Operation Arctic Shield 2013-15
Unmanned Aircraft Systems (UAS)
Onboard USCGC (Icebreaker) HEALY:
Operational Assessment of LASE/LALE Systems

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ABSTRACT

The U.S. Coast Guard (USCG) Research and Development Center (RDC) and the National Oceanic and Atmospheric Administration (NOAA) Unmanned Aircraft Systems (UAS) Program have teamed up to evaluate several airborne systems onboard the USCG Cutter (USCGC) *Healy* as part of an Arctic Technology Evaluation (ATE) conducted during the warm seasons of 2013-2015 as part of the concurrent Arctic Shield exercises. In 2015, coordination with Aerostat, ScanEagle, and Puma All Environment (AE) unmanned system platforms was performed for missions involving Intelligence, Surveillance, and Reconnaissance (ISR); Maritime Domain Awareness (MDA), Arctic Domain Awareness (ADA); and Search and Rescue (SAR) operations. This included the transfer of operational control for a ScanEagle, which flew from a land-based takeoff location to operators onboard the USCGC *Healy*. During this series of exercises, a variety of capabilities and tools were evaluated based on their ability to assist in collaboration, data fusion, and distribution of information across great distances. The primary tools that were vetted for these efforts, respectively, were NOAA's Environmental Response Management Application (ERMA), 2d3's imagery fusion, and Inmarsat's satellite-based data distribution. This UAS Operational Assessment (OA) provides a summary of the multi-platform, multi-purpose mission operations conducted during the ATE.

NOAA Unmanned Aircraft Systems Program

USCGC Healy Unmanned Aircraft Systems (UAS)
Operational Assessment

1. OVERVIEW

1.1 Purpose

This operational assessment (OA) document details the activity and evaluations performed via the joint coordination between the U.S. Coast Guard (USCG) Research and Development Center (RDC) and the National Oceanic and Atmospheric Administration (NOAA) Unmanned Aircraft Systems (UAS) Program, regarding the use of several airborne systems and sub-systems during three consecutive Arctic Shield exercises conducted during the 2013-2015 warm seasons. Based from the USCG Cutter (USCGC) *Healy*, an "icebreaker", over the course of three underway campaigns, the team coordinated multi-platform operations with Aerostat, ScanEagle, and Puma All Environment (AE; also sometimes referred to simply as "Puma") unmanned systems for missions involving Intelligence, Surveillance, and Reconnaissance (ISR); Maritime Domain Awareness (MDA), Arctic Domain Awareness (ADA); and Search and Rescue (SAR) operations. Testing of the Puma AE platform was assessed for water, ice, flight deck, and net capture recovery operations. Land-based missions were also conducted, in which operational control of a ScanEagle, launched from Oliktok Point, was transferred to operators onboard the USCGC *Healy*. Furthermore, a variety of tools used for data fusion, data distribution, and peer-to-peer collaboration were evaluated, based primarily on the use of 2d3's imagery fusion software, Inmarsat's satellite-based data distribution capabilities, and NOAA's Environmental Response Management Application (ERMA) as a Common Operating Picture (COP).

1.2 Background

This OA began with Low Altitude Short and Long Endurance (LASE/LALE) Analysis of Alternatives (AOA) conducted in accordance with the U.S. Air Force Analysis of Alternative (AOA) Handbook[1] for UAS shipboard operations. The Puma (LASE) and ScanEagle (LALE) were selected for further evaluation based on their ruggedized design, reliability, supportability, multi-agency usage and based on the evolution of the sensors/instrumentation required for the NOAA's diverse missions. These platforms were readily available at a Technology Readiness Level (TRL) of 9 level with only the capability assessment needed to capture NOAA's various missions requirements.

The Arctic Technology Evaluation (ATE) 2015, in support of Operation Arctic Shield, was NOAA's third trip to the Arctic with the USCG and the Puma AE onboard USCGC *Healy*. In 2013, the NOAA/USCG team conducted a joint technology demonstration in the Beaufort and Chukchi Seas. The Puma platform was used to search for, detect, and map ice flows from the air, as well as conduct marine surveys, conduct marine debris and oil spill exercises, and assess *Healy's* shipboard UAS capabilities (Figure 1). Utilizing its standard payload configuration, the Puma provided real-time imagery back to the ship, improving situational awareness of the exercise.

[1] USAF Analysis of Alternatives (AoA) Handbook (2010), (2013)

The imagery depicted actual on-scene ice conditions and movement, in addition to identifying the location and dimensions of simulated marine debris and oil spills. This information was vital to the success of the associated Oil Spill/Marine Debris Response Demonstration. The successes and lessons learned were captured in the *Healy* 2013 Final Cruise Report (Enclosure 1).

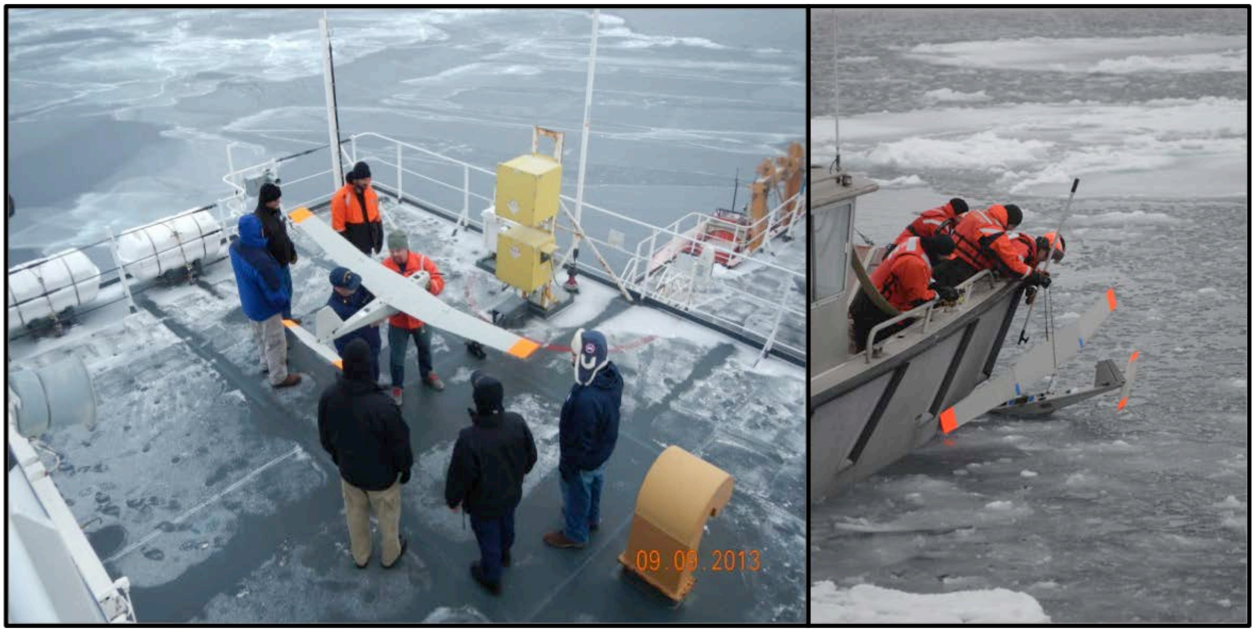

Figure 1. Flight deck launch (left) and small boat recovery (right) of a Puma AE UAS platform during Arctic Shield 2013.

