maritime law enforcement agency, the Coast Guard is tasked with enforcing immigration law at sea. The Coast Guard conducts patrols and coordinates with other federal agencies and foreign countries to interdict undocumented migrants at sea, denying them entry via maritime routes to the United States, its territories and possessions. Thousands of people try to enter this country illegally every year using maritime routes, many via smuggling operations. Interdicting migrants at sea means they can be quickly returned to their countries of origin without the costly processes required if they successfully enter the United States.

### 3.8.1 Migrant Vessel Detection

The first step in deterring illegal immigration by sea is detecting vessels carrying migrants. This can be exceptionally difficult given the numerous unique vessels used for this purpose. Many of the migrants construct their own vessels and incorporate design features intended to thwart detection. Vessels designs vary from drifting rafts to high speed vessels. USVs could be deployed with radar coverage of areas known to be used by migrant vessels. UAVs could also be used to conduct searches for migrant vessels from the air using radar in conjunction with standard EO/IR payloads.

### 3.8.2 Migrant Vessel Stopping

When migrant vessels are interdicted often the occupants are non-compliant and do not stop their vessel. At times the migrant even threaten violence against themselves and others. Unmanned platforms could initially be used to de-escalate these scenarios. Unmanned aerial systems could provide initial intelligence about the type of vessel and it occupants. Additionally any of the CONOPs discussed in Section 3.2.3 could be used to stop migrant vessel from entering the US.

## 3.9 Marine Environmental Protection

The Marine Environmental Protection program develops and enforces regulations to avert the introduction of invasive species into the maritime environment, stop unauthorized ocean dumping, and prevent oil and chemical spills. This mission is complemented by the Marine Safety program's pollution prevention activities.

### 3.9.1 Oil Spill Detection

A near term opportunity for the integration of unmanned technology is in the detection of oil spills. There is a need for persistent MDA type monitoring, but this report will focus on short term monitoring of specific investigations of potential oil spills. UAVs and USVs are the preferred platform for detecting oil on the surface, but UUVs that could detect subsurface oil are also needed. UAVs could provide a better situational awareness of the extent of the oil spill and its real time location. In the Deepwater Horizon Response surface oil would be detected by air and by the time a response vessel had transited to that location the plume had drifted elsewhere. A long endurance UAV could detect the oil and track it as moved with the wind and current providing real time updates on its location as response assets were vectored in. There are some sensors commercially available for the detection of oil that could be easily integrated onto unmanned assets. However, many of these sensors only indicate the presence of oil, not a measurement of the oil thickness to determine if it is in sufficient quantities to be collected. The payload for UUV or USV oil spill should also be able to take samples of the detected oil for further analysis.

### 3.9.2 Oil Spill Response

After an oil spill is detected there are a number of ways unmanned platforms could be used to assist in the recovery efforts. USVs could be used to deploy oil containment booms. Several USV companies already advertise that this is an intended use of their system. USVs could be deployed in shallow water environments that are only accessible to small vessel with a shallow draft. Smaller unmanned systems could also be used in environmentally sensitive areas that would be damaged by larger equipment.

USVs could be used to assist in the skimming of oil during the response. Traditional recovery systems use an oil containment boom to funnel surface oil to the collector. A USV could be used to maintain a wide opening of the funnel to gather more oil and allow response boats to conduct skimming operations individually. Another application of unmanned systems in oil spill response is the ignition of in-situ burns. Igniting collected oil can be dangerous because the properties of the oil and its flammability are often unknown. The collected oil could be ignited from specially designed UAVs or USVs.

### 3.9.3 Chemical Spill Response

Substantial amounts of hazardous chemicals are transported safely on the navigable waters of the US every day. But when accidents do occur responding to chemical spills can present a wide variety of dangers to Coast Guard personnel. Often toxic fumes are present, but additionally the chemicals could cause burns or pose an explosion risk. Deploying an unmanned asset to respond to a chemical spill would allow the operators to be at a safe distance reducing the risk to personnel. It is difficult to propose CONOPs for a chemical spill since this topic covers such a wide range of substances, but an EO/IR payload could provide the ability to evaluate the situation before personnel entered the area. Additionally, other existing chemical detection sensors could be integrated and installed for specific chemical response categories.

