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CF Joint Arctic Experimentation 2012

Potential use of UXVs in CF Arctic Operations

Mae L. Seto
DRDC Atlantic

Paul Pace
DRDC Ottawa

David MacKay
DRDC Suffield

Robert Thwaites
CFMWC / NETE

Defence R&D Canada – Atlantic

Technical Memorandum

DRDC Atlantic TM 2013-003

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Technical Memorandum
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Principal Author

Original signed by Mae Seto

Mae L. Seto

Defence Scientist

Approved by

Original signed by David Hopkin

David Hopkin

Head / Maritime Asset Protection Section

Approved for release by	Approved for release by
Original signed by Dr. Leon Cheng	*Original signed by Colonel G. Dufour*
Dr. Leon Cheng	Colonel G. Dufour
Acting Chief Scientist / DRDC Atlantic	Commanding Officer CFWC

Abstract

Canadian Forces Joint Arctic Experiment 2012 (CFJAE12) was a joint capability development experiment conducted in and around Gascoyne Inlet, Nunavut from Aug 4-23, 2012. It was conducted in accordance with the Canadian Forces Strategic Experimentation Guidance and funded through the Strategic Experimentation Account. CFJAE12 was implemented by DRDC Centres – specifically, Suffield, Ottawa, and Atlantic. The maritime parts were based off CFAV QUEST (Atlantic) and the shore-based aerial parts (Suffield, Ottawa) were based at the DRDC Gascoyne Inlet Remote Camp. CFJAEA12 examined autonomous systems (UXV) such as fixed and rotary wing unmanned aerial vehicles (UAV), unmanned surface vehicles (USV), and unmanned underwater vehicles (UUV) as sensor platforms for future CF operations in harsh and remote environments like the Canadian Arctic. In such environments it can take days for external help to arrive in response to an incident or emergency. The focus of CFJAE12 was on Humanitarian and Disaster Operations (HADO) and Canadian Arctic sovereignty patrol missions.

CFJAE12 showed that having UXVs on-board a nearby ship represents a lot of capability to initially respond to the incident or emergency. CFJAE12 demonstrated UXV capabilities towards: confirming northern anchorages and approaches for ships; detection, localization and situational awareness for search and rescue; providing safe passage for RCN ships in uncharted and broken-ice waters; detection and potential tracking of anti-submarine warfare targets; autonomous bathymetric surveys (especially in shallow waters); and support for ship boarding operations. With their inherent force multiplication, persistence, reach, and stealth, the UXVs gathered and transmitted back timely situational awareness to ships and ground personnel to assist with making decisions. Critical operational issues are briefly discussed. The impact of the harsh and rugged environment on UXV operations, implementation logistics for Arctic experimentation, and lessons learned from CFJAE12 are documented. A way-ahead is also provided as guidance for CFJAE14.

Résumé

L’Expérience interarmées des Forces canadiennes dans l'Arctique 2012 (*Canadian Forces Joint Arctic Experiment 2012* – CFJAE12) est une expérience interarmées de développement de capacité qui a eu lieu du 4 au 23 août 2012 dans l’inlet Gascoyne (Nunavut) et les environs. L’expérience a été réalisée conformément à l’Orientation en matière d’expérimentation stratégique des Forces canadiennes et financée par Compte d’expérimentation stratégique. CFJAE12 a été réalisée par des centres de recherche de RDDC, soit ceux de Suffield, d’Ottawa, et de l’Atlantique. Les volets maritimes ont été menés à partir du NAFC QUEST (Atlantique) tandis que les volets aériens ont été effectués à partir de la côte (Suffield, Ottawa) au camp éloigné de Gascoyne Inlet de RDDC. Elle a servi à étudier l’utilisation de véhicules sans équipage (UXV), dont les engins télépilotés (UAV) à voilure fixe et tournante, les véhicules de surface sans équipage (USV) et les véhicules sous-marins sans équipage (UUV), comme plateformes de capteurs pour les opérations futures des FC dans des milieux éloignés et hostiles tels que l’Arctique canadien. Dans ces environnements, il peut s’écouler plusieurs jours avant que des secours extérieurs atteignent le lieu d’un incident ou d’une urgence. L’accent de CFJAE12 a porté sur les opérations humanitaires et les opérations de secours aux sinistrés ainsi que les missions de patrouille d'affirmation de la souveraineté dans l'Arctique canadien.

CFJAE12 a montré que le fait de disposer de véhicules sans équipage dans un navire proche offre une grande capacité pour la réponse initiale à l'incident ou à l'urgence. Elle a aussi démontré que les véhicules sans équipage ont les capacités suivantes : confirmation des approches et des mouillages de navires dans le Nord; détection, localisation et connaissance de la situation pour la recherche et le sauvetage; passage sécuritaire des navires de la MRC dans des eaux non cartographiées et chargées de glace brisée; détection et poursuite possible de cibles de guerre anti-sous-marins; relevés bathymétriques autonomes (particulièrement en eaux peu profondes); appui aux opérations d'abordage de navire. Grâce à leurs attributs intrinsèques de multiplication de force, de persistance, de portée et de furtivité, les véhicules sans pilotes ont recueilli et retransmis rapidement des éléments de connaissance de la situation aux navires et au personnel à terre pour aider à la prise de décision. De plus, des questions opérationnelles essentielles sont brièvement abordées. L'effet des environnements hostiles sur les opérations de véhicules sans équipage, la logistique de mise en oeuvre d'expériences dans l'Arctique et les leçons retenues de CFJAE12 sont documentés. Une voie à suivre est également définie pour CFJAE14.

Executive summary

CF Joint Arctic Experimentation 2012: Potential use of UXVs in CF Arctic Operations

Mae L. Seto; Paul Pace; David MacKay; Robert Thwaites; DRDC Atlantic TM 2013-003; Defence R&D Canada – Atlantic; November 2013.

Introduction: Canadian Forces Joint Arctic Experiment 2012 (CFJAE12) was a joint capability development experiment conducted in and around Gascoyne Inlet, Nunavut from Aug 4-23, 2012. It examined autonomous systems (UXV) like fixed and rotary wing unmanned aerial vehicles, unmanned surface vehicles, and unmanned underwater vehicles as sensor platforms for future CF operations in harsh and remote environments like the Canadian Arctic. CFJAE12 was implemented by teams from DRDC Centres – specifically Suffield, Ottawa, and Atlantic. The maritime parts of CFJAE12 experiments were performed off Canadian Forces Auxiliary Vessel QUEST by DRDC Atlantic and the shore-based aerial parts were conducted at the DRDC Gascoyne Inlet Remote Camp by DRDCs Ottawa and Suffield. The focus of CFJAE12 was on Humanitarian and Disaster Operations and Canadian Arctic sovereignty patrol missions.

Results: CFJAE12 demonstrated UXV capabilities for confirming northern anchorages and approaches for high value ships; detection, localization and situational awareness for search and rescue; providing safe passage for RCN ships in uncharted and broken-ice waters; tracking of anti-submarine warfare targets; autonomous bathymetric surveys in waters that are shallower than ship keel depths; and support for boarding operations. Critical operational issues as well as a brief discussion of the UXV role in the OODA (observe orient decide act) decision-making loop are included. The impact of the harsh and rugged environment on UXV operations, implementation logistics for Arctic experimentation, and lessons learned from CFJAE12 are documented. A brief way-ahead is also provided as guidance for CFJAE14.

Significance: UXVs represent a lot of capability given their relatively small footprint on-board a ship. In harsh and remote environments it is not always possible to bring resources in a timely manner to address an emergency or incident**.** CFJAE12 showed that UXVs on-board a nearby ship represents a lot of capability to initially respond to the incident or emergency. With their inherent force multiplication, persistence, reach, and stealth the UXVs gathered and transmitted back timely situational awareness to ships and ground personnel to assist with making decisions.

Future plans: There are plans for the Canadian Forces Warfare Centre to continue sponsoring these experiments as a series. Future experimentation will support Capability Based Planning. The primary area of activity will relate to Concept Development and Experimentation (CD&E). Ongoing CD&E activity is linked to Force Employment and Force Development. The experiments themselves would occur every other year with the next approved for August 2014.

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CF Joint Arctic Experimentation 2012: Potential use of UXVs in CF Arctic Operations

Mae L. Seto, Paul Pace, David MacKay, Robert Thwaites; DRDC Atlantic TM 2013-003; R & D pour la défense Canada – Atlantique; novembre 2013.

Introduction : L'Expérience interarmées des Forces canadiennes dans l'Arctique 2012 (*Canadian Forces Joint Arctic Experiment 2012* – CFJAE12) est une expérience interarmées de développement de capacité qui a eu lieu du 4 au 23 août 2012 dans l'inlet Gascoyne (Nunavut) et les environs. Elle a servi à étudier l'utilisation de véhicules sans équipage (UXV), dont les engins télépilotés (UAV) à voilure fixe et tournante, les véhicules de surface sans équipage (USV) et les véhicules sous-marins sans équipage (UUV), comme plateformes de capteurs pour les opérations futures des FC dans des milieux éloignés et hostiles tels que l'Arctique canadien. CFJAE12 a été réalisée par des centres de recherche de RDDC, soit ceux de Suffield, d'Ottawa et de l'Atlantique. Les volets maritimes ont été menés à partir du NAFC QUEST par RDDC Atlantique tandis que les volets aériens ont été effectués à partir de la côte par RDDC Ottawa et RDDC Suffield, au camp éloigné de l'inlet Gascoyne de RDDC. L'accent de CFJAE12 a porté sur les opérations humanitaires et les opérations de secours aux sinistrés ainsi que les missions de patrouille d'affirmation de la souveraineté dans l'Arctique canadien.

Résultats : CFJAE12 a démontré les capacités des véhicules sans équipage suivantes : confirmation des approches et des mouillages de navires de grande valeur dans le Nord; détection, localisation et connaissance de la situation pour la recherche et le sauvetage; passage sécuritaire des navires de la MRC dans des eaux non cartographiées et chargées de glace brisée; poursuite de cibles de guerre anti-sous-marins; relevés bathymétriques autonomes dans des eaux dont la profondeur est inférieure à celle de la quille du navire; appui aux opérations d'abordage de navire. De plus, des questions opérationnelles essentielles sont traitées et le rôle des véhicules sans équipage dans la boucle de prise de décision OODA (observer, orienter, décider, agir) est abordé. L'effet des environnements hostiles sur les opérations de véhicules sans équipage, la logistique de mise en oeuvre d'expériences dans l'Arctique et les leçons retenues de CFJAE12 sont documentés. Une voie à suivre est également définie pour CFJAE14.

Portée : Les UXV offrent une grande capacité par rapport au peu de place qu'ils prennent à bord d'un navire. Dans les milieux éloignés et difficiles, il n'est pas toujours possible d'acheminer rapidement les ressources nécessaires pour répondre à une urgence ou à un incident. CFJAE12 a montré que la présence d'UXV à bord d'un navire proche offre beaucoup de capacité pour la réponse initiale à l'incident ou à l'urgence. Grâce à leurs attributs intrinsèques de multiplication de force, de persistance, de portée et de furtivité, les véhicules sans pilotes ont recueilli et retransmis rapidement des éléments de connaissance de la situation aux navires et au personnel à terre pour aider à la prise de décision.

Recherches futures : Le Centre de guerre des Forces canadiennes prévoit continuer de parrainer cette série d'expériences. Les prochaines expériences porteront sur la planification fondée sur les

capacités et comporteront surtout des activités d'élaboration et d'expérimentation de concepts (EEC). Les activités d'EEC en cours sont liées à l'emploi et au développement des forces. Les expériences elles-mêmes se tiendraient tous les deux ans, la prochaine expérience ayant été approuvée pour août 2014.

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1 Introduction

1.1 Background

The Canadian Forces Joint Arctic Experiment 2012 (CFJAE12) was a joint capability development experiment conducted in and around Gascoyne Inlet, Nunavut from 4-23 August 2012. This experiment examined autonomous systems such as fixed and rotary wing unmanned aerial vehicles (UAV), unmanned surface vehicles (USV), and unmanned underwater vehicles (UUV) – collectively referred to as UXVs. Of interest were their abilities as sensor platforms performing future CF operations in remote areas like the Canadian Arctic. The experiment was conducted in accordance with the Canadian Forces (CF) Strategic Experimentation Guidance [1][2][3] and was funded through the Strategic Experimentation Account.

1.2 Mission

The Canadian Forces Maritime Warfare Centre (CFMWC), on behalf of the Canadian Forces Warfare Centre (CFWC), conducted joint defence experiments in Gascoyne Inlet, Nunavut (see Fig. 1) from 4-23 August 2012 to promote development of CF joint capabilities to support future operations in the Canadian Arctic.

1.3 Intent

The CFMWC led a joint CF effort with participants from the Canadian Army, Directorate of Land Concept and Development, the Royal Canadian Air Force, Canadian Forces Aerospace Warfare Centre, and Defence R&D Canada (DRDC). This was an experiment to identify, assess and explore capabilities and shortcomings of civilian technologies to support concept development and potential solutions to defence problems. Elements of concepts under development from operations and research were tested. These included the CFMWC Maritime Remote Autonomous Systems Concept Development Project [4] and a number of DRDC research projects.

CFJAE12 is the first of a series of planned experiments that promote the development of joint capabilities to support future operations in the Canadian Arctic. This experiment was also intended to identify and document requirements related to the planning, coordination and execution of joint Arctic defence experiments to mitigate issues for future deployments.

1.4 Objectives

CFJAE12's objectives were: to plan and execute a joint Arctic experiment; practice Concept Development and Experimentation (CD&E) processes and methodologies; assess technologies, procedures and processes in an Arctic environment; demonstrate capabilities that can be used to improve operations in the Canadian Arctic or other CF missions, and execute a comprehensive lessons learned program to improve the planning and coordination of future defence experiments.

1.5 Vignettes

The CFJAE12 experimentation followed CD&E methodologies [1] as advised by CFWC. The focus of CFJAE12 was on Humanitarian and Disaster Operations (HADO) and Canadian Arctic sovereignty patrol missions. Four *vignettes* for each mission illustrate potential Canadian Arctic CF events that involve an RCN ship (played by CFAV QUEST) tasked to respond to the events. The vignettes are intended to examine the role ship-based UXVs could play in Arctic missions. This is discussed in more detail in Section 2.

1.6 Legal, Administrative and Legislative Aspects

There were legal, administrative, and legislative aspects that were part of the preparation for Arctic experimentation. These administrative requirements, personnel documents, forms, permits, and licenses are listed in Annex B. They are included to fulfill the intent to document the planning, coordination and execution of defence Arctic activities. Annex C documents some of the public affairs aspects of CFJAE12.