The 2013 report highlights that, "the SUAS operations provided the Test Director with useful information of the ice pack and open water. This information was used to determine navigational routes to initiate the simulated oil recovery phase." The report also identifies that "Due to the adverse environmental conditions present in the Arctic, shipboard landings of the SUAS would be inherently safer than using a small boat or an on ice recovery for retrieval." This became a major focus of the spiral development, discussed below, that the NOAA UAS Program later conducted with the Puma AE manufacturer, AeroVironment, to improve the safety and efficiency of maritime and Arctic UAS operations. As NOAA's marine survey requirements became more refined, improved imagery and advanced sensor development also became a team focus.

In 2014, through a Cooperative Research and Development Agreement (CRADA), the NOAA UAS Program invited AeroVironment to collaborate on efforts to enhance the Puma AE base-line capabilities, concentrating on the previously captured shipboard requirements from the 2013 exercise (Figure 2). This led to the successful testing of several flight deck landings during the 2014 Arctic Shield activity, utilizing newly developed procedures and net-capture recovery techniques. As part of the same campaign, the team was also able to effectively exercise beyond line-of-site "due regard" operations in international, uncontrolled Arctic airspace, out to a radial distance of 5 nm from the ship. The mission successes and lessons learned were documented in the USCG RDC *Healy* 2014 After Action Report (Enclosure 2).

Figure 2. USCGC *Healy* flight deck dimension analysis (left) and images of the actual flight deck, which were studied and used for deck landings of Puma AE during Arctic Shield 2014.

The 2014 Puma AE assessment included, “During the Joint Technology Demonstration (JTD), the Small UAS (SUAS) was used to search, detect, and map the ice floes and oil surrogates from the air. Depending on sensor payload, the SUAS provided the [demonstration] with real-time imagery which improved situational awareness. In addition, operational evaluations were performed for flight deck landings and a net landing system to develop specific concepts for operation (CONOPS) for these two evolutions.” (Figure 3) Following this activity, the successes of the prototype recovery system were well documented and shared with the U.S. Navy (USN) for further exploitation. Other missions that were effectively accomplished with the Puma platform during the 2014 campaign include: sea ice ridge detection and monitoring, assistance during SAR operations, detection and monitoring of ship-based oil spills (Figure 4), detection and monitoring of marine debris, and the affective sharing and distribution of data through NOAA’s ERMA collaboration tool.

While the team did not have the opportunity to image marine mammals, the proper authorizations were granted to image them if there was an opportunistic encounter. All indications were that the base-line system would be able to identify them.

Figure 3. Images from flight deck and net-capture recovery operations of the Puma AE platform onboard the USCGC *Healy* during Arctic Shield 2014.

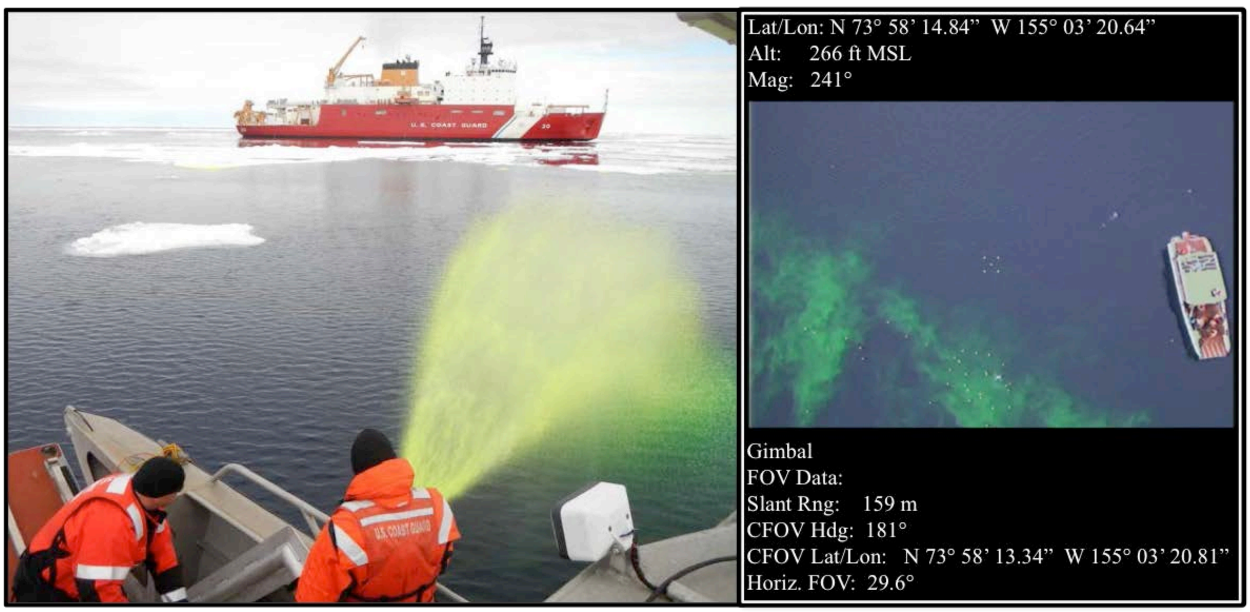

Figure 4. The crew from the USCGC *Healy* dispersed fluorescein dye (left) to simulate an actual oil spill at sea, which was later detected and tracked via a real-time data stream provided from the Puma AE imager (right).

Having conducted successful water, ice, deck, and manual net capture recoveries during Arctic Shield 2013 and 2014, the need for an autonomous net-capture system was documented with the objective of increasing reliability and safety. This would act to relieve the *Healy*'s Arctic Survey Boat (ASB) crew from UAS retrieval duty (Figure 5), which poses a threat to the boat crew's safety and often exposes these individuals to the Arctic's harsh environmental conditions for extended periods of time, as well as to the dangers of small boat operations in an area that is typically characterized by high winds and heavy seas. As a result, one of the recommendations for future operations was to develop an autonomous landing capability (equipment and procedures) for the Puma AE and obtain the necessary permissions needed to continue pursuit of this objective in order to reduce associated safety risks to personnel and equipment.

Figure 5. Image of the USCGC *Healy* Arctic Survey Boat (ASB) crew, en route to recover the Puma AE platform from an ice landing (left). View of the icy water conditions, as seen from the deck of the ASB vessel (right).

Engineering, testing, and evaluation began immediately and included testing from NOAA, USN, and USCG vessels. The NOAA testing was conducted from the NOAA Research Vessel (R/V) *Shearwater* in the Santa Barbara Channel. The *Shearwater* provided an affordable test bed and proving ground for the smaller triangle net capture system. These operations were successfully conducted in May 2015 with 10 consecutive autonomous captures during this developmental test phase (Figure 6).

Other recommendations that were provided during the Arctic Shield 2014 Post Mission Review and proposed in the 2015 Mission Concept Review for new or continued operational assessment include: due regard operations, beyond line-of-sight (5 nm) missions, expansion of the Puma AE's wind envelope to 30 knots with gusts to 35 knots, expansion of the operational weather criteria to merely remain "clear of clouds", development and airborne testing of advanced payloads, development and ground testing of an ice prediction system, development and ground testing of an anti-/de-icing system with granted flight clearance, as well as testing of enhanced data fusion with 2d3 software, data transfer using Inmarsat capabilities, and data sharing/mission collaboration through the NOAA ERMA COP.