## 3.10 Ice Operations

The Coast Guard conducts icebreaking services to assist vessels and communities in emergency situations and facilitate essential commercial maritime activities in the Great Lakes and Northeast regions. Beyond domestic operations, the Coast Guard operates the only U.S.-flagged heavy icebreakers capable of providing year-round access to the Polar Regions. In 2008, the busiest iceberg season in a decade, the International Ice Patrol facilitated commerce by broadcasting position information on 1,029 icebergs crossing south of 48 degrees north latitude.

### 3.10.1 Iceberg Detection

Iceberg detection missions take place far from the shore in the North Atlantic. Large UAVs with extended endurance times would be required to conduct these missions. Many of the UAVs that are being evaluated for their ability to conduct MDA missions could easily be transitioned into iceberg detection. Specialty long endurance USVs could also be used to patrol the shipping lanes of the North Atlantic and provide real time ice warnings.

### 3.10.2 Iceberg Tagging and Tracking

Once the icebergs have been detected there is a mission need to tag and track them as they drift south. A potential CONOP for this would be to land the unmanned asset on the iceberg and then transmit its location. A solar power source could be used to ensure the long mission endurance required for this CONOP. Alternatively the UAV could drop a beacon onto the iceberg that would report its location similar to how it is currently done by manned over flights.

### 3.10.3 Inland Waterways Icebreaking

Unmanned systems could be used to measure ice thickness so that the Coast Guard's limited icebreaking fleet can better prioritize its missions. Research is being conducted to develop a UAV payload for this mission but currently no COTS UAV sensors are available that can provide reliable ice thickness measurements. As USVs become more autonomous, the icebreaking mission is especially well suited for automation. An unmanned icebreaker would have to be much larger than most USVs are today. A large USV could be operated in front of non-ice hardened vessels. The close proximity of the USV would make the command and control system relatively easy and could be accomplished with existing COTS components.

### 3.10.4 Arctic Operations

The RDC has worked extensively with NOAA and their group 1 UAV for ice route mapping in both the Arctic and Antarctic. In the past this mission was conducted using rotary wing Aviation Detachments (AVDET). Although the UAV did provide some imagery useful for determining the path of least resistance, the operating environment proved to be very challenging for a group 1 UAV. Often winds exceeded the operational parameter of the UAV. Some tests were conducted with a prototype anti-icing system on the UAV but currently no reliable anti-icing measures are available for small UAVs. The constant fog and low cloud ceiling that reduced visibility was also a limiting factor for operations in the Polar Regions.

## 3.11 Other Law Enforcement

Preventing illegal foreign fishing vessel encroachment in the Exclusive Economic Zone (EEZ) is a primary Coast Guard role vital to protecting the integrity of the Nation's maritime borders and ensuring the health of U.S. fisheries. The Coast Guard also enforces international agreements to suppress damaging illegal, unreported, and unregulated (IUU) fishing activity on the high seas.

### 3.11.1 High Seas Driftnet (HSDN)

Large-scale High Seas Drift Net (HSDN) fishing on the high seas is highly destructive to the living marine resources and ocean eco-systems of the world's ocean. HSDN fishing vessels can be difficult to detect in the expansive open ocean that they fish in. UAVs could be used in conjunction with other air and surface assets to widen the search swath to make detecting HSDN easier. Once detected, UAVs could covertly take images of the violations as well as vector in manned interdiction forces. Platforms capable of long endurance and outfitted with EO/IR payloads would be required for this mission.

## 3.12 Other Coast Guard Operations

The Coast Guard operates a number of unique maritime platforms over a wide range of environmental conditions and there exist some additional ways that unmanned systems could be used to increase the efficiency of these operations.

