PAPER

Testing and Evaluating Low Altitude Unmanned Aircraft System Technology for Maritime Domain Awareness and Oil Spill Response in the Arctic

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ABSTRACT

National and international policies and treaties require the protection and exploration of the Arctic. The maritime services play a primary role in pursuing responsible Arctic stewardship by protecting the environment and the personnel conducting operations and research in this harsh environment. The National Oceanic and Atmospheric Administration (NOAA) is an important partner to the U.S. Coast Guard (USCG) in hazard response and mitigation (including oil spills and search and rescue). During Arctic Shield exercises, as part of the USCG Research and Development Center's Arctic Technology Evaluation, manned and unmanned systems including the AeroVironment Puma™ All Environment (AE) (Puma) Unmanned Aircraft System (UAS), were used to provide real-time information for maritime domain awareness and oil spill response in the Arctic. Real-time information distribution and maritime domain awareness are critical to prepare for and respond to potential environmental disasters in the Arctic. Additionally, the Puma was assessed for shipboard operations capabilities, Arctic air space coordination, deconfliction and safety issues, and real-time data visualization through the Arctic Environmental Response Management Application® as part of a larger data management plan. The results are provided from the successful Puma testing during the Arctic Shield 2013 and 2014 exercises aboard the USCG Cutter (USCGC; Icebreaker) *Healy*. An overview of these operations is given with recommendations for future testing and technology assessments of small UAS platforms for Arctic shipboard operational deployments. These findings are put into context for utilization in the field to support operations and decision making in the case of a real oil spill in the Arctic region.

Keywords: UAS, unmanned, Arctic, Coast Guard, oil spill

Background

The Arctic is becoming increasingly relevant to the future of the United States, other Arctic nations, and the world. As global climate change is causing the polar ice caps to melt, human activity is increasing on that part of the planet. Commercial ships are documented as having routed through the fabled Northwest Passage, which is the most efficient route between Asia and Europe. The U.S. Coast Guard (USCG) deployed the USCG Cutter (USCGC) *Healy*, a polar icebreaker, to conduct a search and rescue mission this summer when the crew rescued a person aboard a privately owned sailboat that had been caught in the shifting pack ice (USCGnews.com, 2014). Activities related to oil exploration and drilling development are also ramping up during the short summer season when the ice retreats. These types of activities elevate the potential for a discharge of oil, even the smallest of which could have catastrophic consequences in the extremely remote and fragile ecosystem that exists within the harsh Arctic environment. To that end, one major issue is that very little is known, both about the behavior of oil when it is introduced in and under the sea ice and about the capability of current state of the art equipment needed to image, quantify, and, most importantly, clean up oil in the Arctic. During 2013 and 2014, a group of U.S. federal agency and private industry partners collaborated to evaluate unmanned observing technologies with the potential to assist with oil spill monitoring, ice monitoring, and maritime domain awareness in the Arctic.

Partners and Resources

The National Strategy for the Arctic Region (United States, 2013) and its subsequent Implementation Plan (United States, 2014), released by President Obama, outline three primary lines of effort. These lines are to advance U.S. security interests, to pursue responsible Arctic region stewardship, and to strengthen international cooperation. As the nation's lead federal agency for ensuring maritime safety and security in the Arctic, the USCG performs statutory missions to ensure that the Arctic continues to remain a safe, secure, and environmentally protected region. The USCG Research and Development Center (RDC) has established icebreaker cruises called Arctic Shield as annual unmanned systems testing exercises from the USCGC *Healy* in support of RDC's Arctic Technology Evaluation (Alaska.Coastguard.DODlive.mil, 2014). The USCG objectives for Arctic Shield 2014 were to (1) seasonally perform select USCG missions and activities in the Arctic; (2) advance Arctic maritime domain awareness through operations, intelligence and partnerships; (3) improve preparedness and response capabilities; and (4) test capabilities and refine Arctic resource requirements (USCG.Mil, 2014). The Arctic Shield operations focus on increased maritime activity around the Seward Peninsula, Bering Strait, and the Northern Alaska Continental Shelf. As part of Arctic Shield 2012–2014, the USCG deployed cutters, aircraft, and personnel to the region and leveraged its partnerships to combine efforts toward ensuring the safety of the maritime community. During 2014, the USCG allowed the Oil Spill Recovery Institute (OSRI) based in Cordova, Alaska, and Inland Gulf Maritime, LLC (IGM) based in Mobile, Alabama, to deploy an IGM Aerostat-IC tethered balloon (Inlandgulf.com, 2014) from the USCGC *Healy* to provide continuous real-time aerial video.