Figure 6. Autonomous net recovery of the Puma AE platform during intensive testing of this capability in May 2015 onboard the NOAA R/V *Shearwater*.

1.3 NOAA / USCGC Healy 2015 Deployment

1.3.1 Operational and Scientific Objectives

In preparation for the 2015 Arctic Cruise, the USCG RDC requested support from the NOAA UAS Program to assist in the testing of UAS technologies and methods to help overcome Arctic challenges. Evolving from lessons learned and future goals obtained during the above-referenced 2013 and 2014 Arctic missions, NOAA and AeroVironment (with the Puma) were invited to return aboard the USCGC *Healy* in 2015 for additional ISR, MDA, Arctic SAR and Ice Exercises. The increase in multi-mission, multi-platform planning and coordinated use of manned and unmanned systems teaming (MUM-T) was the focus of Arctic Technology Evaluation 2015 (ATE-15), which included 14 different scientific investigations and technology evaluations. The campaign concluded with a successful SAR exercise that involved the collaborative utilization of several disparate assets, including multiple unmanned systems (Figure 7). The results were captured in the USCG RDC's After Action Report for ATE-15 (Enclosure 3), and many of the achieved airborne science and operational objectives from the campaign are compiled in Table 1. As Arctic ice continues to recede and maritime activity increases in this part of the world, through the pursuit of these objectives, NOAA continues to supply environmental intelligence in support of the USCG, so that it is able to perform its missions off the coast of northern Alaska and in other parts of the Arctic.

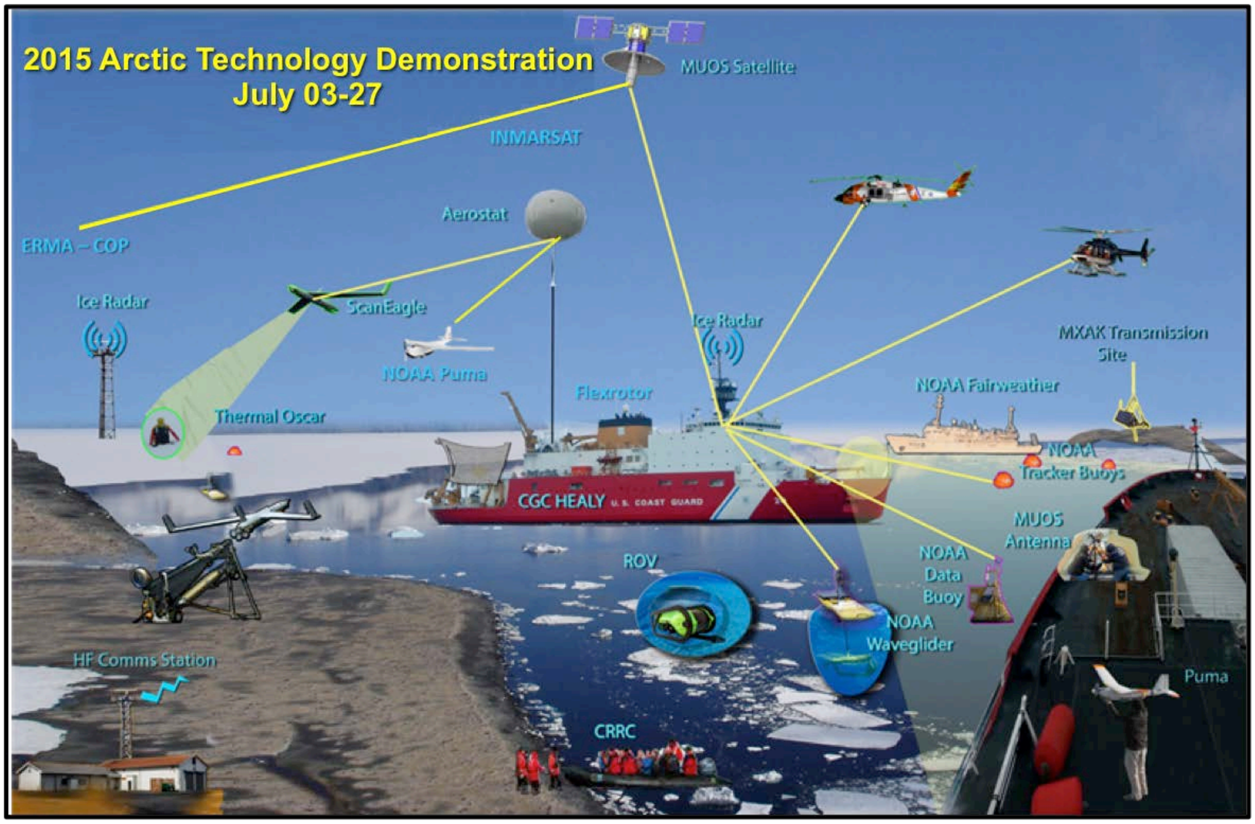

Figure 7. High-level operational concept graphic of the ATE-15 SAR exercise.

Science/Operational Objectives Achieved	Additional Information
Conduct Puma AE operations safely on/off board U.S. Icebreaker ships while underway in the Arctic in international, uncontrolled airspace	-Included beyond line-of-sight "due regard" operations -Flights were conducted out to a radius of 5nm from the ground control station -Operational Availability was > 95%
Conduct shipboard recoveries utilizing autonomous net capture procedures and develop/refine tactics, techniques, and procedures (TTPs)	
Expand the Puma AE's operational wind envelope	Increase to 30 knots sustained; gusts to 35 knots
Demonstrate the ability to acquire, monitor, and reacquire marine debris, oil and/or distressed personnel over an extended period of time	Addressed a portion of the SAR exercise objective
Conduct ISR, MDA and ADA operations with the Puma through multi-agency science crew and USCG/NOAA/USN operational crew collaboration	Streamed full motion video (FMV) of electro-Optical (EO) and infrared (IR) imagery, along with other advanced payload(s), from Puma AE for the following target sub-objectives:

	-Detection and monitoring of sea ice and ridges -Advanced payload testing was incomplete due to operational constraints. -Producing a Digital Elevation Map (DEM) of ice ridge and surrounding area -Assistance during SAR (and other types of emergency response) scenarios -Detection and monitoring of marine debris -Preparation for future boundary layer research from UAS
Utilization of NOAA's ERMA COP tool	ERMA® is an online mapping tool that integrates both static and real-time data, such as Environmental Sensitivity Index (ESI) maps, ship locations, weather, and ocean currents in a centralized, easy-to-use format for environmental responders and decision makers. ERMA enables users quick securely upload, manipulate, export, and display spatial data in a Geographic Information System (GIS).
Conduct Puma Carbon Nano-Tube Anti-Ice System ground testing with the National Aeronautics and Space Administration (NASA)	
Coordination with Inland-Gulf Maritime (IGM) Aerostat flight operations with advanced payloads	
Coordinate with NOAA's Wave Glider Missions for Puma AE overflight of sensing equipment and operating area	
Coordinate with Conoco Phillips and Insitu for ScanEagle flight operation coordination, overflight, and data exchange with possible operational hand-off	
Coordinate with 2d3 for imagery data fusion	
Coordinate with Inmarsat for real-time data transmission and distribution	
Conducted PEMDAS Ice Prediction System ground testing with the Office of Naval Research (ONR)	This activity was a prelude to later, similar ScanEagle missions
Conducted Aerovel Flexrotor fit-checks and concept of operations reviews	The Flexrotor did conduct fit-checks but was not available for the referenced 2015 campaign

Table 1. List of relevant objectives achieved during the 2015 Arctic Shield exercise campaign.