1.7 Scope of this Report

This Report provides an overview of CFJAE12. Section 2 describes the vignettes which drove the capabilities examined and the subsequent experimentation plan. Section 3 describes the UXVs that were deployed to implement CFJAE12. Section 4 examines launch and recovery (L&R) – an important consideration in ship-based UXVs. Section 5 provides a summary discussion of the results from the perspective of the entire CFJAE12. Section 6 summarizes the lessons learned and Section 7 concludes with the CFJAE14 way-ahead. Drafts of the logistical details, experimentation plan, and record of the information collected are found in the Annexes.

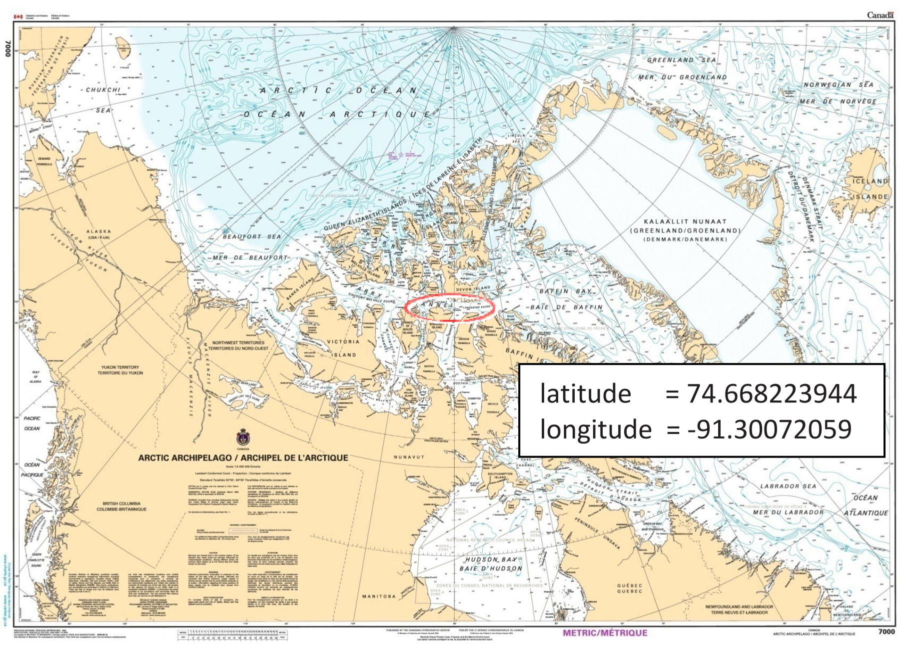


Fig. 1: Working area for CFJAE12 – Gascoyne Inlet, Nunavut.

2 Canadian Arctic of Vignettes

The CFJAE12 experimentation followed CD&E methodologies [1] as advised by CFWC. The focus of CFJAE12 was on Humanitarian and Disaster Operations (HADO) and Canadian Arctic sovereignty patrol missions. Four *vignettes* for each mission illustrate potential Canadian Arctic CF events that involve an RCN ship (played by CFAV QUEST) tasked to respond to the events. The vignettes are intended to examine the role ship-based UXVs could play in Arctic missions. The *vignette* and *task* (order given to the ship on its role), and the *capability* to address the *task* are described in the following.

2.1 Canadian Arctic HADO Missions

These four vignettes represent progressive stages of a HADO mission in the Canadian Arctic that CFAV QUEST is tasked to respond to.

2.1.1 Confirm Approaches for RCN Ships in the Aftermath of a Disaster (V1)

Vignette: A community north of 75^{o} in the Canadian Arctic was struck by an earthquake followed by a tsunami. Vessels were sunk in the harbour due to the tsunami and a major rock face broke off into the entrance of Gascoyne Inlet. CFAV QUEST was previously tasked to support the federal government facility at Gascoyne Inlet near this community. The facility houses a major communications hub for the north, a Transport Canada control centre for transpolar air routes, a CF command and control centre for 5 remote Arctic surveillance systems, and an accommodations complex for 300. This facility, built to modern standards, was only moderately damaged. There is an urgent need for CFAV QUEST to deliver 50 tons of supplies within 6 weeks in order to maintain services.

Task: CFAV QUEST is to confirm harbour approaches and anchorage areas are safe for RCN ships to enter and anchor and provide situational awareness of the Inlet area.

Capability: Employ resources to confirm safe entry and anchorage areas and provide situational awareness for a ship waiting at a safe distance.

2.1.2 Detection, Localization, and SA for SAR (V2)

Vignette: After CFAV QUEST arrived on-site, it anchored in Gascoyne Inlet and offloaded 50 tons of supplies. At 1300 the Officer-of-the-Watch reported a mid-air collision between two Twin Otter aircraft to the east. The first aircraft, trailing smoke and in a steep dive to the west, impacted the inlet water and sank. No survivors were recovered. The second aircraft, trailing smoke, performed a controlled descent to the east, declared an in-flight emergency, and then a Mayday call. No further messages were received. The Master of CFAV QUEST was tasked Scene of Action Commander for SAR. No additional resources were available for 24-48 hours as all other resources were over-tasked.

Task: CFAV QUEST to conduct search and rescue as a first responder.

Capability: Conduct search and rescue in a remote environment on land and underwater with only on-board resources.

2.1.3 Re-Establish Communications Network (V3)

Vignette: As a result of the natural disaster, the northern community suffered major infrastructure damage and the loss of 80% of its communications. A whole-of-government approach was taken to respond, support, stabilize, and re-establish the necessary infrastructure. This involves federal, territorial, and municipal governments. First responders as well as non-government organizations (NGO) are hampered by the lack of simple reliable communications. CF / CFAV QUEST was tasked to provide a cell phone service with local area coverage as well as SATCOM connectivity. This is achievable with a cell phone antenna on the mast of CFAV QUEST.

Task: CFAV QUEST to conduct and support communications with other government and non-government organizations.

The CFAWC experimentation cell at Shirleys Bay was to participate with aerostats designed to carry a cell phone system antenna. This would allow for a larger communications foot print to support OGD activity ashore. Based on pre-deployment experimentation it was assessed that the particular model of aerostat was unsatisfactory and would fail in an Arctic environment. Consequently, the aerostat was not deployed for CFJAE 2012.

Capability: Deploy a ship-based cell network with local area coverage.

2.1.4 Provide Safe Passage for RCN Ships in Uncharted Waters (V4)

Vignette: As CFAV QUEST performs its HADO mission, RCN ships (denoted HMCS) from outside the Arctic are delayed in their arrival with resources for the mission. This is due to the charting in Canadian Arctic waters. Only 10% of the Canadian Arctic is charted to modern standards and the rest is data that does not ensure safe ship navigation. These waters are also covered with ice or dynamic broken ice that is not amenable to predictions [5]. The RCN ship transit is as follows: first 50 nm will be in modern charted waters; next 30 nm will be in non-ice/ open water with inadequate charting, and the last 20 nm will be in ice with inadequate charting.

Task: CFAV QUEST and HMCS are to conduct search and rescue.

Capability: Safe ship transit through and within Arctic waters.

2.2 Canadian Arctic Sovereignty Patrol Missions

The following four vignettes examined the role that CF can play in employing UXVs in conjunction with other government departments (OGD) in an Arctic sovereignty patrol mission.

As part of a whole-of-government approach to solve problems and share resources, CF could work with OGDs and NGOs with UXVs. Three of the next four vignettes involve RCN ships working with OGDs and NGOs in the Arctic.

2.2.1 Autonomous Bathymetric Mapping Surveys (V5)

Vignette: CFAV QUEST is tasked to conduct a comprehensive bathymetric survey of Gascoyne Inlet so incoming HADO ships know where the safe docking points and routes are through the Inlet. The survey is to be performed in very shallow waters that are comparable to the keel depth of CFAV QUEST (5 m) in order to determine the shoreline. The concern is with newly submerged objects due to the earthquake and outdated charts. The Inlet is quite narrow, 600-1000 meters wide and there is ice moving through unpredictably. Given the data resolution needed, limited maneuverability of a ship in a confined space, and moving ice, this is a difficult task for CFAV QUEST or any Arctic ship.

Task: CFAV QUEST is to support the Hydrographic Service with bathy surveys.

Capability: Hydrographic quality survey work in shallow waters, ice, and confined areas.

2.2.2 Assist with Maritime Interdiction Operations (V6)

Vignette: A vessel of interest (VOI) believed to be carrying illegal migrants is transiting through Canadian Arctic waters. The VOI is detected by HMCS, performing a Canadian Arctic sovereignty patrol in the area. There is no helicopter on-board the HMCS for this sovereignty patrol. The identity of all persons on-board has to be confirmed and a search conducted.

Task: HMCS to support a Canada Border Services Agency VOI boarding.

Capability: Remotely gather intelligence and situational awareness on a VOI from a ship.

2.2.3 Autonomous Sonobuoy Deployment & Monitoring (V7)

Vignette: An HMCS is conducting a Canadian Arctic sovereignty patrol with no helicopter embarked. There are indications that a submarine may be transiting into Canadian Arctic waters. The HMCS is tasked to conduct anti-submarine warfare (ASW) operations. Specifically, conduct underwater surveillance operation at a choke point in the Barrow Strait. Maritime Patrol Aircraft resources are limited and will be released for 24/7 operations once a contact is acquired.

Task: HMCS to conduct anti-submarine warfare.

Capability: Covertly detect, identify and track a contact with the ship at a distance.

2.2.4 UXV Assist with Indications & Warning for Vessels of Interest (V8)

Vignette: An HMCS while conducting a Canadian Arctic sovereignty patrol is tasked to provide indications and warnings (I&W) of a VOI should it depart Gascoyne Inlet. This VOI is currently at anchor in Gascoyne Inlet. It is expected to leave within the next month. There are indications the VOI has conducted illegal fishing in Canadian Arctic waters. Once CF confirms departure, the Department of Fisheries and Oceans will task PAL flights to conduct 24/7 surveillance for data collection to support prosecution of the VOI for illegal fishing.

Task: HMCS to support the Department of Fisheries and Oceans in tracking a VOI.

Capability: Remotely conduct covert surveillance on a vessel of interest from a ship.

See Annex D for a more complete review of the results. The next section describes the UXVs that were used at CFJAE12 to implement the vignettes.

3 UXVS Deployed

The UXVs and remotely operated vehicles (ROVs) deployed, summarized in Table 1, are from DRDC Centres involved in CFJAE12. These UXV are not necessarily the best that could be used for experiments in the Arctic. In most cases they are test beds that support DRDC research more so than they are operational grade platforms. Platforms 1-6 in Table 1 have autonomous capability. Platforms 7 and 8 are ROVs, which are robots tethered to the operator for communications, control, and power, were used to support the experiments. Platform 9 is CFAV QUEST which is the DRDC research ship that the USVs and UUVs were deployed from during CFJAE12. Platforms 1-3 and 7-8 in Table 1 have their ground control stations (GCS) / operator consoles on-board the CFAV QUEST Dry (2), Wet (1, 3), or Forward Labs (7, 8). These platforms send data in near real-time either over telemetry (1, 2, 3) or a tether (7, 8) to the operators on-board CFAV QUEST. The next subsections describe these UXVs in more detail.

3.1 Unmanned Surface Vehicles

The two USVs deployed during CFJAE12 were the USV-HH (platform 2, Table 1) and USV-2600 (platform 1, Table 1). USV-HH is a gas-powered planing craft capable of higher speeds (30^+ knots) and is currently used as a drone for at-sea target practice by the CF. The fleet of USV-HH are maintained by the MARLANT N34-51 Operations and Readiness cell and are accessible to DRDC for experimentation and research. USV-2600 is a DRDC platform used as: a gateway buoy for submerged assets; a test bed for path-planning research; and a platform for shallow water surveys. It is powered by lithium-ion batteries. The USV-2600 is a robotic catamaran which is stable and manoeuvrable at low speeds (< 5 knots) whereas USV-HH is less so.

3.2 Unmanned Underwater Vehicles

The three IVER2 UUVs are test bed platforms at DRDC Atlantic that support research and development. They are also requested and used at CF exercises. These UUVs are torpedo-shaped, free swimming, untethered vehicles powered by lithium-ion batteries and equipped with sonars (side scan, bathymetric). With a typical sensor configuration, these UUVs have an endurance of 4 hours or more.

3.3 Unmanned Aerial Vehicles

UAV-FW (platform 4, Table 1) is a small fixed wing aircraft. While it can achieve higher speeds than a similarly sized rotary wing aircraft it requires runways for take-offs and landings. UAV-HELO (platform 5, Table 1) is a rotary wing aircraft (helicopter) powered by a gasoline engine. It can take up to 25 lb of payload with 50 minutes of flight time. It is capable of vertical take-offs and landing which is appealing in unstructured environments that may not have groomed runways. UAV-QUAD (platform 6, Table 1) is a quadrotor that can withstand 50 km/hr winds, has a 3 km range, has a flight time of 20 minutes and is powered by lithium-ion batteries. Quadrotors are generally more stable in high winds compared to a helicopter. Both UAV-HELO and UAV-QUAD can hover, whereas UAV-FW cannot; this hovering capability is useful for obtaining good, stable images and measurements. In contrast, the fixed wing aircraft shown in Table 1 can only provide images and measurements in a "fly-by" manner. Another difference between UAV-HELO and UAV-QUAD is the endurance and payload capacity possible with a gasoline engine versus lithium-ion batteries.

With the exception of UAV-FW all the other UXVs are available as commercial-off-the-shelf. The CFJAE12 USV and UUV experiments were based off CFAV Quest (Atlantic, Lead Scientist M. Seto) and the UAV experiments were based at the DRDC Gascoyne Inlet Remote Camp (Ottawa, Lead Scientist P. Pace; Suffield, Lead Scientist D. Mackay). The environment that the UXVs operated in is summarized in Table 2 and detailed in Annex A.

The next section discusses the launch and recovery for these UXVs – an important consideration for ship-based operations.

Table 1: Summary of DRDC Platforms Deployed at CFJAE 2012.