After the release of the National Strategy for the Arctic Region, the National Oceanic and Atmospheric Administration (NOAA) released its Arctic Action Plan (NOAA, 2014) as part of its active engagement in the Arctic to provide environmental intelligence and to support science, service, and stewardship to this rapidly changing region, its inhabitants, the nation, and the international community. NOAA has conducted a broad range of activities to address the plan's strategic goals and has undertaken a collaboration with the USCG in Arctic Shield exercises as a key activity to assess the feasibility of unmanned observing technology for Arctic oil spill monitoring, sea ice monitoring, and maritime domain awareness. The Unmanned Aircraft Systems (UAS) Program within the NOAA Office of Oceanic and Atmospheric Research, the Office of Response and Restoration (ORR) within the NOAA National Ocean Service, and NOAA Office of Marine and Aviation Operations (OMAO) contributed UAS and data visualization personnel, expertise, and resources to the Arctic Shield exercises during 2013–2014. This cooperative effort is the sort of activity that is envisioned in the Arctic Action Plan to improve stewardship and management of Arctic ocean and coastal resources.

Industry partner AeroVironment, under contract to NOAA and the manufacturer of the Puma™ All Environment (AE) UAS (Puma; Avinc.com, 2014), has also teamed with the Arctic Shield exercises by providing Puma systems, UAS operators, and training for NOAA operators. The Puma is designed for land-based and maritime operations, and it is capable of landing on land, in the water, and onboard ships. The Puma UAS provides operational flexibility due to a durable fuselage construction, man portable attributes, and launch or recovery operations without auxiliary equipment. However, the AeroVironment team demonstrated both deck landing procedures and a net capture system for aircraft recovery during the Arctic Shield 2014 as risk mitigation options when recovery from water or ice landings are considered too dangerous for personnel safety. The Puma system is also very quiet, making it a suitable platform for use in wildlife studies while avoiding disturbance of the native fauna. The nominal Puma payload includes an electro-optical (EO) and an infrared (IR) camera—plus illuminator—on a lightweight mechanical gimbaled payload, which allows the operator to keep "eyes on target." Currently, the maximum Puma takeoff weight is approximately 13 pounds, and it boasts a payload capacity of 2.5 pounds. For increased payload capacity, an optional under wing "transit bay" is available for easy integration of third party payloads, such as Lidar, upgraded cameras, and communication repeaters for civilian applications.

Materials and Methods

The NOAA UAS Program assesses the feasibility of civilian applications of UAS to provide cost-effective and operationally feasible solutions to meet NOAA observing needs. This program has been evaluating the potential of low-altitude UAS, such as the Puma, for transition into operational application for marine and polar monitoring when real-time imaging is needed in dangerous environments or remote regions. The NOAA UAS Program provided funding and scientific oversight for the Puma operations which included 12 flight evolutions. NOAA OMAO personnel conducted the Puma operations during 2013 and supervised AeroVironment operations in 2014. In an effort to maximize the amount of information gathered during the Arctic Shield exercises from 2013 and 2014, the NOAA ORR sent specialists in Geographic Information Systems (GIS) aboard the USCGC *Healy* to test the Environmental Response Management Application® (ERMA; Response.Restoration.NOAA.gov, 2014) as an interactive mapping tool for environmental response data to be used during a simulated Arctic oil spill. The ERMA "Oil in Ice" exercises during Arctic Shield included the data synchronization of multiple manned and unmanned aircraft operations in addition to the Puma.