1.3.2 Operational Assessment Schedule

The schedule of operational activities throughout the 2015 Arctic Shield exercise campaign remained very flexible, depending on weather conditions and other technology deployment schedules. The USCGC *Healy* ASB crew and command staff were notified well in advance of all planned test activities. Opportunities to execute relevant missions toward meeting the above-referenced scientific and observational objectives were well planned and communicated.

1.3.3 Activity Coordination and Communications Planning

During the 2015 campaign, the USCG/NOAA/NASA/USN UAS technology team coordinated all manned and unmanned missions with other potential manned and unmanned aerial activities in the vicinity of the USCGC *Healy* operations in the Beaufort and Chukchi Seas. In August, the National Marine Mammal Laboratory (NMML), NOAA UAS Program, and USN all conducted concurrent aviation activities, utilizing nearly the same air space for a variety of, both, manned and unmanned operations. As part of this effort, NMML conducted a survey known as the Aerial Surveys of Arctic Marine Mammals (ASAMM), which utilized two manned survey aircraft. Similarly, USCG/NOAA and industry teams coordinated remote ScanEagle operations from Oliktok Point, AK to supplement shipboard Puma operations in the designated area, and the USN also flew ScanEagle platforms out from Barrow, AK for marine and ice monitoring. During these activities, NOAA coordinated events for real-time and post mission data exchange. The following protocol from the Arctic UAS Communication Plan[2] was developed and implemented, at a minimum, to ensure adequate separation, safety, and situational awareness for all teams:

- The night prior to any planned UAS operations, the NOAA/UAS Pilot in Command (PIC) will contact any and all known aviation activity participants in the vicinity of anticipated USCGC *Healy* operations, to include, at a minimum, UAS team leads via e-mail, land line, or satellite phone (in that order of preference). Details include planned locations, times, and types of operations.
- Parties are obligated to immediately communicate significant changes in plans via the methods listed or via radio on VHF Marine Channel 16 (or aircraft emergency frequency 121.5 MHz as a secondary alternative).
- If airborne and either party visually or audibly identifies the other, attempts must be made to hail one another via radio on VHF Channel 16 (121.5 MHz; alternative) and switch to a working channel.
- NOAA Puma AE shipboard standard operating procedures (SOPs) dictate that blind calls will be made on VHF Channel 16 and 121.5 MHz prior to launch, once every half hour while airborne, and once more after landing. If the NMML aircraft receives the transmission, attempts must be made to establish a line of communication to ensure adequate separation exists.

[2] Arctic Science RPAS Operators Handbook, AMAP 2015, http://www.amap.no/documents/doc/arctic-science-rpas-operators-handbook/1221

2. PUMA AE SYSTEM OVERVIEW

2.1 Puma AE Platform Description

The Puma AE is a small, fixed wing UAS designed for land based and maritime operations. Capable of landing in the water or on land, the Puma AE (Figure 8) is durable, possessing a reinforced fuselage construction and a set of specifications that are suited for rugged, maritime operations (Table 2). Its portable design makes for easy mobility, and it requires no auxiliary equipment for launch or recovery operations.

Figure 8. Image of the Puma AE, fixed wing UAS platform.

Length:	4.6 ft
Wingspan:	9.2 ft
Weight:	13.5 lbs
Speed:	Max: 45 knots; Cruise: 20 – 45 knots
Ceiling:	12,500 ft
Range:	15 kilometers (9 statute miles)
Endurance:	Primary Battery: 3+ hours
Propulsion:	Electric motor

Table 2. Engineering and operational specifications for the Puma AE platform.

2.2 Puma AE Payload Description

The standard configuration for the Puma AE is a gimbaled payload with 360 degree continuous pan and +10 to -90 degree tilt stabilized range of motion, carrying an EO/IR camera and IR illuminator. Advanced payloads considered for the Arctic exercises included a 24 MP nadir camera, Lidar/14 MP system, and multi-spectral camera.

3. UAS OPERATIONS AND ASSESSMENT

3.1 Technology Demonstration Procedures

The UAS systems and sub-systems were operated in accordance with their operating manuals and coordinated with the manned systems. The Puma AE was operated in accordance with flight manuals that were co-produced by NOAA and AeroVironment. Each operational mission commenced with a hand-launch of the platform from the USCGC *Healy*. The ship was equipped with passive Remote Video Terminals (RVTs), which allowed personnel onboard to observe a real video/data feed, streaming from the Puma AE. At the conclusion of each flight, the aircraft completed either a net recovery or a water landing.

3.1.1 **Mission Flight Profiles**

Once launched, the Puma AE was flown within a radial distance of 5 nm from the ship while in international airspace (i.e., the air space existing outside of 12 nm from the coast of Alaska). These operations adhered to the approved Puma AE Shipboard Operations Plan as well as Appendix A of NOAA Aircraft Operations Center UAS Policy 220-1-5, regarding NOAA Small UAS Operations in Uncontrolled International Airspace. The platform was flown between 100 and 2,000 feet Above Ground Level (AGL) in a suitable systematic search pattern to search for signs of marine debris and/or simulated oil spill, toward fulfillment of the noted ISR and MDA operational assessment objectives. Once the Puma successfully detected marine debris or simulated oil spill contaminants, attempts were made to provide quantifiable assessments of location, size, and, in the case of the oil spill exercises, potential characteristics such as thickness of oil and proximity to ice. EO/IR payloads provided real time data feed via RVT to ship-based personnel, and the data was distributed off-board to computers and smart phones across the country via the Internet, using the Inmarsat global communications satellite system.

3.1.2 **Roles and Responsibilities of Personnel for Puma AE Operations**

In order to safely and effectively operate the Puma AE UAS, clear roles and responsibilities, as outlined below, were implemented and maintained for all UAS operations during the referenced Arctic exercises. At a minimum, there must be three individuals at all times present during operations to fulfill specified ground control system (GCS), UAS operation, and "see and avoid" roles and responsibilities. For vessel-based UAS operations, the ship's command, in consultation with the UAS PIC, determined if weather, sea, vessel, aircraft, or human factors were such that safe UAS operations could be conducted in accordance with documented criteria.

3.1.2.1 **Pilot in Command**

The Pilot in Command (PIC) is tasked with the overall responsibility for safe execution of the mission. It is the PIC's responsibility to ensure that all crewmembers understand and can properly perform their specific roles for the flight. Additionally, the PIC is responsible for ensuring that all procedures are followed, including pre- and post-flight briefs, and that all required documentation is produced. The PIC is charged with ensuring adherence to all SOP and checklist requirements. This individual must also ensure proper communication with the authorities that control airspace, and then maintain communication with the appropriate Air

Traffic Control Authority. While conducting air operations, the PIC is the final authority to the safe operation of the aircraft. Lastly, the PIC must oversee all efforts for aircraft system preparation, launch, airborne operations, landing, and preventative maintenance.