(*L* = length, *B* = beam, *H* = height, *T* = draft, OEM = original equipment manufacturer)							
	#	**image**	**platform type**	**OEM / UXV name**	**top speed (kt) / propulsion**	**payload sensors**	**dimensions (m)**
autonomous	1		USV (ATL) (semi-displacement catamaran)	Sea Robotics/ *USV-2600*	5 – 6 (127 Whr Li-ion batteries)	• JVC video PTZ camera • ES3-M Sonar (240 kHz) • Furuno Echo Sounder • 10 kHz WHOI micromodem • sonobuoy launcher (3) • differential GPS • AIS transmitter	4 × 2× 1 ($L×B×T$)
	2		USV (ATL) (planing craft)	Meggitt/ Hammerhead or *USV-HH*	30^+ (135 hp gas engine)	• video camera • FLIR • Garmin marine radar • differential GPS • AIS transmitter	5× 1.5 × 1 ($L×B×T$)
	3		UUV (ATL)	OceanServer/ IVER2	3 – 4 (600 Whr Li-ion batteries)	• Yellowfin Sidescan Sonar (400 kHz) • 10 kHz WHOI micromodem • Janus Doppler velocity log	0.15×1.5 (dia×L)
	4		UAV (OTT) (fixed wing) 3 sizes	Experimental / Caribou Cam or *UAV-FW*	100 (60 cc twin cylinder, gas)	• Nikon D3X Camera with NIKKOR 24-120 mm lens • GoPro HD Hero2 Camera	2×0.5×4 ($L×H$ ×span)
	5		UAV (OTT) (rotary wing)	Copterworks/ AF25B or *UAV-HELO*	15 (80cc twin cylinder - gas)	• Nikon D3X Camera with NIKKOR 24-120 mm lens • GoPro HD Hero2 Camera	1.8×0.7×0.5 ($L×H$ ×width)

(*L* = length, *B* = beam, *H* = height, *T* = draft, OEM = original equipment manufacturer)

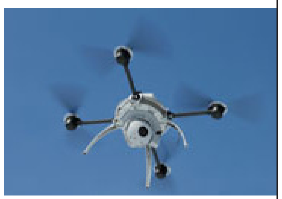
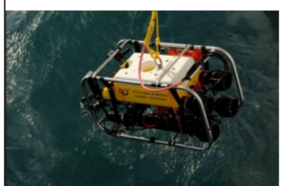
	#	image	platform type	OEM / UXV name	top speed (kt) / propulsion	payload sensors	dimensions (m)
	6		UAV (SUF) (quadrotor)/ UAV-QUAD	Aeryon / Scout or *UAV-QUAD*	30 (Li-ion battery)	• VideoZoom10x video camera • Photo3S still camera	0.2 × 0.8 (*H* ×wingspan)
remotely operated	7		ROV (ATL) (light work class)	Phantom DHD 2+2	3 (7 hp, QUEST power)	• Sony Ex color video camera • DSP 11 b/w video camera • Imagenex 855 sector scan sonar • Kongsberg 900 sector scan sonar	1.4×0.6×0.67 (*L*×width×*H*)
	8		ROV (ATL) (inspection class)	Seamor	1 – 2 (0.6 hp QUEST power)	• DSP and Light color video camera • Didson 300M bathymetric sonar	0.9×0.35×0.5 (*L*×width×*H*)
manned	9		surface ship	DRDC / CFAV Quest	15 twin diesel electric and gas turbine	• bathymetric XBT • echo sounder • wind sensors • temperature sensors • over-the-bow wave sensor • radar • rated for 1m ice breaking • can deploy 2 RHIBs	76× 12.6× 4.8 (*L*×*B*×T)

Table 2: Environmental Conditions at Gascoyne Inlet, Nunavut (August 2012).

environmental condition	**UXV challenge**
high winds (up to 30 kt)	• limits operation of UAVs • causes higher seas which limits USV-2600 operation
fog	• compromise LOS visibility for operation of UXVs and any in-water RHIB support
snow squalls	• compromise LOS visibility for USV and UAV and in-water RHIB support for UUV
below zero temperatures	• UUV and USV batteries difficult to start • ES3-M multi-beam sonar difficult to start • UAV icing on wings (fixed wing) • UAV carburetor icing (UAV-HELO)
broken ice in the water	• obstacles to track and avoid for USV, UUV, & CFAV QUEST
magnetic north fluctuations	• inability to navigate if based on magnetic compass (*e.g.,* UAVs) • difficulty aligning fibre-optic gyros for navigation
low orbital elevation for GPS satellites	• larger than normal uncertainty in UAV and USV localization and navigation based on GPS
rough land surface terrain (rocks, hills, etc.)	• challenge for small fixed-wing UAV to take-off and land • twin otter aircraft with rough terrain tires can take-off and land
melting ice	• thick fresh water layer on top of the sea water making it difficult for the UUVs to dive and rise
inverted sound velocity profile	• ducting of acoustical signals so that returns from the sonar on-board the USV are not getting back to the sonar
rocky seabed	• multi-path and reverberation (low SNR) for acoustic sensors
rapid weather changes	• challenge to plan which missions should be carried out
challenges of the remote location	• obtaining replacement parts in a timely manner • latency in transporting equipment and people in / out • reliable internet access to consult with contractors • local infrastructure for support (e.g., a crane truck)

4 UXV Launch and Recovery

This section reports on UXV launch and recovery (L&R) in the environment summarized in Table 2. For UXVs to be effective ship resources, L&R issues have to be examined. At Gascoyne Inlet, the UAVs were launched and recovered from shore. The sea-based UXVs were operated from CFAV QUEST.

4.1 Air-Based UXV

It was expected that the natural rugged surface terrain at Gascoyne Inlet would pose problems for UAV-FW. The size of the rocks and the unevenness of the surfaces were problematic (Fig. 2). Attempts were made to take-off and land under these conditions; however, minor damage to UAV-FW was sustained on most attempts. Consequently, the UAV-FW could not be used to undertake the planned experiments and this portion of the program was completed by UAV-HELO. This terrain did not pose problems for UAV-HELO or UAV-QUAD.

Fig. 2: Typical land surface (a) texture and (b) unevenness.

4.1.1 Launch and Recovery of UAV-HELO from Land

Due to an unstable magnetic north reference, waypoint navigation was not possible with UAV-HELO, however, short range flight patterns could still be flown. This was achieved by flying UAV-HELO in a mode which does not require a magnetic heading reference; slow heading drifts were manually compensated by the operator. Three operators are required to launch UAV-HELO.

4.1.2 Launch and Recovery of UAV-QUAD from CFAV QUEST

UAV-QUAD experiments were conducted on CFAV QUEST offshore of Halifax in October 2012 where the magnetic heading was more stable than at Gascoyne Inlet. The UAV-QUAD's reliance on a stable magnetic north reference makes the impact of the local magnetic field disturbances from the ship significant to the UAV's operation. For example, it was not possible to set the gyroscope biases about a stable heading. Therefore, the original equipment manufacturer (OEM) recommended the take-off height be a minimum of 3 metres above the deck to minimize the interference from the local magnetic field. To achieve this take-off requirement, the UAV was held 3 metres in the air from the deck.

The ship superstructure poses hazards to the UAV as it approaches CFAV QUEST for a flight deck recovery. Superstructure are potential obstacles, interrupt communications between the flyer and the GCS, and can cause air flows that deviate the flyer from its intended path. Many ships, CFAV QUEST included, do not have deck areas suitable for UAV-QUAD landings. The OEM recommends grabbing the UAV, as it flies within range, as the best recovery strategy. This worked for the first two flights. For the third flight, recovery challenges resulted in the loss of the UAV. The L&R of UAV-QUAD from CFAV QUEST required 2 operators and the ship at a constant heading at 5 knots.

4.2 Sea-Based UXV

Launch and recovery of UXVs from high freeboard ships is an important consideration in employing UXVs on ships. CFAV QUEST's Aft Deck freeboard, where UXV launch and recovery mostly occurred, is 3 metres high which is quite high off the water for a crane-based launch and recovery. This drove the launch and recovery strategies used.

4.2.1 Launch and Recovery of USVs from CFAV QUEST

To launch the USVs, the ship crane hooks to the lift points directly with a quick release hook. Forward and aft tag lines control the USV motions during the launch. When the USV is on the water, the forward tag line is released. Then, the USV is released from the crane hook. At the same time the aft tag line is pulled to point the USV bow away from CFAV QUEST. Then, the operator steers the USV away from the ship and the aft tag line is released.

As a result of differences in the maneuverability of each of the USVs, the recovery process for each of the two USVs is different. USV-2600 has fine control at low speeds and can be controlled from the Aft Deck by the operator with a wireless handheld controller. As a result, the operator can position the USV-2600 directly under the crane. In contrast, the USV-HH operator does not have fine control of the USV, especially at low speeds, and the operator cannot see the USV when it is close to CFAV QUEST. As a result, the USV-HH is shifted into neutral at 20-30 m from CFAV QUEST and a manned RHIB secures a line on the USV-HH bow, and tows it in to under the crane. From this point, the recovery is identical for both USVs. The RHIB crew places the pendant lift lines, which are on the lift points, onto the Aft Deck crane hook, secures the tag lines onto the USV, and then throws the tag lines onto CFAV QUEST. Six people are required to launch and recover an USV.

4.2.2 Launch and Recovery of UUVs from CFAV QUEST

For the majority of CFJAE12, the IVER2 UUV was launched over the side of the CFAV QUEST RHIB by an operator. However, towards the end of CFJAE12 the operators learned to use a L&R cocoon (Fig. 3) from CFAV QUEST. This is a flexible fibre glass cylinder that holds the UUV as it is lowered to, or raised from, the water by lines through a sheave secured at the crane. Tag lines at both ends of the cocoon minimize its swing. The painter's pole, attached to the cocoon, is used to push the positively buoyant cocoon down once it is at the water surface. Then, the UUV can back out (launch) or swim in (recovery). The cocoon L&R was performed in sea state 2. A UUV cocoon recovery can only be performed with ship freeboards that are comparable to the length of a painter's pole (in this case, 3 m). For this UUV L&R 5 people are required. In contrast, 1 extra person and a deployed RHIB are needed for a RHIB-assist launch.

The next section provides a summary of the results and presents some measures of effectiveness for the experimentation. See Annex D for a more complete review of the results.

Fig. 3: UUV recovery by L&R cocoon over-the-side of QUEST's Forward Deck.

5 Summary Discussion of UXVs Applied to Arctic Missions

For a UXV to be considered for a ship-based mission, it must increase the ship's persistence and reach in ways that allow the ship to better achieve its mission. CFJAE12 provided an opportunity to perform research, development, and experimentation with UUV, USV, and UAVs and to assess that using CFAV QUEST. Based on the insight and experience gained from the larger perspective of the entire CFJAE12, this section outlines the benefits and requirements of ship-based UXVs, discusses considerations that affect UXV selection, and presents potential new requirements that UXVs could uniquely address.

5.1 Ship-based UXVs - requirements and benefits

At CFJAE12, CFAV QUEST's complement of UXVs is shown in Table 1. These UXV systems were collectively contained in a small footprint on CFAV QUEST, a relatively small ship (76 m length). To operate all the UXVs from CFAV QUEST requires 6 operators and 5 crew members (2 of them in a RHIB) to assist with L&R.

In addition to these personnel requirements, the UXVs have logistical requirements on-board the ship. The UXVs require: physical storage space; internet access for firmware adjustments and patches as well as on-line diagnostics; de-conflicted bandwidth for UXV and payload telemetry and communications; power for ship-board ground control stations and consoles, UXV charging, and antennas; explosives lockers for transporting lithium-ion batteries; means and storage to transport volatile fuels like gasoline; a crane rated to deploy the USV / UUV; ship radar to assist with long range ice spotting; and cameras for UXV visibility during L&R for the operators. As well, radio broadcasts are needed for notice to mariners / airmen, intentions of the day, and airspace management.

In addition to these on-board logistical requirements, the UXVs had to function within the Arctic environment. The CFJAE12 environment was remote and characterized by uneven ground cover, below zero temperatures, high winds (as high as 30 knots), occasional snow squalls and falling snow, dynamic moving ice in the Inlet, and fluctuating magnetic headings. The nature of the remote location meant it was not possible to bring in new resources or help within 48 hours and there was no access to high bandwidth internet.

For the HADO (V1, V2, V4) and Canadian sovereignty patrol vignettes (V5-V8) the use of UXVs enhanced the ship's ability to perform its mission. CFJAE12 showed ship-board UXVs allow the ship to increase its reach by remotely and autonomously: confirming safe entry and anchorage, above and below water, in uncertain areas (V1); conducting search and rescue, above and below water, in difficult environments (V2); collecting information for safe ship passage in uncharted waters which may also have ice coverage (V4); assisting with a ship boarding by providing real-time imagery of the VOI's blind side (V6); deploying and monitoring sonobuoys to detect, identify, and track targets (V7), and obtaining indications and warnings of a sea-going VOI (V8).

5.2 UXV Considerations for a Mission

For each vignette thought was given to how the capabilities of each UXV could enhance the ship-based mission. In determining the most effective UXV, consideration was given to transit speed, endurance, payload (sensor), and on-board computational loading. On-board computations are needed for functions like automated target recognition and in situ data processing and analysis towards autonomy functions like mission re-planning, decision-making, path-planning, and sensor usage.

For UXVs the transit speed, endurance, supportable payload and on-board computational loading depend on the energy density for the on-board energy source. The two energy sources trialed at CFJAE12 were gasoline and lithium-ion batteries. The energy density for gasoline (air breathing engines) is higher (12.7 KWh / kg, e.g., UAV-HELO, USV-HH) than lithium-ion batteries (150 Wh / kg, e.g., UAV-QUAD, USV-2600) by over a factor of 80. Higher transit speeds and endurance as well as supportable payload and on-board computations are more readily achieved with gasoline as the energy source. However, gasoline engines require that all the gasoline for an Arctic deployment would have to be carried on-board the ship. CFAV QUEST did not want to carry gasoline on-board if at all possible for safety reasons.

CFAV QUEST's requirement to transit in and out of Gascoyne Inlet in a moving-ice environment (V1) highlights how high and low speed UXVs could be employed for remote and autonomous ISR. Over water, high speed, high altitude / long range UAVs (fixed wings) rapidly and approximately localized the ice fields (*e.g.,* "northeastern shore of the inlet") albeit at lower resolution. Then, lower speed UAVs (*e.g.,* quadrotors), with hover capability, accurately localized (at GPS resolutions) select points like the extent of the ice field.

Similarly, at shallow water depths USVs could complement UUVs by performing the high speed, high altitude / long range (lower resolution) sonar surveys for submerged targets from close to the water surface. Then UUVs, which operate at much lower speeds, were deployed to focus on localizing specific targets and imaging them at higher resolutions. For deeper (> 80m at CFJAE12) water tasks UUVs are used for the large area and small area surveys with no appreciable difference in speed.