### 3.12.1 Hull Cleaning

Biofouling increases the drag on cutters as they move through the water reducing performance and increasing operational cost. Regularly cleaning the underwater portions of the hull can help reduce the negative effects of biofouling. Coast Guard Dive Lockers provide this service when they can, but often it is performed by expensive commercial divers. A number of specialty UUVs have been developed specifically for this job. Highly trained divers and their expensive equipment are not needed to operate an unmanned hull cleaner. Personnel with basic training can operate them which should translate into lower maintenance cost for the cutter. Most of the systems available today can be operated from the ship or a pier next to it. Some unmanned hull cleaners have shown that they can operate autonomously. Typically hull cleaners either use magnetism or water suction to maintain contact with the hull.

The US Navy is evaluating the use of the HullBUG for autonomous hull cleaning. The HullBUG operates on battery power and does not have a tether attached. Testing of the autonomous version by ONR started in 2013.

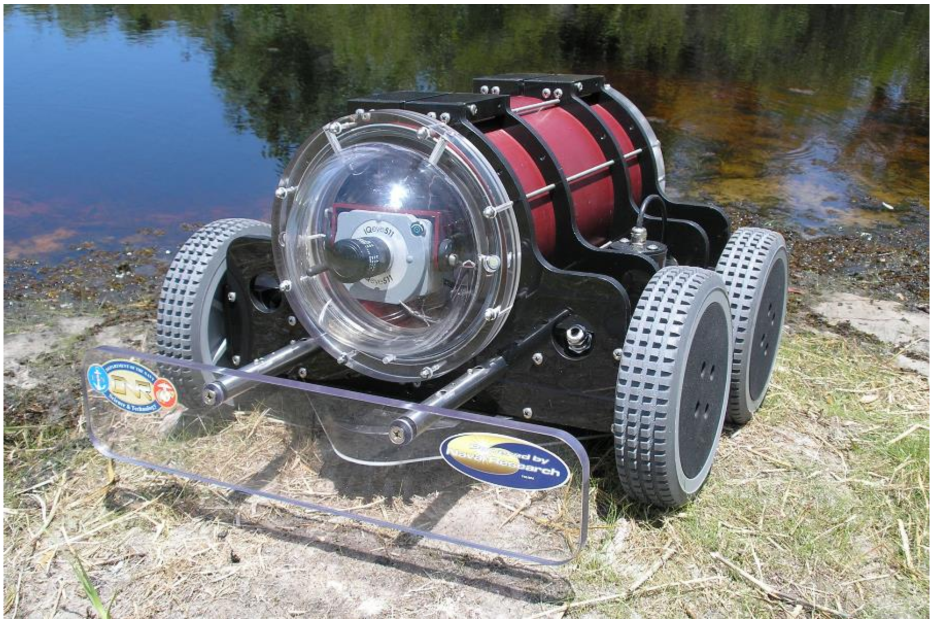

Figure 5. The HullBUG was evaluated by NRL for hull cleaning (US Navy Photo)

### 3.12.2 Underway Ship Inspections

Another application of unmanned systems is that they can enable surface assets to conduct external hull inspections while underway. There are a number of scenarios where an underway inspection could provide useful information about the ship to the crew. Evaluating propeller entanglements, icebreaker appendage inspection, and inspecting seawater intakes are all examples where unmanned systems could assist with underway inspections. Commercially available ROVs already have the capabilities to complete this mission today.

### 3.12.3 Infrastructure Surveys

The Coast Guard is responsible for the construction and maintenance of numerous docks and piers throughout the United States. It can be difficult to assess the condition of underwater structures and minor issues can develop into major ones if corrective action is not taken. Unmanned assets could be used to better monitor the condition of underwater piers and pilings. There are already commercially available ROVs that could be used for this application. ROVs configured for underwater inspections should have bright lights for taking imagery in low light underwater environments as well as sonar systems to better navigate when visibility is low. As UUV autonomy and reliability increases infrastructure surveys will be a good application for them.

## 4. ADDITIONAL CONSIDERATIONS

Due to the unique applications envisioned for unmanned systems there are some additional considerations that should be taken into consideration.