3.1.2.2 **Mission Operator**

The UAS Mission Operator (MO) is the individual responsible for the control of the mission laptop/moving map display. Typically, the aircraft will be mechanically or hand-launched under remote manual control. When at survey altitude, the PIC may cede control of the aircraft to the autopilot, which the MO will have programed to follow a pre-determined survey path. If flying on autopilot, the PIC shall always be ready to take over manual control, and the MO shall always be monitoring the system health. This MO is also responsible for recording all operations and associated flight logs.

3.1.2.3 **External Observer**

There shall be at all times an External Observer for "see and avoid" purposes. The goal of this individual is to aid the PIC in identifying potential hazards or other aircraft in the area, then to help avoid collisions with such objects.

3.2 Operating Limitations

A list of procedures and restrictions were developed, with respect to the operation of the Puma AE UAS during the Arctic Shield exercises (Table 3). The guidance provided by this list was referenced and adhered to for each launch, flight, and recovery the UAS that was conducted from the USCGC *Healy*.

a)	The GCS and UAS shall remain within uncontrolled airspace at all times.
b)	The GCS and UAS shall remain greater than 12 nm (i.e., international waters) from the U.S. coastline or U.S. territory during all phases of flight. (Note: For UAS operations conducted off another country's coastline, please consult with the U.S. Department of State for minimum standoff, which may be greater than 12 nm due to diplomatic concerns).
c)	The UAS shall be operated at or below 2,000 ft mean sea level (MSL).
d)	The UAS shall remain within 5 nm of the GCS at all times.
e)	The UAS shall be operated in visual meteorological conditions (VMC) conditions only. If instrument meteorological conditions (IMC) conditions are unintentionally encountered, return to VMC conditions by the safest and most expeditious means possibly.
f)	Day or night operations are permitted, but associated risks and mitigation measures shall be addressed in each project-specific Operational Risk Management (ORM) document.

g)	Flight operations shall be selected so as not to interfere with established air routes and ocean shipping lanes.
h)	UAS operations shall not be conducted under the veil of Class B or C airspace.
i)	Notices to Airmen (NOTAMs) and Notices to Mariners (NOTMARs) shall be issued for the affected airspace / body of water.
j)	Radio "calls in the blind" shall be made on Marine Channel 16 and on aviation band 121.5 MHz prior to launch and at no greater interval than every 30 minutes.
k)	The launch vessel should conduct a surface search using its radar 10-30 minutes prior to the launch of the UAS in order to identify other vessels within the operational area. A qualified radar operator should monitor the ship's radar display at all times that the UAS is airborne. If another vessel is identified within the 5 nm UAS operational range, the UAS shall remain at least 2 nm from that vessel at all times, unless identification of vessels is a requirement of the mission. Flight specifics shall be addressed in each project-specific ORM.
l)	At least one observer shall be posted during all UAS operations to assist with separation from other aircraft. The observer shall be provided binoculars, or other visual enhancement device, and shall have the means to be able to clearly communicate with the PIC.

Table 3. List of procedures and restrictions developed and complied with for the operation of the Puma AE UAS during the Arctic Shield exercises

3.3 Mission Plans

Prior to each day's operation, a mission briefing was developed by the USCG/NOAA/USN and industry partner team with input and review provided from each of the participating agencies. All missions typically consisted of a launch, ingress to a designated target area, data collection, egress from the target area, and recovery of the Puma AE platform. The Mission Coordinator conducted the briefings, which included the following agenda items: a) weather, b) safety, c) status of equipment and personnel, d) communications plans, e) mission objectives, and f) other relevant information, as necessary. For contingency planning purposes, the USCGC *Healy* ASB crew was placed on standby during all missions, in the event that Puma operations and/or retrievals from the smaller vessel were necessary.

3.4 Data Requirements

The list of NOAA requirements and/or desired attributes for unmanned systems assessed during the campaign can be found in Table 4. It should be noted that this list is applicable not only to the Puma AE, but also to the Aerostat, ScanEagle, and Flexrotor systems, which will be discussed in a subsequent section. Specifically this compilation applies to platforms and sensors that have been optimized for conducting SAR, ISR, and MDA operations for marine surveys, ice surveys, and the detection and identification of marine debris and oil spill contaminants. All of these requirements were tested during the referenced exercises in the 2015 campaign.

Operational Requirements/Desired Attributes Tested During ATE-2015	Detailed Requirement Information
a) Number of Cameras and Resolution	Two to three digital video cameras are optimal. One of them would be capable of producing high resolution imagery with a narrow field of view (FOV) of approximately 60-120 m and a nadir resolution of 1-2 cm Ground Sample Distance (GSD; from the chosen flight altitude), with preference of 1080p output, as opposed to 1080i. The other camera(s) would be able to produce a wide FOV at approximately 300 m with a reduced resolution of approximately 10 cm GSD. With respect to configuration, the two wide field of view cameras (if two are available) would be obliquely oriented with overlapping FOVs at nadir.
b) Object Size to be Detected	Imagers should be capable of allowing observers to detect and identify a floating object of 8 inches (~20 cm) in diameter (thus the requirement for a resolution of 1-2 cm). This includes detection and identification of the USCG simulated SAR victim, "Thermal Oscar".
c) Object Discrimination	Imagers should be capable of allowing observers to discriminate between a debris object and natural floating material, such as kelp. Individual objects, not collections of objects, need to be detected.
d) Spectral Bands	Red-Green-Blue (RGB) video is preferred; however, the usefulness of IR cameras is still being investigated.
e) Dynamic Range	8 bits per channel
f) Polarization/Filters	Polarization should be possible, at least for oblique views, but usefulness is currently under investigation. The optical port should permit polarization. One way to accomplish this is with the use of polarized coatings on the optical ports
g) Sampling Frame Rate (overlapped or non-overlapped)	A variable frame rate is preferred.
h) Downlink/Recording Capabilities	The system should be capable of allowing real-time transmission of imagery from at least one

	camera to the ship, while recording the output from all cameras. The real-time transmission should be possible from 5-20 nm away.
i) Fixed Camera –vs– Steerable Camera	Fixed swath with multiple cameras, or gimbal-mounted steerable camera
j) Global Shutter –vs– Rolling Shutter	Global shutter; i.e., all charge coupled device (CCD) detectors exposed at same time, is preferred for sharper images. However, this presents a cost/weight trade off, since rolling shutter cameras are cheaper and lighter.
k) Interface with Airframe	With respect to optical aperture design and material, the aperture material should most likely be composed of plexiglass, which could be polarized. If a polarized filter is used instead, this may present a problem, since visible radiation that is transmitted through plexiglass affects polarization. Each camera should have its own aperture.
l) Documentation of Sensor Selection	Documentation of differences and tradeoffs between a specified "ideal sensor" and a selected "practical sensor" should be captured.
m) Metadata	Information about Global Positioning System (GPS) location and time, altitude, aircraft attitude, and gimbal angle (if available) should be stored in the metadata with each image. This information should not be implanted into the image itself.
n) Anomaly Detection Software and Algorithm	Information regarding the detection of anomalies from onboard the UAS should be identified and sent to the ship, along with the GPS positions for where those anomalies were encountered.
o) Method for Identifying Areas of Interest	Areas of interest should be marked by image and by coordinates. For purposes of the survey missions, it is expected that the aircraft location/coordinates are sufficiently accurate (i.e., should not require slant-range post-processing for object location)
p) Quantification and Classification of Imaged Targets	Provided imagery should allow for, both, the quantification and identification of debris objects or other targets, and should allow for easy differentiation between multiple objects.
q) Archival of ISR and SAR Missions Data (including marine surveys, debris, and oil spill operations)	Archive format and archive organization still needs to be determined. There are options for archival at the Northern Gulf Institute (NGI), the

	NOAA Oceanographic Data Center, and the NOAA UAS Program. Previous manned aircraft surveys have recorded debris locations in an Excel file containing time, latitude, longitude, item identification, and comments. This information should be recorded by the USCG, as well. The NOAA UAS Program has coordinated with the NOAA ERMA Program and the USCG for real-time data distribution through its COP and data archiving with NGI.