The availability of wireless data bandwidth impacts the concept of operation for a mission employing an UXV. An UXV that transmits its data in real-time to a ground control station / operator console for 'in-situ' human analysis into information can provide timely situational awareness and mission adaptability. This is contrasted by a scripted mission that logs data for download and human analysis after its recovery. For example, UAV-FW logged video imagery for its long range ice surveys. This could only be downloaded and interpreted after UAV-FW was recovered by its operators. Therefore, the operator could not adapt the UAV-FW mission to also survey newly discovered ice. In contrast, UAV-QUAD was able to adapt its mission in the experiments for in-stride safe ship navigation. Without the wireless data bandwidth such in-stride capabilities would not be possible. Sufficient data bandwidth gives the UXV mission adaptability and rapid situational awareness beyond the extended reach the UXV already provides. The next sections summarize the analysis from the HADO and Canadian Arctic sovereignty patrol experiments that are covered in more detail in Annex D.

5.3 Humanitarian and Disaster Operations

For the above and below water cases described in the previous section, the UXVs mitigated risk to the ship and allowed the ship to obtain situation awareness (ice location, objects in the water, etc.) from a safe distance. UXVs were also applied to search and rescue in difficult areas over land and in-water (V2). High speed UXV, powered by air-breathing engines, provide rapid large area surveillance and reconnaissance at lower resolution. Low speed UXV, powered by lithium-ion batteries, are suited to focussed localization and inspection of targets over small areas. In the two HADO vignettes, CFJAE12 showed that UXVs can perform timely detection, classification and identification so manned forces can carry out more informed prosecution when they arrive.

Vignette V4 examined the role UXVs can play in assisting ships transiting from outside the Arctic to the HADO mission through uncharted waters and waters with ice coverage. The USV-2600 was tasked to run ahead of the ship to take, and stream back, water depth measurements from an echo sounder, and ice cover from a video camera. This information was used to assist the ship to plan its path. As well, the UAV-QUAD transmits near real-time information on where large breaks in the ice are for the ship to potentially transit through. The UAV communicates the ice breaks to the USV-2600 which confirms the below water ice extent with in-water sensors. As mentioned in Annex D there are operational issues in operating UAVs from ships (flight deck space, vehicle interfaces). It is recommended for the next CFJAE to assess these requirements.

5.4 Canadian Arctic Sovereignty Patrol

For the Canadian Arctic sovereignty patrol vignettes (V5-V8), CFJAE12 focussed on UXV Arctic capabilities that were also of interest to OGDs and NGOs. CF, as a federal government department, has experience and expertise in UXV R&D, operations and maintenance. To date, other departments and agencies have not had reasons to develop this expertise. Therefore, CF is in a unique position to work with OGDs and NGOs in using UXVs. The rest of this section briefly presents the results of the sovereignty patrol vignettes.

Vignette V5 examined the use of USVs as platforms for autonomous hydrographic bathymetric surveys. In addition to integrating the bathy sonar on-board the USV, the USV working in the CFJAE12 Arctic environment also needed ice avoidance with above (radar) and below water (forward looking sonar) sensors, seabed avoidance with echo sounders, accurate positioning from GPS, and navigation by compass-independent means like DGPS, The utility of ice avoidance sensors (e.g., forward looking sonar) was not proven at CFJAE12 for autonomous surveys. During CFJAE12 the ice avoidance was performed with CFAV QUEST crew using the ship radar.

It is difficult for Arctic-bound ships with hull mounted sonars to maneuver close to shorelines and confined areas at low speeds for hydrographic quality bathy surveys. During Vignette V5 the USV-2600 used its low speed maneuverability (3-4 knots) to map inlets and near shore areas to the resolution required for hydrographic maps. The USV-2600 showed it was possible to survey a 600 m wide choke point with transects that are 30m apart and to water depths of only 3 metres. Another requirement for hydrographic quality surveys is the ability to sea-keep to sea state 3 at 3-4 knots. USV-2600 can sea-keep well to sea state 2 and is marginal at sea state 3. However, there are other USVs that can sea-keep well to sea state 3. It is also desired that the USV be easily deployed and recovered from vessels of opportunity going to the Arctic to increase the surveys that can be performed. It is recommended that for the next CFJAE, a better quality hydrographic bathy sonar on the USV-2600 be integrated to further assess catamaran platforms for autonomous bathymetric surveys.

Vignettes V6-V8 examined UXV capabilities that are not uniquely applicable to the Canadian Arctic. Vignettes V6 and V8 are concerned with monitoring other ships suspected of illegal activities. USVs and UAV-QUAD can monitor a ship visually in real-time. UAV-QUAD especially showed it can stream real-time video of the VOI and its occupants from altitudes and ranges that are not apparent to the VOI. It is recommended that for the next CFJAE, UAV navigation methods that are not reliant on a stable magnetic heading be developed.

Vignette V7 showed it was possible for a USV to remotely and autonomously deploy sonobuoys to detect targets on or under the water. The USV can also monitor the sonobuoy with its PTZ camera to confirm that its float had surfaced. It is recommended that for the next CFJAE, the USV relay the sonobuoy signal to the ship. This can also involve collaboration with a UAV as an in-air relay to extend the ship's reach to well beyond the horizon from the sonobuoys.

5.5 New Arctic Capabilities with Ship-Based UXVs

In vignette V5, USVs were examined to perform autonomous bathymetric surveys. These surveys are a new Arctic capability and potential improvement over ships with hull mounted sonars and increases the possibility for more opportunistic Arctic surveys. As well, the aforementioned in-stride safe navigation assists (V4) for ships transiting through uncharted and / or ice infested waters is a new Arctic capability.

In remote and rugged environments it is difficult to bring in resources in a timely manner for an emergency as help from outside the Arctic can be days away. An RCN-like ship in the Canadian Arctic carrying a complement of UXVs is equipped as first responders to address a wide variety of tasks as shown in the vignettes. These on-board UXVs add to the ship capability due to their persistence, reach, and force multiplication.

Critical operational issues in the application of UXVs are examined based on the results of the experiments from the vignettes. This is summarized in the next section.

5.6 Critical Operational Issues

Critical Operational Issues (COI) are operational effectiveness and suitability issues (not parameters, objectives, or thresholds) that are examined to evaluate the UXVs' capability to perform its mission. COIs must be relevant to the required capabilities for a system and represent a significant risk if not satisfactorily resolved. Two types of COIs exist: effectiveness COIs (E-COIs) and performance COIs (P-COIs), which determine respectively the effectiveness and the performance (suitability) of the system to accomplish the mission. COIs are examined and related to Measures of Effectiveness (MOE) and Measures of Performance (MOP). A COI is phrased as a question that is answered in the affirmative to evaluate operational effectiveness. The COIs shown in Table 3 are proposed within the context of the CFJAE12. From the initial experimentation with the eight CFJAE12 experiments an estimate of the COI requirements was obtained. Table 3 presents the findings to date. They address the overall UXV effectiveness and not a specific vignette, task, or capability. In response to posed COI questions, answers were: *yes*, *no*, *unknown*, or *not entirely* with some justification.

Based on the experience of CFJAE12, the employment of UXVs in the context of OODA (observe, orient, decide, and act) is briefly discussed in Annex E.

Table 3: Critical Operational Issue Evaluation.

effectiveness	UAV	USV	UUV
COI-1 (search) *Can the UXV perform search missions to detect the targets when given approximate coordinates?*	**Not Entirely.** UAV-QUAD could not fly from a ship in the Arctic and UAV-FW could not fly from shore. Also depends on required detection probability and false alarm rate. SAR target detection in low-clutter Arctic environment has a high probability of success and a low false alarm rate	**Yes.** Proven for visual sensors. Not proven for acoustic sensors.	**Unknown.** Inadequate testing in this environment. In other environments it is able to.
COI-2 (classification) *Can the UXV classify targets?*	**Yes.** Images with 6.5 < NIIRS ratings < 7.5 necessary to accomplish this.	**Yes.** For visual sensors. Unproven for acoustic sensors.	**Unknown.** Inadequate testing in this environment.
COI-3 (communications) *Can the UXV communicate with, and transfer data to, the operator?*	**Not entirely.** Flight control data and communication with autopilot with Iridium satellite - needed for BLOS operation. Bandwidth insufficient for image transfers.	**Not entirely.** If within radio range (2 nm), vehicle status, video images, and whatever is available with telemetry. Echo sounder returns good but entire swaths of acoustic imagery difficult.	**Not entirely.** Low bandwidth communications over longer distances via a USV relay. Not enough bandwidth for acoustic images.
COI-4 (response) *Can the UXV respond in a timely manner to situational demands?*	**Not entirely.** Variable weather can be detected and UAV can be controlled from ground station; however, intruding aircraft requires approved sense and avoid system. ADS-B under development for this.	**Yes.** If within the sea state rating of the vehicles. Low speed catamaran can respond quickly for ice detection. Vehicle endurance could be a limitation.	**Unknown.** Inadequate testing in this environment.
COI-5 (support) *Can the UXV support and improve the effectiveness of the capability?*	**Unknown.** Have quantified image resolution requirements, detection and classification probabilities; however, BLOS flights presently impossible. Until possible, UAV may not be viable.	**Yes.** Can perform unmanned ISR in unknown areas, smaller USV footprint allows covert tracking and monitoring of targets; USV can do bathy surveys in waters shallower than ships can go.	**Unknown.** In other environments able to provide below water situational awareness on what is on the seabed.
COI-6 (dull) *Can the UXV minimize the use of personnel and platforms for the performance of dull tasks and missions?*	**Yes.** Human can be removed from flight operations but operators still required. Analysis requires human but a combination of automated algorithms and human improves processing time and accuracy.	**Yes.** For autonomous shallow water surveys, deployment and monitoring of sonobuoys, coverage of blind ship side during boarding, harbor approach confirmation.	**Yes.** Can perform autonomous surveys of shallow areas.
COI-7 (suitability) *Is the performance of the UXV suitable for the operational environment?*	**No.** Inability to fly BLOS ⇒ not suited to environment. Will eventually be viable. Sensors adequate but improved sensors would only improve detection. Suggest hyperspectral imaging be considered with UV and near IR.	**Yes.** With DGPS showed navigation w/o magnetic compass, USV-2600 low speed stability and maneuvering permits ice field and general reconnaissance, USVs sea-keep to almost sea state 3, with echo sounder can work in shallow water.	**Yes.** Sea states not high in this environment, on-board INS allows navigation independent of magnetic compass. Acoustic propagation conditions occasionally problematic.

6 Lessons Learned

As per CD&E procedures, the DRDC technical staff attended a debriefing session where their personal and team lessons learned were discussed and documented. These can be along the lines of scientific, technical, operations, personnel, individual, or tasking nature. The collected lessons learned are located on a CFMWC DWAN website hosted at:

http://kms.mil.ca/kms/CentralInstance.aspx?Type=ExperimentAndTrial&Id=918

This website is only available to the Canadian military. The five most important categories for the high level lessons learned are summarized below. Annex G contains further details.

1: Universal command & control unit for operation of UXV platforms and their payloads.

The UXV control stations used during CFJAE12 were unique or proprietary. Since each system was different there was a training/operation load on the operators. This reinforces the requirement for a long term approach to develop the NATO 'Multi Domain Unmanned Control System' (MDCS) to support future CF experiment/operations in the Arctic and elsewhere. As quoted from [6] "*It is technically feasible and advisable to design and build a single Multi Domain unmanned Control System (MDCS) for all of the [UAV, UGV, USV, and UUV] vehicle domains."* Based on that finding, together with the strong US DoD support [7] for this type of interoperability, it is likely a MDCS-like control system will be fielded soon. This type of control system could be considered for experimentation in future CFJAE experimentations.

2: 24 months is recommended for the preparation, work-ups, and execution of future CFJAEs.

To effectively prepare and mitigate risk for future Arctic experiments, a 24 month time line should be allocated. A number of items listed in Table 4 can have lead times of 24 months. The 24 month time frame allows parts of the experiment to be built into Unit budgets and programs of work. Specifically, two items are identified as needing this amount of time:

- PWGSC procurement with enough time after delivery for systems integration, training, development of maintenance capability, mitigation of risk and safety issues, vetting SOPs, and work-ups.
- *Request for DRDC Support* to be processed and resources assigned. This is required for the DRDC business planning cycle to allocate resources to future CFJAEs.

3: The benefit of autonomy to UXVs should be examined for increased efficiency, effectiveness and economy to future capability. It is linked to the personnel costs associated with future UXV systems.

Autonomy observation:

- Future UXV systems could be more manageable as the required personnel costs to support them could decrease. An integrated autonomy framework across different types of UXVs means the operators would not have to be as familiar with different UXVs or learn as many separate command and control systems.

- Future UXV systems could deliver timely data. The complexity and volume of data within the UXV C4 part of the system needs to be assessed to determine how autonomy can best be utilized in future CFJAEs. Operations Research should be employed towards analysis that compares relative costs and outcomes to specific courses of action.

4: Effect of magnetic north fluctuations on magnetic-based navigation systems.

The effects of the fluctuating magnetic field on magnetic-based navigation systems were known prior to deployment. It was assessed that the impact would be substantial and options were selected to compensate for this negative impact. One example was the implementation of DGPS for the USV navigation systems. Another example is the purchase of fibre optic gyroscopes for the UUVs to improve their inertial navigation when submerged. The negative impact on the magnetic compass navigation systems that were employed was greater than anticipated for this location. Magnetic-based navigation systems should not be employed in future northern operations/experiments at this latitude.

5: Legislative, Policy, Legal, CF Orders and procurement processes that need to be considered in developing future CF Joint Arctic Experiments.

This is covered in Annex B.

7 Way-Ahead for CFJAE14

Based on the experience and results from CFJAE12, a way-ahead is provided for the follow-on experimentation, CFJAE14. The way-ahead focuses on lessons learned and successes to date. They are shown itemized under several categories i.e., experiments to consider, research to pursue, participants, and the schedule. The development work for the UXV platforms to ready them for CFJAE14 is detailed in Annex G.

Experiments considered:

The following recommendations are from Summary Discussion and COI Evaluation (Section 5), and the Lessons Learned (Section 6). Specifically:

- Assess the requirements to operate UAVs from ships (Summary Discussion).
- Integrate a higher quality bathymetric sonar than the Teledyne ES3M multi-beam sonar used to better assess the stability of catamaran platforms like the USV-2600 as a hydrographic platform (Summary Discussion).
- Develop UAV navigation systems that are not based on a stable magnetic heading (Lessons Learned).
- Use the USV to relay the sonobuoy signal to the ship and also involve collaboration with a UAV as an in-air relay (COI evaluation).

The recommendation is that new experiments focus on: (i) persistent capability in harsh environments and (ii) assess the impact of the orient step on the decide step in the OODA decision-making process with UXVs.