NOAA owns two Puma systems with a ground control station and three air frames composing each complete system. NOAA conducted its first Arctic deployment of a Puma system during Arctic Shield 2013 as a general proof of concept. During Arctic Shield 2014, the specific NOAA mission objectives for the Puma operations were to (1) conduct Puma operations safely on/off board U.S. icebreakers while underway in the Arctic and in international, uncontrolled airspace; (2) conduct shipboard flight deck landings utilizing newly developed landing procedures; and (3) demonstrate the ability to monitor sea ice and a simulated oil spill during an extended period of time (oil in ice exercise objective). All of these objectives were tested and fulfilled.

Building on lessons learned during operations from previous years, enhanced coordination, communication, and applied innovation proved to be valuable assets during the 2014 Arctic Shield exercises. Through joint test and evaluation efforts, AeroVironment, NOAA, the U.S. Navy, and the USCG developed and successfully conducted shipboard flight deck landing and net-capture recovery procedures for the Puma. The overall goal was to reduce the frequency of exposure to life-threatening hazards associated with the execution of water and ice Puma recoveries via the lowering of small manned boats into the ocean.

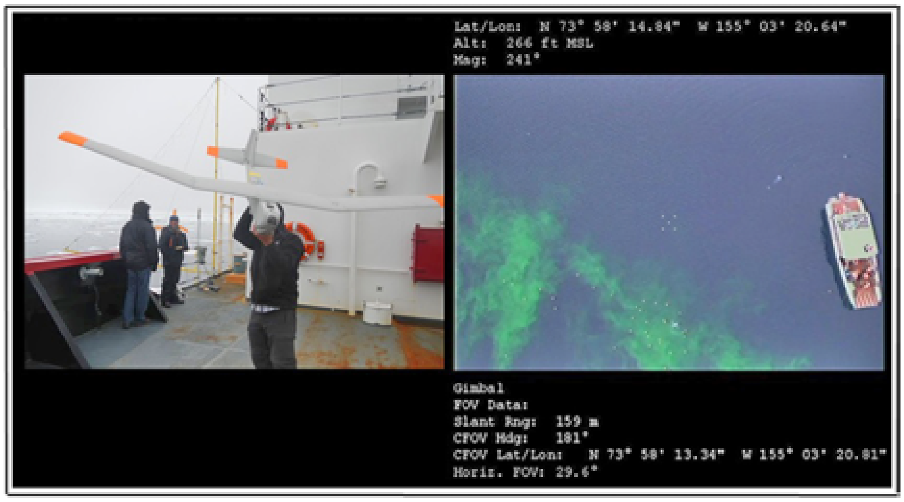
For the Arctic Shield 2014 exercises, a combination of fluorescein dye, peat moss, and oranges were used as oil spill simulants. The dye was used in the water to simulate an oil sheen, the oranges were used to track drift rates, and the peat moss was used to simulate oil on the ice. Each of these analogs were selected and approved for use in the Arctic, as they are considered innocuous to the marine environment. Testing and development of a protocol for applying fluorescein dye in the ocean for oil spill simulations were conducted off the coast of California in August of 2014 in conjunction with NOAA ORR and the California Office of Spill Prevention and Response. This dye is a biodegradable and nontoxic fluorescein dye from the Cole-Parmer Company. The Alaska Department of Fish and Game previously approved use of this dye by the Alaska Clean Seas, the North Slope Oil Spill Response Organization, during their oil spill containment and recovery training activities. Figure 1 shows the Arctic

FIGURE 1

USCGC *Healy* on the ice while oil-simulating green dye is deployed for Arctic Shield 2014.

FIGURE 2

Puma just prior to a flight over the marginal ice zone from USCGC *Healy* and a screen capture of the simulated oil spill from the Puma Observer's Screen.