## 4.1 Personnel Requirements for Unmanned Systems

The manning requirements for some unmanned systems can be substantial. Most unmanned systems are carried to the area of operations by manned platforms for launch and retrieval. Often this requires specially trained personnel familiar with the system. Many systems require highly trained operators to control their movement and sensors. The CONOPS for even the smallest UAVs recommend two personnel for operations. Additionally, many of these systems have only recently achieved a high technology readiness level and technical support for their command and control systems as well as their sensor suite can be very demanding on support personnel. Each system requires trained operators with intimate knowledge of their design and construction to conduct maintenance and support. If conducting shipboard operations berthing for additional unmanned systems operators may be required. Potentially existing crew members could be trained to operate and support these systems, but that would increase their workload and potentially prevent them from preforming their primary function on the ship. As automation becomes more standard and sensors improve, manning requirements may be reduced, but specially trained personnel for operations and maintenance will always be required for unmanned systems.

## 4.2 Unmanned Systems Integration on Existing Assets

Many of the systems discussed in the report will require manned Coast Guard assets as a base of operations. However, the existing Coast Guard assets have not been design to accommodate unmanned systems or their operators. Operating even the smallest UAV from a Coast Guard boat can be very challenging. There is little room onboard for the storage boxes for the UAV components. The electrical system on many small boats does not have enough reserve capacity to support the electrical needs of a power hungry UAV base station. Alternating current power is also uncommon on smaller boats but is the standard power source required for many unmanned systems ground control stations. There is not a lot of room to add unmanned systems operators to the crew of Coast Guard Boats. Every existing crewman on the boat has a number of tasks already assigned to them, so training an existing crewmember to operate the unmanned system might not be the best answer either. There are a host of issues with integration on larger cutters, too. Many of the larger UAV systems require substantial amount of supporting apparatus to be installed like launchers, retrievers, large directional antennas, storage boxes, specialty maintenance equipment etc. Room for all of this equipment has to be found on a cutter not designed for it. Sometimes this can displace other aviation assets and their equipment. The launching and retrieval of USVs and UUVs from larger ships can be very difficult as well. Some vehicles can be very large making their recovery in higher sea states risky to lives and equipment. A number of unique and complex apparatus has been developed to make launch and recovery less difficult, but it remains a challenge.

## 4.3 Future Developments of Unmanned Systems

The term ‘unmanned’ as applied in this report simply indicates that a person is not in the vehicle. Many of these unmanned systems are actually remote controlled vehicles. Human operators must be constantly at the controls making command decisions and interpreting data. The next development in unmanned systems will focus on removing the person in the loop to achieve better autonomy. Due to the difficulties in underwater communication UUVs are far more autonomous than most UAVs. Most government UAVs are remotely controlled by experienced pilots due to the perceived risk of operating in the heavily regulated and trafficked national air space.

Sensors that can autonomously process data in order to detect targets will allow unmanned systems to better work in support of Coast Guard missions by not absorbing human resources to watch screens for target detection. Many of the Coast Guard's manned assets have been specifically developed to be multi mission platforms providing high levels of performance across a wide range of mission requirements. Unmanned systems should be similarly developed with capabilities that can be directed to conduct any of the Coast Guard's Missions.

# 5. RECOMMENDATIONS

- Develop roadmap/strategic plan for integrating robotic systems into Coast Guard missions to drive the direction of future efforts/projects.
- For tasks/missions that stakeholders believe could best benefit from automation, develop cost-benefit analysis for implementing robotic systems versus the continued use of standard assets.
- Continue to work with other government agencies in order benefit from existing well established unmanned system programs. Although many of the mission objectives are not the same, the basis of the existing technology will allow the Coast Guard to develop their unmanned solutions much quicker.

The Coast Guard should build competency in unmanned system operations in order to make fiscally responsible decisions about the best way to integrate these new platforms. Personnel experienced in the operations of unmanned systems will have a better understanding of the realistic capabilities the systems will have once they are fielded.

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