Table 4. List of NOAA requirements and/or desired attributes for unmanned systems capabilities that were assessed during the 2015 Arctic Shield exercise.

4. OTHER AIRBORNE SYSTEM OPERATIONAL ASSESSMENTS

In addition to the Puma AE fixed wing UAS platform, a variety of other unmanned systems and associated sensor payloads were evaluated during the 2015 Arctic Shield campaign.

4.1 Aerostat

In February 2013, the Inland-Gulf Maritime LLC (IGM) Aerostat-IC (Figure 9) was deployed to support the USCG during the oil spill response exercise that was held on Lake Michigan. At that exercise, the system provided the USCG with aerial video of the various exercise components and, through the use of its IR imaging capability, proved to be especially useful during a "man overboard" exercise. As a follow on, the Aerostat-IC deployed on the USCGC *Healy* for the Arctic Shield 2014 Technology and Arctic Oil Spill Evaluation. The system was tested for its capability to support both oil spill tracking and other emergency response scenarios in arctic conditions, which proved the value of utilizing an Aerostat for remote surveillance during these types of missions. The capability provided an aerial perspective of the operation, both in EO and IR imagery, highlighting its worth in providing operators with enhanced situational awareness. As a result, it enabled work crews to quickly discover and attack the heaviest oil, and it increased their encounter rate, so that the oil spill could be efficiently and effectively cleaned up. Furthermore, FMV imagery could also be transmitted to a command center to enable pre-planning for the operational response team. For Arctic Shield 2015, the IGM Aerostat-IC team was once again able to rejoin the rest of the group and participate in the exercise to continue testing and further assessment of this technology with advance payloads in support of ISR, MDA, ADA and SAR missions.

Figure 9. IGM Aerostat-IC onboard USCGC *Healy* during Arctic Shield 2014.

With regard to the mission planning and operational assessment items for the Aerostat team, the primary objectives from the 2014 and 2015 Arctic Shield campaigns were: 1) Familiarization and fit checking of the Aerostat-IC onboard a USCGC vessel, 2) Familiarization with polar observation requirements, 3) Distribution of real or simulated Aerostat data aboard a USCGC vessel, and 4) Aerostat data relay (Wave Relay) with Puma AE (although, it is known that this method of relay reduces bandwidth and output resolution).

4.2 NOAA Buoy and Wave Glider

The NOAA's Pacific Marine Environmental Laboratory (NOAA-PMEL) deployed a suite of oceanographic instrumentation during ATE-15. Ten buoys and two autonomous surface vessels were deployed as part of a PMEL led program, Innovative Technology for Arctic Exploration (ITAE), to evaluate innovative sensors and techniques to increase NOAA's observational capabilities in the Arctic. Data collected by these systems will be used to establish baseline measurements of physical ocean processes occurring in the Arctic Ocean. Supporting projects like these serves to increase our understanding of the climatic dynamics that are going on in the Arctic.Testing was conducted as per the Mission Planning Document HYL-1501 and assessed in Enclosure 3. UAS fly-overs and surveys were coordinated onboard the USCGC *Healy*.

4.3 Insitu ScanEagle

The ScanEagle carries a stabilized electro-optical and/or infrared camera on a lightweight inertial stabilized turret system, and an integrated communications system having a range of over 62 miles (100 km); it has a flight endurance of over 20 hours. The ScanEagle has a 10.2-foot (3.1 m) wingspan a length of 4.5 feet (1.4 m) and a mass of 44 pounds (20 kg) and can operate up to 80 knots (92 mph; 150 km/h), with an average cruising speed of 48 knots (55 mph; 89 km/h). The NOAA UAS objectives were conducting multi-manned and unmanned aircraft missions for ISR and SAR via handoff of the ScanEagle from the land-based GCS at Oliktok Point, AK to the *Healy.* Testing was conducted as per the Mission Planning Document HYL-1501 and assessed in Enclosure 3. UAS fly-overs and surveys were coordinated onboard the USCGC *Healy;* however, limited flight opportunities were provided due to low ceiling/visibility at Oliktok Point.

4.4 Aerovel Flexrotor

The Aerovel Flexrotor unmanned aircraft (Figure 10) is designed to operate over oceans and remote areas while sending high-quality imagery to its control vessel. The platform possesses an endurance of more than 40 hours, and the operations cycle is automatic through flight, retrieval, servicing, and re-launch. The aircraft is accompanied by a lightweight handling apparatus, and it can be stowed and quickly reassembled for flight in a 6 ft (2 m) handling box. A small footprint and an ability to hover allow the Flexrotor to be based on a small open skiff or in spaces of opportunity on larger private or commercial vessels.

The steerable, zoomable imaging turret performs search and target tracking with a visible or IR camera. Its real-time, georeferenced video can be merged with data from other shipboard equipment, such as radar or AIS, and distributed to multiple displays. National Television System Committee (NTSC) Phase Alternating Line (PAL) quality video can be downlinked from a 100 km radius to a 2 m shipboard antenna, and more compact antennas can be used where less video range is required. If desired, multiple aircraft can be managed from a single GCS so that several sectors can be monitored simultaneously.

Flexrotor's range, endurance, economy, basing flexibility, and ease-of-use can enable ships to have an extended ISR and survey capability. Land-based launches were scheduled to be conducted from Oliktok Point, AK, and ISR missions were to be flown in the vicinity of the USCGC *Healy*. Unfortunately, while the USCGC *Healy* "Familiarization" phase was being conducted, the Flexrotor was not available for flight assessment.

With regard to the mission planning and operational assessment items for the Flexrotor team, the primary objectives from the 2015 Arctic Shield campaign were:

1) Familiarization and fit checking of the Flexrotor onboard a USCGC vessel,
2) Familiarization with polar observation requirements,
3) Distribution of real or simulated Flexrotor data aboard a USCGC vessel, and
4) Flexrotor flight from Oliktok Point, AK (unable to meet objective due to UAS availability).