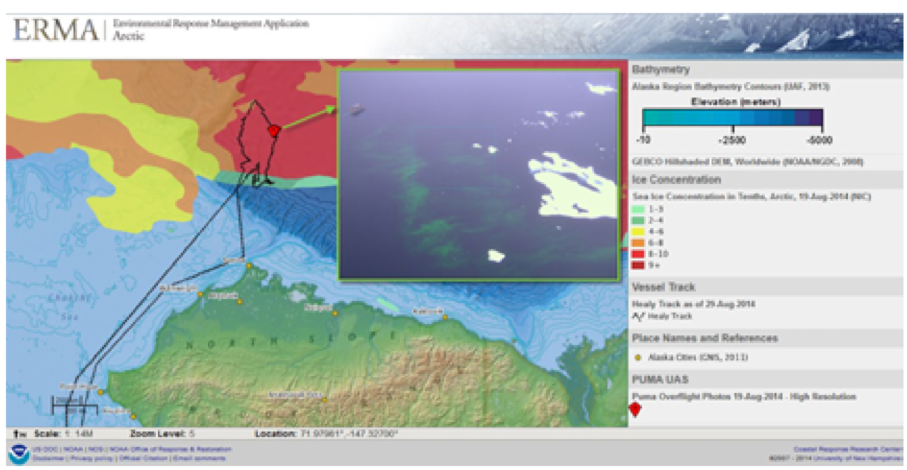
Shield crew dispersing the dye. The left side of Figure 2 shows an image of the Puma just prior to one of its flights during Arctic Shield. The right side of Figure 2 shows Puma visible imagery of the dispersed dye along with aircraft position and attitude information.

The NOAA ERMA is a GIS utility that integrates both static and real-time information, such as Environmental Sensitivity Index maps, ship locations, weather data, and ocean current data, into a centralized, easy-to-use format for environmental responders and resource managers. ERMA enables a user to quickly and securely upload, manipulate, export, and display spatial data in a GIS mapping framework. By having all of these data gathered into a single interactive map, ERMA provides decision makers with a quick visualization of an emergency situation and improves communication and coordination during potential response, injury assessment, and restoration activities. This application was designed by NOAA's ORR, the University of New Hampshire, and the U.S. Environmental Protection Agency. ERMA has been used as the Common Operating Picture (COP) for USCG Federal On Scene Coordinators when dealing with oil and hazardous materials spill responses in the United States. Several other agencies, including NOAA and the Bureau of Safety and Environmental Enforcement, have also used the ERMA tool for high-priority planning and response purposes. As it relates to the scope of this technical note, the data and imagery obtained by the Puma were ingested, visualized, and fully exploited with the ERMA application, which allowed for enhanced efficiency in all of these efforts. An example of the ERMA display is presented in Figure 3.

In addition to the Puma, the IGM Aerostat-IC also collected real-time imaging. It was tethered from the USCGC *Healy's* helicopter deck and was nominally positioned approximately 500 feet above sea level. The Aerostat-IC was equipped with very high resolution optical and IR cameras. The data were delivered through a wireless link embedded in the airborne chassis, and power was delivered through the tether. The Aerostat-IC was able to operate in more extreme weather conditions than the Puma, and although the mobility was limited by the tethered setup, this limitation was simply a result of the available payload technology. Both systems were able to simultaneously conduct flight operations and gather complementary data from the oil spill exercises. As a

FIGURE 3

ERMA Screenshot with simulated oil spill (fluorescein dye) photo from Puma included with the USCGC *Healy's* track and position and bathymetry data.



result of this coordinated operation, it was determined that there is great potential for synergy between the two systems for oil-spill-related work. Areas to explore further include the use of Aerostats as high bandwidth data relays for extending the effective range of UAS operations and to form ad-hoc network communication nodes. The next phase of this operation should include incorporating both the UAS and Aerostat data feeds (and possibly other remote sensing technology) into ERMA for the creation of a COP.

Results

The NOAA, USCG, AeroVironment, and IGM teams were able to deploy new and improved technologies, evaluate their performance in the Arctic environment, and assess their utility to enhance NOAA and USCG capabilities, including full shipboard operations. As with Arctic Shield 2013, NOAA utilized ERMA to integrate and synthesize data collected by the various deployed technologies into a single interactive map and to improve knowledge of sea ice, maritime domain and situational awareness, communications, and coordination among exercise participants and stakeholders. As a result of these efforts, the combined team was able to continue with the safe integration of UAS into international, uncontrolled airspace.