Research to pursue in advance of CFJAE14:

The following are recommended as there was not enough time to address them in CFJAE12:

- As per the COI evaluation for the UUV, model the underwater acoustic environment through tools like Bellhop and in situ sound velocity profile measurements to gain insight into the underwater acoustic propagation conditions in order to improve communications and data transfer to the operator.
- As per the Lessons Learned, develop UXV autonomy to reduce the effort in managing multiple UXVs and to obtain timely analysis and interpretation of in-situ data from sensor measurements. Towards this objective, UXV planning and collaboration tools like the SeeByte Ltd. NEPTUNE should be considered and evaluated.
- Achieve milestones towards cooperative under-ice mapping of ice keels beneath multi-year ice using upward looking Doppler velocity logs on-board UUVs. Also of interest is the ability for UUVs to navigate in and out of ice keels. This supports the capability for UUVs to determine ice thicknesses for ships with ice-breaking capability.

Participants

- Long baseline navigation under-ice with REMUS 100 UUVs should be pursued with Heriot-Watt University. The long baseline navigation in the absence of ice was delivered to DRDC in March 2013. The results show Heriot-Watt University is well prepared to perform this under-ice. The recommendation is that Heriot-Watt University be invited to contribute their under-ice long baseline navigation.
- Memorial University of Newfoundland (MUN) had the capability and resources to contribute to CFJAE12 with their underwater glider and experimental USV. They did not participate due to accessibility issues with their UXVs. MUN is a DRDC research partner through a joint ACOA (Atlantic Canada Opportunities Agency) grant. The recommendation is that they contribute their underwater glider and USV ice-tracking capability towards the persistent capability in harsh environments theme of CFJAE14. The ACOA grant would cover the travel costs of MUN personnel and equipment to and from CFJAE14.

Timelines and schedules:

- There were CFJAE12 objectives that could not be met because of the compressed time line. The recommendation is that CFJAE14 have a longer lead time prior to deployment than CFJAE12 did.
- In the evenings and through the nights in August, the winds and seas are calmer than during the day when the CFJAE12 experiments were performed. Working in the evening and through the night would allow the experiments to be performed with less weather considerations. The issue is whether QUEST's crew can support operations in this manner. The recommendation is that CFJAE14 consider working in the evenings and through the nights.

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Annex A Environmental Conditions and their Impact

Operation of UXVs in the harsh and remote Arctic environment is of interest to CF. The potential of UXVs to uniquely address CF operations, as an off-board asset in this environment, was of particular interest. Operations in an Arctic environment imposed a few additional requirements above and beyond L&R in more southern locations. Note the trial occurred during the summer months with relatively warmer temperatures and reduced ice so it does not represent the harshest Arctic environment. Over the course of CFJAE12 the temperatures were as low as -3^{o} C and there was snow falling on half of the days. Fog was present in the mornings until after 10am. Since UXV operations were initially performed under clear line-of-sight (LOS), this meant that there were no UXVs deployed prior to 10 am or during snow squalls. Most days were windy with the worst winds blowing at 30 knots. While USV and UUVs were deployed in rainy and occasionally snow squall conditions, the UAVs were not. On three days there were ice fields moving in and out of the Inlet in an unpredictable manner. Active ice spotting by the QUEST crew was on-going when the UUVs and USVs were deployed. The impact of this environment on UXV operation is discussed next.

A.1 Impact of Environment on Sea-Based UXV Operation

For the CFJAE12 sea-based parts QUEST was used for 12 hours a day for 7 days (Aug 7-14) starting around 10:00 AM. QUEST was usually anchored in Gascoyne Inlet during the experiments. Exactly where in the Inlet depended on the requirement for water depth, ice, features like choke points, UXV radio range, need for RHIB transfers from the Gascoyne Inlet Remote Camp, winds, or waves. For some experiments QUEST, was tasked to steam around.

For the first 3 days of operations any USV or UUV deployed from QUEST was escorted by a QUEST RHIB with at least 2 crew. The RHIB performed duties such as spotting ice and other navigational obstacles, reacting to UXV problems that could be mitigated by an operator on-the-spot, putting tow lines on the USVs to bring them back, etc. As the confidence of QUEST's crew and the DRDC operators increased in this environment, operation no longer had to be under LOS or even have a support RHIB. For example, the USV-HH reconnaissance experiments were performed on the other side of the choke point from QUEST so well beyond LOS. When there was no RHIB in the water moving ice fields were monitored by QUEST with radar.

The USVs and UUVs were deployed in most of the weather conditions except for very high winds (30 kt) where the launch and recovery from QUEST would be dangerous to the ship and personnel involved. The USVs were deployed in rainy conditions and were caught out in snow squalls on a few occasions. The USVs and UUVs were deployed in light fog and despite the relatively warmer temperatures; the USVs and UUVs were affected by the cold temperatures. Their lithium-ion batteries would not enable at the beginning of the day until they were warmed up. This coincided with about 10 am on most days. There were days when there were opportunities to deploy the UXVs prior to 10:00 am but the temperature, more so than the visibility conditions, governed when the UXVs could deploy.

Both USVs were equipped to navigate by GPS / D-GPS and therefore did not integrate the magnetic compass heading into their closed-loop navigation control thus eliminating the challenge of using magnetic compasses in high latitude conditions. Both USVs were equipped with high quality GPS with their antennas at 2-3 m off the water surface. The low orbital elevation of the GPS satellites, at these latitudes, did not have noticeable impact in their positioning as they were quite precise in arriving at the correct recovery points.

The UUVs were to have fibre-optic gyros on-board for their navigation so that they would not require a stable magnetic north reference. However, despite them being ordered 5 months ahead, they did not arrive until after CFJAE12. Consequently, the UUVs could only dive to shallow depths and performed surface missions to assess the magnetic north fluctuations near the sea surface (e.g., transit in a box, circle, etc.).

Navigation methods in the Arctic for underwater, on-the-water, or in-air cannot rely on a stable magnetic north reference.

A.2 Shore-Based Aerial UXV Operation

The shore / aerial-based parts of CFJAE12 perform their experiments at the DRDC Gascoyne Inlet Remote Camp from Aug 4 - 23. However, Gascoyne Inlet flight conditions were challenging due to winds, snow squalls, and rain. Flights were conducted weather permitting. The unreliable magnetic north reference meant flights were limited to 12-15 knot wind conditions only and that UAV-FW and UAV-HELO could not fly in waypoint mode. The GPS satellites' low orbital elevation angles increase the north-south UAV position error. This was not as much a problem with the USVs as they use D-GPS. The UAV's guidance computer successfully flew the systems however, this was undependable for very long-range flights, as it was navigating by dead-reckoning, position errors grow unbounded with time. The ground safety operator remotely corrected the UAV heading as required. Due to these environmental challenges, data was collected consistently with UAV-HELO using only the position arcade mode of the autopilot, which allows automatic flight control with manual navigation.

CFJAE12 was informed by Aeryon Labs, the Scout OEM, that flying the Scout (UAV-QUAD) as far north as Gascoyne Inlet was not advised, due to the steeply decreasing magnetic field, the horizontal component of the magnetic field is too weak to resolve reliably. This inability to resolve a reliable magnetic heading reference would not just result in an inability to navigate but could be a control issue and result in unstable flight. Since the heading reference is from the on-board magnetometer, if this is incorrect UAV-QUAD could make attitude adjustments about an incorrect axis resulting in a loss of control. Due to the unreliable magnetic north reference, the OEM recommended recalibrating the magnetometer for the local conditions. This was performed on arrival at the flight site and prior to each flight attempt. This was not a complete solution and the UAV-QUAD flyer crashed after its second flight. No more UAV-QUAD flights were performed in Gascoyne Inlet.

While the UAVs use GPS-based navigation, like the USVs, a stable heading reference is still required to go between waypoints. UAV operation was more impacted by the fluctuating magnetic north reference than the USVs, as the USVs can carry out their mission without a stable magnetic north reference.

significance:

Fluctuating magnetic fields and low GPS orbital elevation angle (and consequent north-south positioning uncertainty) creates UAV localization and navigations challenges unique to this environment. The USVs were equipped with high quality GPS/DGPS navigation and did not appear to be affected. Further CF deployments with UXVs should take this into consideration.

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Annex B Legal, Administrative, and Legislative Considerations

B.1 Laws, Rules, and Regulations to Consider

federal government:

- Indian Northern Affairs Canada - Land Use Permit (12 month lead time)

territorial government:

- Nunavut Liquor Control Act
- use of alcohol at Gascoyne Inlet Camp
- Nunavut Water Board Permit - like the Federal INAC land use permit

DRDC / MARLANT / DND:

- Chief Scientist orders for a QUEST cruise
- Environmental Assessment's for all platforms with payloads (12 month lead time)
- Gascoyne Inlet 2012 Deployment Orders
- PWGSC – contracts to purchase (24 month lead time for delivery, set to work, trial of equipment)
- Underwater Object Note

unmanned aerial vehicle:

- marking of aircraft
- UAV area of operations – input to NOTAM (Notice to Airmen) and Special Purpose Flight Permit, and 1 CAD Message
- NOTAM
- Special Purpose Flight Permit (this will include - RARM – Risk Assessment, Technical Airworthiness, Operational Air Worthiness and Air Control Plan)
- 1 CAD message to fly
- Frequency Allocation and Mutual Interference Plan

legal opinion sought for:

- UAV operations in the north - CFJAE 2012
- USV / UUV operations in the North - CFJAE 2012

B.2 Documentation for Personnel

- updated Certification for Wilderness and Remote First Aid Training
- updated medical
- recreational fishing license (optional)
- Guide for Sea-Going Personnel
- estimate for overtime
- Gascoyne Inlet Standing Orders
- Next of Kin
- Gascoyne Inlet Camp overview
- Emergency contact options for families

B.3 Other for Personnel

- arctic sleeping bags
- floater jackets and hard hats for water transport or deck activities

B.4 Forms and Applications for CF Arctic Trials

There are a set of forms (Table 4) that have to be and submitted and approved prior to deployment for an experiment that occurs in the Canadian Arctic.

Table 4: Required Legislative Forms for a CF Arctic Trial.

form / permit / license / Act	who / function	submit prior to deployment (months)
Land Use Permit	Indian Northern Affairs Canada (INAC) / to conduct experiment on land	12
CFAV Quest Cruise Plan and Gascoyne Inlet Camp Form	Environment Canada / environmental assessment of platforms with payloads for risk mitigation in an accident	12
purchase contracts	Public Works and Government Services Canada / to purchase equipment for trial	24
Special Purpose Flight Permit	DTAES / license to fly (includes - RARM – Risk Assessment, Technical, air worthiness, operational air worthiness, and air control plan) needs: frequency allocation and mutual interference plan, UAV area of operations,	9
Waiver for Class F Air Space	1 Canadian Air Division / message detailing permission and limitations for requested flight to AVO; needs: UAV area of operations	9
NOTAM (Notice to Airman)	Transport Canada / NOTice to Air Men regarding air space allocation needs: UAV area of operations	9
Underwater Object Note	Marlant Submarine Operating Authority / notice of intention to submarines of UUV activity	9
Nunavut Liquor Control Act	Nunavut Territorial Gov't / awareness of alcohol use and transport in Territory CFJAE12 did not move/transport alcohol.	prior to deployment
Nanuvut Water Board Permit	Nunavut Territorial Gov't / similar to federal INAC land use permit but, to protect water	12
Quest Cruise Chief Scientist's Orders	Marlant and DG DRDC Atlantic / defines command and control	2
Gascoyne Inlet Deployment Orders	DG DRDC Atlantic / awareness of camp infrastructure, defines command and control	2
Request for DRDC support	DRDC Centres	24

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Annex C Public Affairs and Communications Plan

CFMWC was the lead for the Experiment. As DRDC had the most projects involved in CFJAE, DRD Communications provided communications support for the Experiment. External communications to mainstream media for this Experiment was reactive only. DRDC briefed the team engaged in Op Nanook at the same time. Media response lines were pre-approved for each project. Backgrounders for projects were drafted and spokespersons were identified. As stated by the NRCan Polar Continental Shelf Program (PCSP) Operations Manual for Arctic researchers, we are required to provide the local community with information about the type of research done in the region, and to work with them to build mutually respectful relationships. CFJAE participated in a Community Day hosted by PCSP, to inform residents of Resolute Bay what would happen in their community. Post-event communications focused on the Experiment's partners and the work accomplished. Tools such as the Intranets (i.e., DRDC's Descartes, DIN, etc.), internal newsletters (i.e., Leo Online, Maple Leaf) and base newspapers were used to promote the CFJAE.

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Annex D Experimentation and Results

Section 2 presented vignettes of Canadian Arctic events (V1-V8) where QUEST or an RCN ship in the area was tasked to respond. Within each vignette the *capability* required for the ship to respond to the event was identified. The capability is presented in this Section again against a recommended *solution* (specific tools and concepts of operation) to realize the capability using UXVs. This is followed by a description of the *experimental plan* that implements and tests the solution components. Then, the *results* report on what was achievable in the experimental plan towards the solution tested. Finally, the *significance* of the results is highlighted. Table 6 (Annex H) summarizes each vignette, tasks, capabilities and experimental plan.

Capability, *solution*, and *significance* do not refer to a particular UXV, system, or sensor as it is the *solution components* and *experimental plans* that deal with implementation. Not every solution component has an experimental plan. This is the case with solution components duplicated in other vignettes (e.g., V4-C) or where it was not possible to implement it for CFJAE12 (e.g., V4-B). The CFJAE12 objective was to present a complete solution.

Several UXVs are employed to assess how each might contribute as a component to a solution. Each UXV extends the persistence and reach of the ship in different ways to provide situational awareness. The vignette capabilities along with the UXVs employed in the experimental plan are summarized in Table 5 and described in the following sub-sections. Questions of UXV fitness for other considerations like its control, endurance, powering, on-board computing, maintenance, operations, etc. are not addressed as they vary with UXV cost, model and OEM. The only other UXV consideration discussed is its launch and recovery (Section 4).

D.1 Assumed UXV Baseline Attributes

Generally, it was desired that the CFJAE12 UXVs: possess closed-loop control for attitude, altitude, and speed; autonomously follow waypoints; be commercially available; be launchable from QUEST (2000 lb capacity crane), have control stations and telemetry that can be accommodated on-board QUEST, and use commercially available energy sources that can include lithium-ion batteries. The exception was the experimental UAV-FW which could not be launched from QUEST.