FLEXROTOR SUMMARY SPECIFICATIONS

Endurance	More than 40 hrs with typical payload
Range @ endurance speed	More than 3400 km/1800 nm
Range @ maximum speed	More than 900 km/500 nm
Endurance speed	85 km/h – 46 kt
Maximum level speed	158 km/h – 86 kt
Wing-borne ceiling @ max wgt	7,500 m – 24,000 ft
Hover ceiling (OGE) @ max wgt	900 m – 3,000 ft
Length	2 m
Wingspan	3 m
Maximum launch weight	20.5 kg at sea level, ISA
Engine	28 cc 2 stroke
Fuel	Unleaded automotive gasoline
Communication range	100 km – 55 nm
Storage	205 x 57 x 38 cm box with integral assembly stand
Assembly time	10 minutes
Imaging	Stabilized turret with optical or IR video camera
Video downlink	Digital; NTSC equivalent resolution

SPECIFICATIONS FOR IMAGING TURRET
(WITH VISIBLE-LIGHT CAMERA)

Wavelength	400 – 900 mm
Horizontal field of view	1.1° – 31.5°
Image size	640 x 480 downlinked; HD stored onboard
Analog video output	Composite NTSC
Digital video output	Standard formats
Pan about aircraft roll axis	Endless 360°
Tilt about turret pan axis	30° up; 90° down
Slew rate	50°/sec

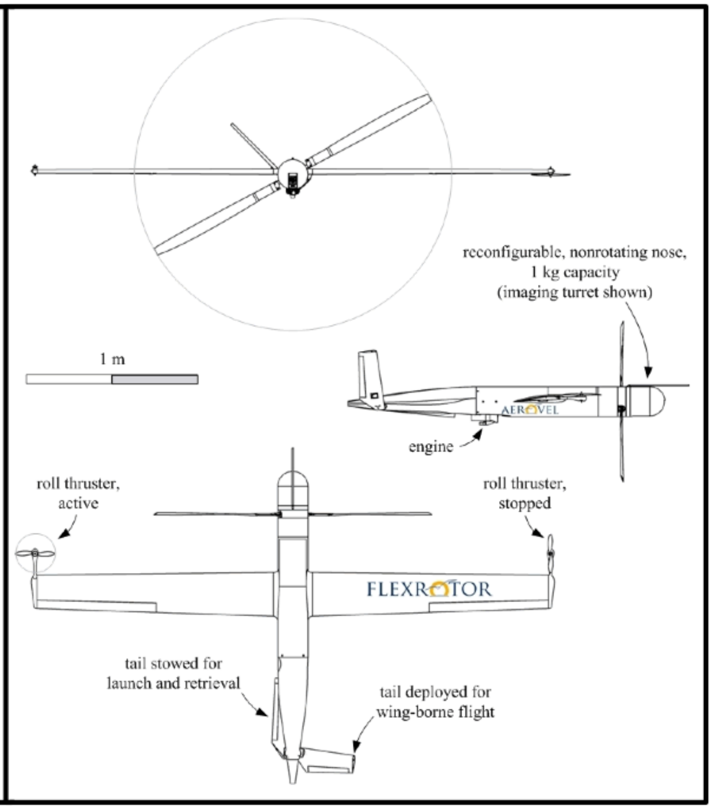

Figure 10. Aerovel Flexrotor specifications (left) and diagram (right).

4.5 NASA Carbon Nano-tube Anti-/De-Icing Coating (Ground Testing)

Unmanned systems icing is a known hazard that has not been properly mitigated, especially for small vehicles that lack the power and weight capacity to carry large, energy depleting systems. The Norwegian University of Science and Technology (NTNU), in collaboration with NASA Ames Research Center, has invented an innovative off-the-shelf anti-/de-icing system that is comprised of an electrically conductive coating (nanotube-based paint) that acts in concert with a power management system to control temperatures of exposed surfaces. This system is primed by onboard ambient humidity and temperature sensors, as well as model-based ice accretion estimation, which have been developed using nonlinear estimation theory and/or fault diagnosis theory.

The coating temperature is adjusted using a feedback controller with input provided from coating-embedded temperature sensors, used to measure the surface temperature of the aircraft, and humidity sensors. The humidity measurement is just as important as the temperature measurements, since icing typically forms only when the ambient relative humidity is greater than 85%. This system has been successfully integrated onto NASA's Dragon Eye UAS and AeroVironment's AE, and it was ground-tested on the Puma to mitigate icing hazards. This exercise was quite significant, as it represents the first shipboard anti-/de-icing testing for small UAS, and we now have a flight clearance for this system for airborne operations.

Figure 11. Image of the carbon nano-tube anti-/de-icing coating, integrated onto the leading edge of a fixed wing airfoil.

With regard to the mission planning and operational assessment items for the carbon non-tube anti-/de-icing capability team, the primary objectives from the 2015 Arctic Shield campaign were:
1) Familiarization and fit checking of the nano-tube onboard a USCGC vessel, along with ground test element placement,
2) Familiarization with polar observation requirements, and
3) Nano-tube ground testing in known icing conditions.

4.6 PEMDAS Ice Prediction System (Ground Testing)

In response to the need for an important mitigation to the aircraft icing hazard, PEMDAS Inc. has developed an ice prediction system, known as the Atmospheric Sensing and Prediction System (ASAPS), that has since been tested on several manned and unmanned aircraft. Integration of ASAPS has been completed by PEMDAS on the AeroVironment Raven and the Insitu ScanEagle. Now, the DOD, NOAA/USCG team is investigating integration of the system onto the AeroVironment Puma AE platform. In this system, the payload data is relayed to a ground station over a command & control (C2) radio link, and icing data is sent from the ground station to a separate computer that runs software used to display the risk of icing and other relevant meteorological data. During the 2015 campaign, ground testing included integration of a sensor set with exposure to the elements.

Figure 12. PEMDAS ASAPS metrological and icing sensor.

With regard to the mission planning and operational assessment items for the PEMDAS ASAPS team, the primary objectives from the 2015 Arctic Shield campaign were:
1) Familiarization and fit checking of the PEMDAS ASAPS meteorological sensor onboard a USCGC vessel, along with ground test element placement,
2) Familiarization with polar observation requirements, and
3) PEMDAS ASAPS Ice Prediction System ground testing in known icing conditions.

4.7 Inmarsat Hughes 9211-HDR Land Portable Satellite Terminal

The rugged and lightweight Inmarsat Hughes 9211-HDR is an affordable High Data Rate (HDR) terminal, ideal for media, governments, non-governmental organizations, mobile healthcare providers, and possibly for shipboard operations in the Polar regions. The

9211-HDR unit has a hardened, compact design and is currently the world's smallest and lightest HDR-capable broadband global area network (BGAN). Users can connect at streaming broadband speeds of over 650 kbps with features such as built-in, multi-user wireless Internet access.

Figure 13. Inmarsat Hughes 9211-HDR.

An external powered antenna was available to support long RF cable runs for temporary or permanent fixed-site installations. The Hughes 9211-HDR enabled users to send and receive Internet Protocol traffic via Ethernet and/or 802.11 b/g/n WiFi, including voice or fax data via a standard telephone connection.

Inmarsat's BGAN HDR service network provided very high data streaming rates. The Hughes 9211-HDR supported the highest streaming rates available (above 650 kbps) for transmitting video and other critical data from the field. Asymmetric streaming rates are supported, enabling users to better tailor the service to their individual preferences and minimize costs. Several of the available features and interface information with the Inmarsat Hughes 9211-HDR system can be found in Table 5.