The Puma successfully completed the objectives in the operational assessment, including operating in uncontrolled airspaces, testing all modes of recovery, and accessing near real-time data streams through ERMA. The NOAA and USCG teams consolidated the exercise data and imagery created by each of the unmanned technologies and integrated them into ERMA to provide better maritime domain and situational awareness and to create an Arctic Shield COP. The ERMA team worked to develop a data management plan for integrating UAS flight tracks, videos, and field photos into a single interactive map. ERMA provided quick visualizations of the situation to improve communication and coordination between the exercise participants that were located, both, onboard the USCGC *Healy* and at remote locations. By successfully integrating field response data with valuable information, such as the extent and concentration of sea ice, locations of ports and pipelines, and natural resources at risk, ERMA brought together the available information needed for an effective emergency response in the Arctic's unique and challenging conditions (Figure 3). By quantifying and modeling the simulated spill, containment and removal efforts could more easily be planned and conducted.

Arctic aviation is dangerous, and airspace deconfliction is an important mitigator in this deadly environment. Airspace coordination, which included beyond line-of-sight UAS operations, was thoughtfully orchestrated between manned and unmanned aircraft operators. Daily airspace coordination communications followed the Federal Aviation Administration's (FAA) Arctic Communication Plan, which included emails, conference calls, satellite, marine radio, and airborne radio communications. These tasks were performed by cooperating members from the FAA, NOAA, U.S. Navy, USCG, University of Alaska-Fairbanks (UAF), and participating commercial partners, as each was simultaneously conducting manned or unmanned operations in Arctic Ocean, Beaufort and Chukchi Seas, and the Bering Strait. The result of the successful coordination resulted in zero incidents between platforms.

The Arctic Shield team also shared ice and weather observations with the Office of Naval Research's (ONR) Marginal Ice Zone (MIZ) field exercises and the UAF ScanEagle UAS missions, as both groups were conducting exercises in the same area during the same period. This kind of coordination demonstrated the feasibility of multiple organizations to simultaneously deploy an optimized, complex array of sensors and platforms on, in, and under the ice for the collection of environmental, oceanic, and buoy data.

Operational Assessments and Lessons Learned

Based on lessons learned from Arctic Shield 2013 and 2014, the NOAA, USCG, AeroVironment, and IGM teams will continue to improve technologies and evaluate performance in the Arctic environment. The Puma UAS, Aerostat-IC, and the ERMA systems for oil spill monitoring show great promise as tools for future spill response and restoration activities. The Arctic is a challenging environment, with extreme cold, strong winds, high seas, limited visibility, and rapidly changing weather conditions that are difficult to predict. The UAS flight envelopes must be expanded for high wind and Arctic flight conditions, including icing. Operationally, that translates into air vehicles that can sense and/or de-ice their control and sensor surfaces and can routinely be operated in wind speeds exceeding 30 knots. UAS platforms that operate in the Arctic environment must also be designed to operate safely and reliably in the anticipated harsh conditions.

Platform recovery processes and technology should therefore continue to be improved for autonomous shipboard recovery in order to minimize risk to personnel and UAS platforms. Flight operations in uncontrolled airspace over international waters should also be expanded to maximize platform optimization and data gathering and to minimize risk to personnel. Flying beyond visual line of sight is crucial to realizing the full potential of shipboard UAS, especially in the Arctic. Partnerships are crucial and UAS Arctic strategies for the maritime services (U.S. Navy, USCG, NOAA) need to be continually coordinated and refined. Furthermore, joint operations that leverage data for multiple purposes and that share lessons learned between partner agencies are paramount for safe and efficient operations in the Arctic. Additional testing with IGM Aerostat-IC will be required to integrate the various data streams into ERMA to provide a complete COP and provide longer-range communication links to/from other platforms.

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