D.2 Implementation of Experiments

The experimental plan that implements and tests the capabilities assume the UXVs are deployed from the ship. While potentially achievable, this was not done for all UAVs during CFJAE12. In August 2012, the UAVs were deployed from the DRDC shore-based Gascoyne Inlet Remote Camp since QUEST does not have a large enough clear deck space for a fixed wing UAV-FW to land and take-off. It was also unknown whether QUEST's magnetic signature would interfere with the navigational compass for UAV-QUAD. The CFJAE12 is the furthest north that a UAV-QUAD has ever flown. The UAV-QUAD was launched and recovered from QUEST for the CFJAE12 part in October 2012 during Q347. Given the short time QUEST was available for CFJAE12, it was also logistically easier to perform the UXV experiments concurrent with the maritime part but at another location.

The CFJAE12 tasking across the DRDC Centres was distributed along the lines of where the UXV platforms and their operators were. DRDC Ottawa developed the UAV-FW and owns and operates UAV-HELO. DRDC Suffield owns and operates the UAV-QUAD and DRDC Atlantic owns and operates the USV-2600, USV-HH, and the IVER2 UUVs. This division meant DRDC Atlantic had greater responsibility for the sea, and hence ship-based experiments, and DRDCs Suffield and Ottawa had primary responsibility for the aerial / shore-based experiments.

D.3 Confirm Approaches for RCN Ships in the Aftermath of a Disaster (V1)

capability: Remotely confirm safe entry and anchorage areas and provide situational awareness for a ship waiting from a safe distance.

solution:

Deploy UXVs equipped with ISR sensors to survey the areas and routes as follows:

- UAV fixed wing performs a high speed high altitude air reconnaissance (V1-A)
- USV planing craft performs high speed water surface reconnaissance (V1-B)
- UAV rotary wing for low altitude and low speed inspection of surface targets identified through V1-A/B
- USV catamaran and UUVs for detection and inspection of in-water targets – this will occur at low speeds (V1-D)

solution V1-A: ***Launch fixed wing UAVs with ISR/sense payload to conduct airborne reconnaissance to confirm safety and provide situational awareness.***

experimental plan: *Launch UAV-FW from the Gascoyne Inlet Remote Camp (simulates ship launch) with video and still cameras to conduct an airborne reconnaissance of Gascoyne Inlet to confirm safety and provide SA.*

results:

UAV-FW was successfully launched and recovered from the Remote Camp. Video images were collected with the GoPro Hero 2 camera on-board UAV-FW. These were downloaded *after* UAV-FW was recovered. The objective was to detect ice and other obstacles to ship navigation then provide localization information to pass to the USVs for refined localization. Due to navigational restrictions in flying UAVs, UAV-FW was flown along the coast and the camera imagery was generated looking seaward. Fig. 4 shows a typical image which was adequate to detect and approximately localize obstacles. Flying UAV-FW directly over the intended route would produce better imagery. NIIRS ratings (Annex I) of 4-7 (which are good) were achieved with this system.

In its airborne reconnaissance, UAV-FW detected ice on the northeast shore of the Inlet. However, UAV-FW could not provide GPS coordinates on the ice location. The USVs were deployed next to obtain those.

significance: An organic system able to provide unmanned, rapid, high altitude and large area aerial reconnaissance of shore and sea prior to entering an unknown area.

Table 5: Summary of UXVs Tasked for the Vignettes.

mission	vignette		capability	UXV tasked		
				UAV	**USV**	**UUV**
HADO / SAR	V1	Confirm Approaches for RCN Ships in the Aftermath of a Disaster	Remotely confirm safe entry and anchorage areas and provide situation awareness for a ship waiting from a safe distance.	X	X	X
	V2	Detection, Localization, and SA for SAR (Mid-Air Collision)	Conduct search and rescue in a remote environment on land and underwater with only the resources on-board.	X	X	X
	V3	Re-Establish Communications Networks	Deploy a ship-based cell network with local area coverage.			
	V4	Safe Passage for RCN Ships in Uncharted Waters	Safe ship transit through and within Arctic waters.	X	X	X
sovereignty patrol	V5	Autonomous Bathymetric Mapping Surveys	Conduct hydrographic quality survey work in waters that include shallow depths, ice, and confined areas.		X	X
	V6	Assist with Maritime Interdiction Operations	Remotely gather intelligence and situational awareness on a VOI from a ship.	X	X	
	V7	Autonomous Sonobuoy Deployment and Monitoring	Covertly detect, identify and track an underwater contact with the ship at a remote location.		X	
	V8	Indications and Warning of Sea-Going Vessel of Interest	Remotely conduct covert surveillance on a vessel of interest from a ship.	X	X	X

Fig. 4: Route reconnaissance image from UAV-FW to initially detect and localize in-water obstacles such as ice (V1-A).

solution V1-B: ***Launch USVs with ISR/sense payload to conduct <u>water surface</u> reconnaissance to confirm safety and provide more detailed situational awareness.***

experimental plan: *Launch the GPS-enabled USV-HH from QUEST with video and IR cameras as well as radar to survey up and down Gascoyne Inlet. Transmit the 3 data streams back to QUEST in near real-time to confirm safety and focus in on areas of interest initially identified by UAV-FW.*

results:

The USV-HH was deployed from QUEST to localize and confirm the extent of the ice coverage reported by UAV-FW and to detect anything on, or near, the shore with marine radar and video and IR cameras (Fig. 5). All these sensors transmitted real-time data to the operator consoles on QUEST via telemetry. In areas where the bathymetry is shallow USV-HH was remotely operated otherwise it was autonomously operated. The USV-HH profiled up the west coast then down the east coast of the Inlet (Figs. 6, 7). This rapid reconnaissance showed the western shore to be free of ice and other obstacles that are visible from the surface. The USV-HH confirmed the ice on the eastern shore reported by UAV-FW. The USV-HH had a minor grounding on the eastern shore that the operator was able to remotely free it from. The grounding occurred between the 4 – 5 m contour line on the chart. The reason why is unclear. It is likely not due to north-south uncertainty from the low orbital elevation of the GPS satellites as this is an east-west localization error. One theory is that the shoreline migrated towards the water (‘slumped’) as a consequence of higher temperatures thawing the permafrost. Another possibility is that the 1984 map datum change inadvertently shifted map coordinates further west than they actually are.

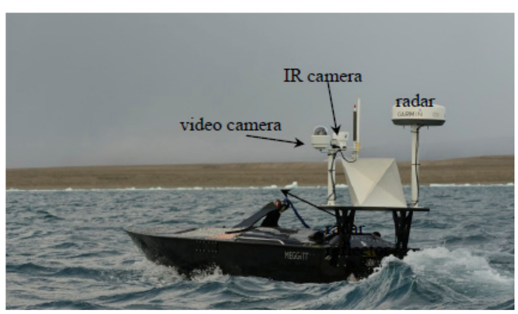

Fig. 5: USV-HH integrated with EO, IR, and radar payload sensors (V1-B).

Fig. 6: Still from video of real-time ice sighting by USV-HH on eastern shore while searching for obstacles to ships (V1-B).

Fig. 7: Nearly simultaneous (to Fig. 6) ice sighting from USV-HH with IR camera looking for obstacles to ships on eastern shore (cooler objects are darker, V1-B).

significance: An organic system that can refine the localization of ship navigation obstacles at high (20+ kt) speeds beyond the initial detection of the obstacles by an aerial reconnaissance.

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solution V1-C: ***Launch rotary wing UAV with ISR/sense payload to conduct airborne reconnaissance to confirm safety and provide situation awareness***.

experimental plan: *Launch UAV-QUAD with video and still cameras to focus on objects that UAV-FW and USV-HH detected initially and to perform a higher fidelity airborne reconnaissance. Recover UAV-QUAD on QUEST.*

results:

For the first flight, surface winds were 10 knots and QUEST was moving downwind at 5 knots. Following pre-flight preparations, the flyer was launched and commanded to ascend to 30 meters above QUEST's flight deck and 10 meters off the port side. Then the flyer, in 'Follow Me' mode, tracked its base station on QUEST. Next, the flyer was dragged forward parallel to QUEST's course. Throughout this flight, video and still imagery of QUEST were collected.

For the second flight surface winds had increased to 15 knots. The sea state was between 1 and 2. QUEST moved downwind again at 5 knots for the flight duration. Following take-off, the flyer was commanded to ascend to 100 meters above QUEST's flight deck and dragged to the starboard side. At that altitude, there was no danger of it losing communications with the base station. The flyer was again in 'Follow Me' mode and video and still imagery was collected during the 5 minutes the flyer was on station.

For the third flight, a man overboard exercise was conducted (Fig. 8). QUEST deployed a SAR target off its stern. The intent was to perform a search pattern for the target, but given prevailing winds and the UAV recovery challenges this was aborted. Instead, upon take-off UAV-QUAD was commanded to ascend to 100 meters above the flight deck with the camera panned straight down. Then, UAV-QUAD was sent aft to overfly the target. By the time UAV-QUAD caught up with the target and imaged it, it was about 1 km astern of QUEST and had 11 out of a possible 20 minutes of power left. UAV-QUAD was commanded to return to the base station. It had difficulty catching up with QUEST though it was descending and flying downwind towards it. When it was over QUEST it had only 7 minutes of power left. There was an attempt to recover it as it flew over the flight deck aft railing, as before. On the first two attempts the UAV drifted upwards on approach and towards the ship's centerline. While this was happening, the pilot operator was alternately trying to drag the UAV outboard and maintain its altitude just above the flight deck railing. Following these two unsuccessful recovery attempts, QUEST slowed from 5 to 2 knots as the UAV had only 3 minutes of power left. On the third approach, the UAV rose higher than before and may have risen into clear air, as it overshot, at speed, about 4 meters above the flight deck. The pilot operator attempted to drag UAV-QUAD outboard as it passed over but in doing so UAV-QUAD struck the QUEST port side HF antenna and was lost.

UAV-QUAD has advantages over USVs in that it can image target from as high as hundreds of meters away to just meters on top of it. UAV-FW and USVs are incapable of this. UAV-QUAD has only 20 minutes of endurance. The operator has to allow 5 minutes to recover the UAV from aloft. The protracted recovery process limits its mission time on station. Recovering the UAV in tight confines like the QUEST flight deck is unworkable without an auto landing behavior (as evidenced in the third flight).

significance: Launching and recovering UAV-QUAD off the deck of QUEST in 15 knot winds is achievable though not in the Arctic due to the need for a magnetic north reference.

Fig. 8: Man overboard exercise with UAV-QUAD for SAR (a) target (circled) deployed from QUEST and (b) UAV-QUAD (circled) deployed to localize target (oval) (V1-C).

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solution V1-D: ***Launch an UXV system (consisting of 1 USV and 3 UUVs). These four platforms with ISR/sense payloads form a UXV system to conduct underwater reconnaissance to confirm safety and provide SA.***

- ***beyond-line-of sight communications from UUV to USV to UAV to QUEST***

experimental plan: *Launch USV-2600 with an underwater micromodem to relay data or information detected by sensors on-board the IVER2 UUVs to QUEST. When operating over-the-horizon, UAV-FW would relay information from the USV-2600 to QUEST.*

results:

With approximate knowledge of the ice field span from the high speed USV-HH reconnaissance, the first goal was to deploy the USV-2600 to perform detailed depth measurements with an echo sounder and a better PTZ camera to refine the ice field location. This was performed successfully. The depth soundings and video images were transmitted back to the ship in near real-time. The USV-2600 is more maneuvrable than the USV-HH at ≤ 4 knots, which is recommended, when going through an ice field. From the visual profiling with the USV-2600 PTZ camera the ice field extent was confirmed out to the 4-5 m depth contour line on the chart. As well, the latitude and longitudes of the ice field's north-south extent were also determined. For the second goal, a long baseline localization (LBL) transponder was used to localize the DRDC IVER2 UUV (Fig. 9) using the micromodem with one way travel time (OWTT) ranging and bearing. The UUV was able to communicate its position to the USV-2600 via the WHOI underwater micromodem. The USV relayed the UUV position to QUEST through its in-air ethernet Freewave radio. However, the UUV was not over the horizon from QUEST. Still, it represents a milestone towards a capability to track the UUV position from the ship.

Fig. 9: IVER2 UUV with tow float on the surface of the Inlet (V1-D).

Since the IVER2 UUVs could not submerge for extended periods they were unable to perform the LBL exercise with the REMUS 100. These UUVs were to be at CFJAE12 but were delayed in their shipping. The LBL between a REMUS 100 UUV and the hovering UUV, NESSIE, was demonstrated during the CFJAE12 part in March 2013 at Loch Earn near Edinburgh, Scotland.

significance: An organic ability for a ship to remotely confirm uncharted or ice filled harbour approaches and anchorages for large ships to transit in and anchor; identify obstacles and their extent, and transmit data from mobile underwater sensors to the ship.

D.4 Detection, Localization, and SA for SAR (V2)

capability: Conduct search and rescue in a remote environment on land and underwater with only the resources on-board.

solution:

After two aircraft collide in mid-air the wreckage of one is on land and the other is submerged in water. The search and rescue is thus divided into two separate efforts.

The primary location for the crash site on land is a rescue effort. The procedure is as follows:

- deploy UAV fixed wing to perform a fast, high altitude reconnaissance to detect the emergency position indicator, localize the crash, and provide situational awareness – near real-time video is streamed back to the ground control station (on land or ship) (V2-A)
- based on coordinates of crash location from V2-A, deploy UAV rotary wing to do a low altitude low speed (hover if necessary) inspection of the site and specific points of interest identified in V2-A (V2-B)
- based on wide area reconnaissance from V2-A and inspections from earlier parts of V2-B deploy UAV rotary to determine the optimum route for land-based rescue forces to get to the crash site (V2-B)

The secondary location for the crash site is an underwater recovery effort. This is achieved as follows:

- deploy the USV planing craft with PTZ cameras and echo sounder to perform a fast water surface reconnaissance for debris and to determine the water depths of the area (V2-C)
- deploy the USV-2600 catamaran and the UUVs with in-water sensors like side scan sonar, echo sounders, and black box receivers to perform a low speed search to detect and localize the extent of the wreckage (V2-D)

solution V2-A: ***Launch fixed wing UAVs with ESM, communications relay and ISR/sense payload to conduct airborne reconnaissance to detect (emergency position indicator), locate and provide SA of primary SAR crash site to the east.***

experimental plan: *Launch UAV-FW with ISR/sense payload (video and still cameras) to conduct airborne reconnaissance of eastern (land) and western (water) Gascoyne Inlet crash sites to provide SA of sites and surrounding areas (i.e., polar bears and other threats to potential survivors). Provide site coordinates to other UXVs.*

results:

Dedicated flights were not conducted as data was previously obtained to demonstrate the ability to detect and localize debris from an air crash, or other incident, on the surface of Gascoyne Inlet. Fig. 10 shows the detection of an oil barrel at 1.5 km range from the UAV. It is concluded that high definition video imaging and a suitable search pattern over the Inlet would result in detection and localization of the debris. NIIRS ratings of 5-6 are possible at these ranges. The second part was not addressed as the UUVs could not submerge for long.

significance: Organic capability to provide rapid unmanned reconnaissance to localize a crash site on.