Primary Features
Rugged and durable IP65 rating
User-friendly LCD display with four-button control
802.11 b/g/n WiFi supporting multiple user access
Advanced Web user interface
Automatic context activation
Automatic context activation
XL-band supported
External antenna options
HDR streaming above 650 kbps
Interfaces
Ethernet connection (RJ45)
POTS connection for voice and fax (RJ11)
External antenna connector

Table 5. Features and interface information for the Inmarsat Hughes 9211-HDR system.

With regard to the mission planning and operational assessment items for the Inmarsat Hughes 9211-HDR team, the primary objectives from the 2015 Arctic Shield campaign were:

1) Familiarization and fit checking of the Inmarsat Hughes 9211-HDR system onboard a USCGC vessel,

2) Polar observation requirement and regional satellite familiarization,

3) Real-time distribution of real or simulated data through the system from a USCGC vessel, and

4) Real-time data distribution for fusion and infusion into ERMA.

5. Summary and Lessons Learned

The USCG RDC cited in their ATE-15 After Action Reported, "The RDC sponsored ATE-15 aboard the HEALY made some significant advances. Of particular note were the Puma AE UAS operations and the SAREX. These operations accomplished several firsts that will pave the way for increased UAS shipboard operations. They successfully tested beyond line of sight operations, autonomous net capture onto the forecastle of the ship, autonomous net capture onto the flight deck of the ship, and they were able to stream live video to the ship and back to shore for viewing over the internet from any location. The SAREX was the first of its kind with a complete simulation that included industry participation, a shore launched UAS whose control was passed off to a vessel at sea, a UAS search of Arctic waters, and the live video of the search in progress, as it occurred, sent ashore over the internet. These advances can help move the UAS systems forward to becoming usable tools for the CG to have when conducting missions not just in the Arctic but anywhere."

Many of the systems tested, including the Puma AE and ScanEagle, have been utilized in several joint technology demonstrations from the Arctic to the Equator for use in MDA, ADA, Marine and Marine Mammal Monitoring, and Rapid Response missions, including oil spills and marine debris detection and monitoring. The ScanEagle final assessment is described in the USCG RDC's final report (Enclosure 3).

The ruggedized and ship-capable qualities of the Puma AE enable it to be operated in a remote ship-board environment that few other aircraft are capable of reliably operating including the Arctic. During testing, the Puma airframes often encountered high impacts into the ship and rails, resulting in no damage, except to the wings. The imagery captured during this exercise fulfills several NOAA observation requirements, but several improvements to the system and operational procedures are still required.

With respect to the Puma AE net-capture testing, captures were attempted with both a triangular, rail-mounted net and a square flight deck-mounted net. Differential GPS drifting rendered the triangle net inoperable for autonomous approaches during the 2015 exercise. Further testing and developments should be required prior to the next NOAA or USCG sponsored underway ship deployment.

For real-time data transmission, a high gain forward-looking antenna was successfully tested, with a range out to 5nm with no appreciable signal loss of signal. Furthermore, there was no loss of link when flying around and behind the ship at 300 ft of altitude and 1,000 ft around the ship.

The following outstanding capability test and evaluation items should be considered:
1) Expanded "due regard" operations,
2) Extended beyond line-of-sight operations to a radius of 25 nm,
3) Continued Puma AE envelope expansion, with operations in sustained winds of 30 knots and gusts up to 35 knots,
4) Weather criteria expansion to include "Clear of clouds" operations,
5) Autonomous net-capture system utilization on all capable NOAA vessels, and
6) Continued development and testing of advanced payloads.

Integration with the Aerostat-IC platform was successful, as was the demonstration using AeroVironment Data Definition Language (DDL) equipment. However it was discovered that the AeroVironment relay reduces bandwidth and resolution, therefore, precluding it from acting as an optimal solution. Consideration may be given to utilizing "Wave Relay". Alternatively, or another similar use of technology for this purpose would be to use an Aerostat to extend radio telemetry for beyond line-of-sight operations in any direction.

While the carbon nano-tube wing deicing system was only tested on a “static” Puma AE wing, which was mounted on an external rail, facing forward on the ship’s Aloft Con, this activity represents the first shipboard anti-/de-icing testing for small UAS. Due to net capture instability, it was decided the risk was too great to fly the prototype deicing system, only to chance having it get destroyed if the Puma had to land in the water or make a hard landing on the flight deck. Results from the data logger attached to the static wing will be reviewed and analyzed by Kim Sorenson, the inventor/engineer of the system, as well as by the NASA Ames Research Center.

The PEMDAS ASAPS was mounted in an unobstructed location atop the bridge of the USCGC *Healy* for preliminary testing in the Arctic environment. It performed ten testing periods of two to five hours in duration under various atmospheric conditions. The sensor processes meteorological data, compares it to existing weather forecasts, and presents a much more accurate and up-to-date prediction of impending icing conditions for an aircraft or UAS. The system has been tested on manned aircraft in various locations around the U.S. and has proven to be an incredibly successful technology for integration onto UAS in the very near future.

Similar to the reasons for foregoing Puma AE flights with the nano-tube deicing system, it was decided that it would be too great of a risk to test the 24 MP nadir camera payload during actual flights in the 2015 Arctic exercise. However, AeroVironment has demonstrated the advanced version of this payload to NOAA in January 2015 at Avon Park, FL and again following the Refugio oil spill event at Santa Barbara, CA in May 2015. The results from each of the testing applications were extremely positive, making this a useful payload for future Arctic UAS operations.

During one of the Puma AE flights, while the platform was being operated between 2 and 5 nm ahead of the ship, a real-time stream of the resulting aerial imagery was placed adjacent to the display from the USCGC *Healy*’s existing ice radar output for direct comparison of ice ridge detection and monitoring. The results of this initial test were favorable. As an outcome of this exercise, a recommendation has been put forth to co-locate the Puma operators (including the GCS and external monitor) with the ship’s radar operators during future similar exercises and operations. This would greatly improve the communication between the two parties and allow for a more timely and accurate transfer of information regarding targets of interest and their positions.

In closing, the USCG RDC has provided NOAA with excellent opportunities to field test Puma AE UAS, Aerostat, and data integration into ERMA in the Arctic environment, which is arguably one of the most challenging places in which the agency operates. Without the support of RDC and USCGC *Healy*, NOAA may not have had the opportunity to work with AeroVironment toward the development of the autonomous net capture system for the Puma AE. This safer, more efficient type of recovery system will greatly optimize NOAA Puma UAS operations from its own ships and may potentially support USCG Operation Deep Freeze 2016 (ODF16).

Furthermore, both the Puma and Aerostat platforms were successfully used in support of the previously referenced Santa Barbara oil spill in early 2015. Similarly, they were also integrated and used for demonstration during a simulated oil spill drill, aboard the USCGC *Healy* for Arctic Shield 2015. Had both unmanned systems not been aboard this vessel as part of Arctic Shield 2014, the ensuing opportunities to continue operational testing and development may likely not have been encountered. The ability to collaborate with the USCG RDC and USCGC *Healy* teams has provided a fertile and safe ground for continued advanced coordination and testing, and the efforts put forth by each of these groups is greatly appreciated.

Enclosures

The Enclosures are USCG unclassified, For Official Use Only (FOUO) documents and will be furnished upon request.

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