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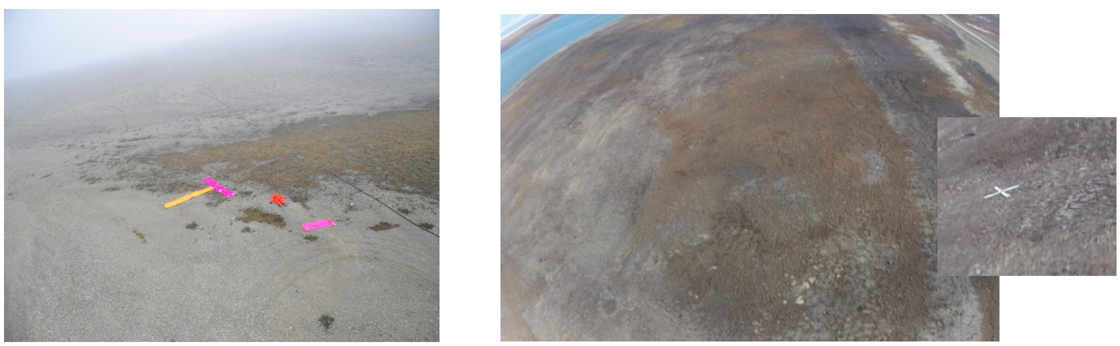
solution V2-B: ***Launch rotary wing UAVs with ISR/sense payload to conduct airborne reconnaissance to detect, based on cueing from UAV fixed wing (V2-A), locate and provide SA of primary SAR crash site to the east and secondary crash site to the west.***

experimental plan: *Launch UAV-HELO with ISR/sense payload (Nikon D3X and GoPro Hero2 cameras) to conduct airborne reconnaissance to detect, locate and provide SA of crash sites with color targets.*

Fig. 10: Oil barrel at 1.5 km range using the UAV-FW showing localization of debris (V2-A).

results:

A series of targets were deployed including a human shaped target (OSCAR) dressed in an orange Mustang survival suit along with two standard search and rescue color targets. A white cross with 2m arm lengths was also a target. UAV-HELO was flown in a linear search pattern (with reduced search area up to a maximum of 2km × 2 km). Fig. 11 shows a typical image of the targets obtained with the GoPro camera on-board. The white cross is at 400 m range and the coloured targets are at 50 m range. NIIRS image quality of 6.5-8.5 can be achieved for this data.



(a) (b)

Fig. 11: SAR rescue targets detected by UAV-HELO cameras at: (a) 50 m (b) 400 m (V2-B).

Typical flight altitudes were 400-600 ft. above ground. Both the Johnson criteria and the Tactical Targeting Procedures [8][9] estimate the number of resolution cells on target for detection and classification. The images were analyzed by both humans and a learning neural algorithm (HNeT). HNeT was trained to recognize the color of the targets from the Red, Green and Blue (RGB) content of the pixels. It was trained by comparing the RGB colour of the pixels on the targets against the typical background RGB colours. Once trained, the algorithm searched through the entire image pixel by pixel and marked those pixels which met the color criteria. An example of this process is seen in Fig. 12 where pixels meeting the criteria are highlighted pink.

Using the data from a number (> 50) of images a Receiver Operating Curve (ROC) analysis was performed. The results are shown in Fig. 13. The results are very encouraging indicating that the SAR targets will be detected with a probability approaching 100% with a low false alarm rate on a pixel by pixel basis. It is also suggests the HNeT algorithm can be used to assist the human in the evaluation process.

Fig. 12: HNeT methodology successfully detects SAR targets (highlighted in pink) (V2-B).

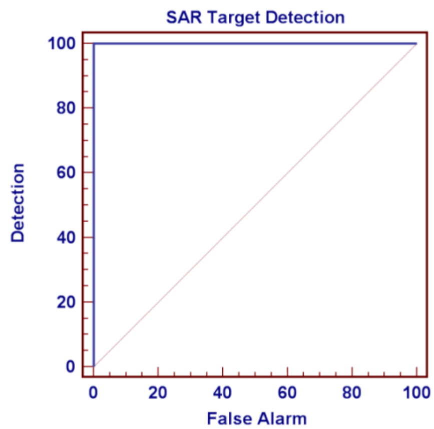


Fig. 13: ROC analysis of SAR target detection shows near 100% probability of success (V2-B).

Once the crash site coordinates were confirmed there was still the issue of getting SAR resources to the site. If the crash was in a mountainous region of a remote area some reconnaissance would be needed to determine the optimal route to get people and equipment there.

Using the stereo enclosure, two GoPro Hero 2 cameras were mounted on UAV-HELO to obtain stereo video of the terrain along the proposed route to the crash site. From this, a 3D video stream was generated allowing large ridges, river beds and other obstacles to be identified. This provided the situational awareness to plan a route to transit to the area. Fig. 14 shows a 2D representation of typical frames. Note these were generated in post-processing.

Fig. 14(a) shows the view from the soldier on the ground while Fig. 14(b) indicates the obstacles just over the vision horizon of Fig. 14(a). While this is insufficient to create an accurate map of the area, it provides a quick overview of route obstacles and alternative routes. Flying directly over the intended route at low altitude would provide further detail. NIIRS ratings of 4-7 were achieved.

(a) (b)

Fig. 14: UAV-HELO imagery to determine a traversable route to the crash site at: (a) beginning of route and (b) partway through (V2-B).

significance: Organic capability to localize, detect, and provide situation awareness as part of search and rescue efforts in remote, unfamiliar, or difficult-to-traverse locations.

In this scenario, UAV HELO was also used to deliver a small food and medicine package as well as radios once the land SAR location was determined.

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solution V2-C: ***Launch USV Hammerhead with ISR/sense payload to conduct surface reconnaissance of crash site to the west and provide SA.***

A dedicated mission was not performed for this as it is similar to capability V1-C.

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solution V2-D: ***Launch UUVs and ROVs with ISR/sense payloads to conduct underwater reconnaissance to detect (emergency position indicator), locate and provide SA of secondary SAR crash site to the west. Conduct recovery with ROVs.***

experimental plan: *Launch UXV system consisting of USV-2600 and two UUVs. The three platforms with ISR/sense payloads (bathymetric sonar, side scan sonar, black box receiver, etc.) create a UXV system to conduct underwater reconnaissance to search an X × Y area to localize a downed aircraft's black box transponder. Use the Seamor and Phantom ROVs to perform recovery of an OSCAR.*

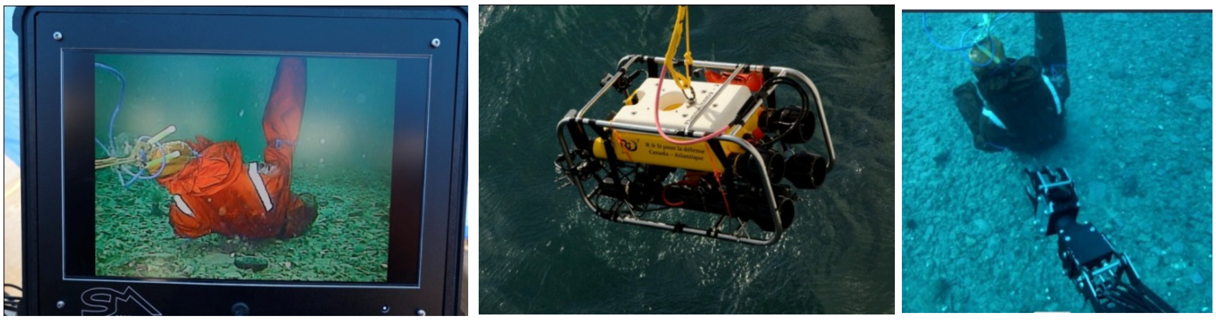
results:

The first part was not performed as it was not possible to get a black box transponder. This will be considered for CFJAE14.

OSCAR, a human shaped target dressed in a Mustang floater suit, was weighted down at the bottom of 35 m of water. An inspection class ROV, Seamor, was deployed with a Didson bathymetric sonar and a video camera to survey the area (identified bottom type as rocky), to localize OSCAR. Once localized, a working class ROV, Phantom, was deployed to recover

OSCAR which it did successfully despite OSCAR being unexpectedly negatively buoyant (Fig. 15). Once Phantom had OSCAR on the surface a RHIB crew continued the recovery.

significance: Organic capabilities for search-and-rescue as well as recovery operations in the Arctic based off a ship in a remote area.



(a) (b) (c)

Fig. 15: (a) OSCAR localized on Seamor ROV video (b) launching Phantom ROV for recovery (c) Phantom ROV prepares to recover OSCAR (V2-D).

D.5 Re-Establish Communications Networks (V3)

capability: Deploy a ship-based cell network with local area coverage.

solution: ***Install a cell phone base station system on the ship with the antenna on the railing of the flight deck. Use a broadband spectrum analyzer to map power levels for cell phone reception areas to validate radio frequency propagation models in the Arctic environment.***

experimental plan: *Gather data to assess the possibility of establishing a cell phone network in the area. Determine the ranges possible to the ship at anchor in the Inlet.*

results:

A STAR Solutions CDMA 2000 base station was installed at the base camp on Devon Island. A 6 dBi gain antenna was mounted on a post to place it 3 meters above the ground. The unit operated at 884 MHz with an output power of 5 Watts. System handsets were available for evaluation purposes. Power measurements were taken around the area using an Anritsu spectrum analyzer with a 3 dB gain antenna. The results were compared against a simple prediction (Annex J).

Establishing a cell phone network at the Gascoyne Inlet base camp, including the remote radar sight, is feasible. Line of sight communication should be possible to a distance ~ 4 km. This means communication to QUEST while at anchor in Gascoyne Inlet is also possible; however, communication from the camp to the QUEST at sea is not feasible because of line of sight issues for ranges greater than 4 km. Future experimentation should consider a high gain directional antenna for communication with QUEST at sea. A 24 dB gain parabolic antenna at the upper radar site would permit line of sight communication with QUEST to 30 km range.

significance: The ability to set up a communications network based off of a ship.

D.6 Safe Passage for RCN Ships in Uncharted Waters (V4)

capability: Safe ship transit through and within Arctic waters.

solution:

Ships transiting through Arctic waters could be going through uncharted waters and ice. To assist with safe navigation, these ships could deploy:

- USV-2600 catamaran with an echo sounder and forward-look sonar to run ahead of the ship (at 5^+ knots) to radio back minimum water depths and ice detections to the ship so it can plot a safe course. It works in waters that are uncharted and have moving ice (V4-A)
- UUV with depth sensors and upward and downward looking Doppler velocity logs to run ahead of the ship to report on water depths and keel depths of ice (to determine ice thicknesses) – works in ice covered and inadequately charted waters (V4-B)
  - USV-2600 catamaran can be deployed if the ship wants to operate from a larger stand-off range from the ice field
- employ rotary wing UAV rotary equipped with PTZ cameras and potentially ice-thickness sensors (using wideband acoustics) to conduct in stride airborne reconnaissance to survey ice conditions ahead of the ship (V4-C)
-

solution V4-A: ***When transiting in non-ice covered inadequately charted waters use a USV for safe transit (water depth). In this case transit is to a SAR sight.***

experimental plan: *A USV-2600 equipped, with a bottom-looking multi-beam scanning sonar (Teledyne ESM-3) and a Furuno echo sounder, transits ahead of a high valued asset (QUEST). The USV would do some on-board processing to transmit back to the ship the best path through the water.*

results:

The first stage of the experimental plan was realized. Near real-time depths from the echo sounder and the ES3-M bathymetric sonar were transmitted to QUEST from the USV-2600 system running ahead of the ship (Fig. 16). The next stage is to perform basic on-board processing of the data so the USV-2600 can do path-planning for the ship. CFJAE12 did not get to this point as an upgrade to the USV-2600 processor was needed.

significance: An organic capability, in the form of an USV equipped with echo sounder and/or bathymetric sonar, to survey the waters ahead of an RCN ship to determine the best path through uncharted waters.

solution V4-B: ***When transiting ice covered & inadequately charted waters employ a UUV for safe transit (for bottom and ice depth) to a SAR location.***

This will be performed during CFJAE14.

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solution V4-C: ***When transiting in ice covered & inadequately charted waters employ a UAV system for safe transit (leads through ice). In this case transit is to a SAR location.***

This capability was demonstrated in V1-A

significance: UAV can provide SA awareness that provides a safe transit route employing leads in the ice for a ship.

Fig. 16: USV-2600 runs ahead of QUEST in uncharted water to provide advanced situational awareness on water depths (V4-A).

D.7 Autonomous Bathymetric Mapping Surveys (V5)

capability: Conduct hydrographic quality survey work in waters that include shallow depths, ice, and confined areas.

solution: Deploy a USV catamaran integrated with a multi-beam sonar that scans at hydrographic quality resolutions (V5-A).

solution V5-A: ***Conduct a survey of Gascoyne Inlet by employing a USV catamaran and a CHS - Odom ES3-M multi-beam sonar.***

- ***QA/metrics for this experiment involves the comparison of collected data against current CHS data.***

experimental plan: *With QUEST anchored at the north end of the inlet, deploy USV-2600, integrated with an ODOM ES3-M bathymetric sonar, to perform a hydrographic survey of Gascoyne inlet.*

results:

The USV-2600 with the ODOM ES3-M 240 kHz bathymetric sonar (Fig. 17) was deployed. The system performed detailed bathymetric survey of the choke point in Gascoyne Inlet. The survey consisted of lawn mower patterns on headings 045 / 135 that propagate from the eastern to the western side of the choke point. The lawn mower mission geometry (transect lengths and separations) was driven by the water depth and sonar capability. Given the sonar, the survey mission was transects of 300 m lengths separated by 25 m. This provided sonar coverage with overlap across neighbouring swaths. The USV-2600 was able to survey in water depths of 3 m which is shallower than a ship could survey. On the western side of the inlet, the chart in the mission planner incorrectly shows the USV-2600 to be on land when it was in 20 m of water. This fact, along with the USV-HH grounding on what was labelled an area between the 4-5 m contour on the map of the eastern shore, suggests the 1984 datum change may have shifted the maps of this area west. This does not preclude the possibility of slumping on the eastern Inlet shore as well. From the analysis the ES3-M sonar data it was not considered hydrographic quality by the CHS. A sonar upgrade is being considered for CFJAE14.

As it was not possible to integrate a forward-look sonar to assist with ice detection, this part was not done. However, this is a common capability on ships and would be useful on a USV.

The USV-2600 was able to successfully maneuver in tight spaces and turn with a much smaller turn radius than a ship.

significance: Provide RCN ships, like the future CF Arctic Offshore Patrol Ship (AOPS), with an organic capability to move safely and effectively in uncharted and/or ice infested waters.

D.8 Assist with Boarding Operations (V6)

capability: Remotely gather intelligence and situational awareness on a VOI from a ship.

solution:

The ship is to employ UXVs in advance of the boarding (preparation of the battlespace) and during the boarding (force protection).

Prior to the boarding, deploy:

- UAV-HELO with a camera system that streams video images back to the ground control station on the RCN ship for imagery for facial recognition, this can be at considerable (100 m) range from the VOI (V6-A)
- UAV-HELO to collect imagery for situational awareness (number of decks on ship, number of people onboard, whether people are armed, indications of intent, etc.) (V6-B)

During the boarding, deploy UXVs to cover the blind side of the vessel of interest:

- UAV-HELO to cover at close range (performed during Q347)
- UAV-FW to cover at a range that can see the entire ship (not during CFJAE12)
- USV-2600 catamaran to monitor VOI at close and far ranges and to especially focus on the ship at the lower decks and levels (V6-C)

(a) (b)

Fig. 17: USV-2600 with ES3-M sonar (a) on-board QUEST (b) performing survey (V5-A).

D.8.1 UAV-HELO for Boarding Operations

solution V6-A: ***Deploy rotary wing UAV to collect images prior to a ship boarding.***

experimental plan: *Deploy UAV-HELO with a high resolution digital camera. Simulate the transit from QUEST to the VOI as this is performed at the Gascoyne Inlet Camp. Upon arrival at the VOI, gather images of human faces at ranges of 10-100m. Demonstrate the ability to monitor the VOI for the duration of a boarding mission with either UAV-HELO or UAV-QUAD.*

results:

Past work indicates automated identification algorithms perform well on human faces if there are at least 32×32 resolved pixels for the face. This performance was achieved with the HNeT [10] algorithm trained for facial recognition.

Images were collected with UAV-HELO using the Nikon digital camera with various focal length lens at varying slant ranges from human faces. The resolution was measured as a function of slant range. Vibration effects and the ability to point the camera narrow field of view were studied. Fast shutter speeds (< 0.001 s) were required to minimize vibration effects. The azimuthal / elevation non-stabilized camera mount on UAV-HELO was sufficient to align the camera with the human targets. Fig. 18 shows the result for targets at 50 m range using a 200 mm focal length lens. Further tests are needed but it is predicted that human facial recognition is feasible using this type of system at 75 – 100 m ranges. An evaluation of the HNeT algorithm performance will be conducted on this data in the future. NIIRS ratings of 8.5-9 were obtained.

significance: Advance intelligence on who is on-board prior to boarding – especially if their image is logged in a database. This capability can be deployed from the ship.

Fig. 18: Example facial recognition imagery collected by UAV-HELO at 50 m range (V6-A).

D.8.2 UAV-QUAD for Boarding Operations

solution V6-B: ***Employ UAV to for boarding operations.***

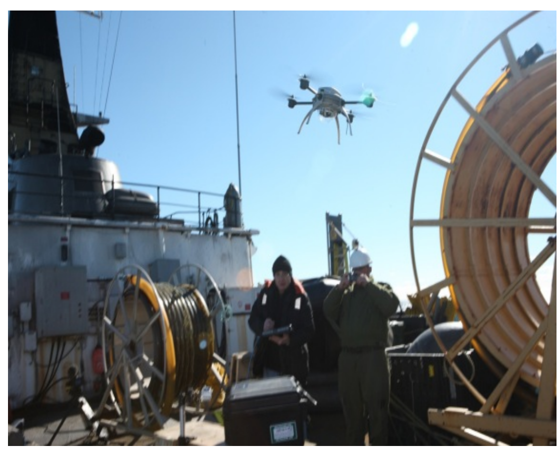
experimental plan: *UAV-QUAD equipped with video cameras streams images back to QUEST as it covers the blind side of the ship being boarded.*

results:

UAV-QUAD went from 100 m above QUEST to just hovering over the flight deck to gather images on the people and equipment on-board (Fig. 19). Care has to be taken when UAV-QUAD is very close to the VOI as pockets of clear air can push the UAV in unpredictable directions.

significance: An organic capability to perform in-air surveillance of the blind side of a VOI at various ranges.

(a)



(b)

Fig. 19: UAV-QUAD images from (a) flying over VOI from 100 m and (b) hovering at close range to VOI (V6-B).

D.8.3 USV-2600 for Boarding Operations

solution V6-C: ***Employ USV for boarding operations.***

experimental plan: *Launch USV HH and USV-2600 with ISR/sense payload to conduct ISR operation to cover blind side of VOI during boarding.*

results:

Images were captured by USV-HH and USV-2600, equipped with video cameras streaming real-time video of the VOI back to QUEST, while travelling around the stopped VOI. For this experiment QUEST was the VOI. While both USVs are capable of autonomous behaviours they were remotely piloted by operators in order to respond quickly to an unpredictable and dynamic situation.

The choice of which USV depends on the USV speed and maneuverability required. Again, USV-HH is capable of over 30 kt. USV-2600 has a top speed of 6 kt but is highly maneuverable and stable at low speeds. This stability and maneuverability produces better imagery while station-keeping or panning up/down the side of the VOI in a sea state.

Prior to boarding, and perhaps as part of the interdiction, USV-HH could better overwhelm or stop the VOI or escort it to its boarding point all the while streaming back real-time video to provide SA on the VOI. Higher speeds facilitate QUEST working at a greater stand-off range from the VOI prior to boarding. This was not originally part of the experimentation.

If the VOI has agreed to stop and be boarded the USV-2600 has the low speed stability and maneuverability to slowly pan QUEST (transit up and down the blind side) and stream good video back to QUEST. It performs well 'covering' the blind side of the VOI prior to and during boarding. While USV-HH could also do this it is not as maneuverable or stable at the low speeds needed for this. It is difficult to drive reliably and maneuver well that close to QUEST.

Like UAV-HELO and UAV-QUAD, USVs can come to within meters of the VOI. USVs currently carry and power larger payloads than comparable cost UAVs and have much better endurance. However, UAVs can come in very close and almost 'board' the VOI

significance: Organic capabilities (in the air or on the water) that can stream real-time video back to the ship for situation awareness on a VOI before and during boarding. This is especially useful on the blind side of the VOI.

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D.9 Autonomous Sonobuoy Deployment and Monitoring (V7)

capability: Covertly detect, identify and track an underwater contact with the ship at a remote location.

solution:

Deploy a USV that can autonomously launch sonobuoys at pre-determined locations (over-the-horizon if needed) and remain in the area until the sonobuoys' floats were seen on the surface through a PTZ camera that can send this information back to the ship in near real-time (V7-A).

USV can also act as a relay for the sonobuoy signal sending it over-the-horizon to where the ship may be monitoring. (V7-A)

solution V7-A: ***employ UXVs to detect, identify and track an underwater contact.***

- ***use USV-2600 to deploy a field of sonobuoys and stealth buoys.***
- ***then, use the USV-2600 to monitor the sonobuoy field.***

experimental plan: *With QUEST anchored at the north end of the inlet, deploy USV-2600 with the sonobuoy launcher. It transits and stops at 2 locations south of QUEST to deploy 53G sonobuoys. The USV-2600 loiters in the area of the 2nd sonobuoy to monitor. After 2 hours have elapsed, QUEST brings the USV-2600 back to it.*

results:

The experimental plan was carried out almost exactly as described. The USV-2600 has a sonobuoy launch system (Fig 20a), that deploys up to three sonobuoys of 53D, 53F, or 53G form factors, either remotely or autonomously at designated latitudes and longitudes. The USV-2600 was tasked with a mission to deploy 2 sonobuoys at pre-determined locations. The USV-2600 then relayed video images of the sonobuoy float coming up (Fig. 20b). Then, the USV-2600 performed a square spiral (Fig. 20c) away from the sonobuoys at a predetermined speed in order to acoustically range the USV-2600. This was done successfully at speeds of 2, 3, and 4 knots. The sonobuoy receivers on-board QUEST were able to detect the USV-2600 as it performs its autonomous spiral away from the sonobuoy. The USV-2600 transmits alot of noise underwater that was audible out to hundreds of meters on a windy day (Fig. 21). This was especially true when the USV-2600 changed heading.

significance: An organic USV that can autonomously and covertly deploy sonobuoys at designated locations over-the-horizon from the ship. The USV can loiter and monitor the sonobuoy to ensure its float surfaces as determined through the USV PTZ video camera.

D.10 Indications & Warning of Sea-Going Vessel of Interest (V8)

capability: Remotely conduct covert surveillance on a vessel of interest (e.g., illegal fishing) from a ship.

solution:

Deploy a USV that can launch sonobuoys and stealth buoys at pre-determined locations and monitor them from the RCN ship that can be as far away as the horizon. Processing of the sonobuoy signal is specifically for monitoring a specific VOI to detect changes in its status based on its acoustic signature. (V8-A)

solution V8-A: ***employ a UXV to provide I&W of a VOI departing an area***

- ***deploy barrier of stealth buoys across entrance/exit of***
  - ***use USV catamaran to deploy stealth buoys***
  - ***report on VOI only (signal in dB)***
  - ***call into DRDC(A), Halifax (RJOC)***

experimental plan: *QUEST to anchor in Gascoyne Inlet at a range where its acoustic noise would not be picked up by the sonobuoys. The sonobuoy monitoring equipment would be on-board QUEST. The USV-2600 will be deployed from QUEST with a full complement (3) of 53G sonobuoys. They will be autonomously deployed at specific locations to span the chokepoint in the Inlet. Several vehicles including USV-2600 and QUEST will go from the north end of the inlet, through the choke point and continue to the mouth of the inlet (4 nm transit) while the sonobuoys are active.*

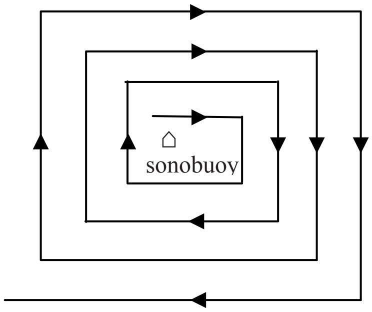
results:

Due to a technical difficulties stealth buoys were not used. Sonobuoys, with the same form factor, were used in their place. The stealth buoy would have called, via SATCOM, DRDC or another CF location. They have a 30 day life whereas the sonobuoys have an 8 hour life. With a stealth buoy, the ship can perform other business once the stealth buoy is deployed. With sonobuoys the ship has to remain in the area to monitor them.

During the experiment, the USV-2600 autonomously deployed two sonobuoys, in a line running roughly west-east, across the choke point of Gascoyne Inlet. Then, a variety of targets were run through the sonobuoy line including the USV-2600, USV-HH, QUEST's RHIB, and then QUEST itself. The targets ran a north-south pattern at both low and high speeds. The data has not been fully analyzed. However, it was clear the sonobuoy line was able to detect all the targets based on an aural and lofargram analysis of the sonobuoy data. While the ability to autonomously and covertly detect targets was shown, the ability to identify and track contacts has to wait for a more comprehensive analysis that compares V7-A results with V8-A.

significance: An organic system that can provide covert and autonomous monitoring of targeted VOIs (potentially over-the-horizon) suspected of illegal activity (e.g., illegal fishing, carrying illegal cargo, pollution). The system reports when the VOI has changed its status (e.g., leaving the area).

(a) (b)



(c)

Fig. 20: USV-2600: (a) deploys sonobuoy from middle launcher (b) monitors sonobuoy until float is on surface, and (c) self-ranging maneuver (V7-A).

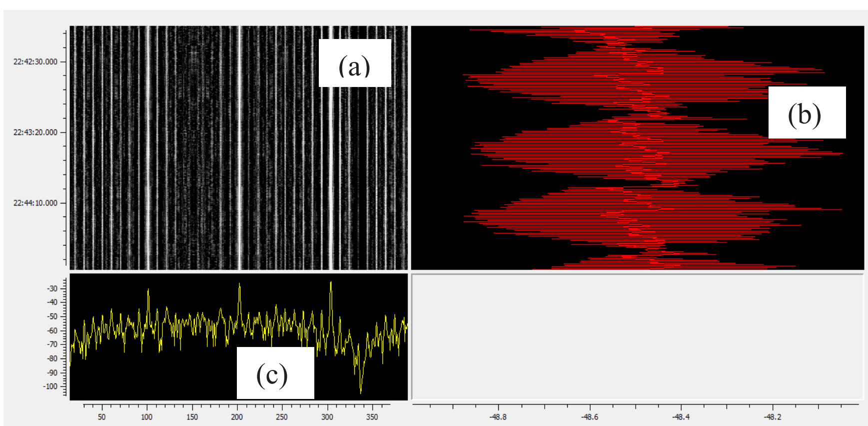


Fig. 21: Sample (a) sonogram, (b) time series (time on ordinate axes) and (c) Fourier analysis for sonobuoy detection of USV-2600 transiting Gascoyne Inlet choke point (V8-A).

Annex E UXVs in the OODA Loop

The OODA (observe, orient, decide, and act) military decision-making process is applied to prepare tactics for evolving situations. The steps are briefly: (1) *observe*: collect current information from many sources; (2) *orient*: analyze this information, and use it to update situational awareness; (3) *decide*: determine a course of action; (4) *act*: follow through on the decisions, and (5) loop back to *observe* as required. *Observe* and *orient* are critical to good decisions. If these steps are lacking, flawed decisions and actions will result.

How could UXVs fit into this OODA decision-making process? The first two steps, *observe* and *orient*, correspond to UXVs collecting and analyzing information. As shown in CFJAE12, UXVs can autonomously place sensors to *observe* in strategic locations (e.g., autonomous USV deployment of sonobuoys, UAVs equipped with cameras) in order to provide current information. Successful missions depend on the *orient* step – the ability to process observations into timely information. This information is integrated with other information to form knowledge upon which *decisions* could be made. Decisions manifest as orders and orders into *actions*. While decisions could be suggested by UXVs, manned forces still *decide* and *act*. In other words, UXVs perform the timely detection, classification and identification so manned forces can carry out more informed prosecution.

To achieve the OODA process in demanding environments and/or situations like the Arctic the requirement is to *observe* and *orient* more data, at a higher rate. Information dominance comes from collecting, controlling, exploiting, and defending information while denying the adversary the ability to do the same. If information collection is based on UXVs, the ability to work within the enemy decision loop rests on processing power, the ability to move through the loop as quickly as possible. The objective is to operate faster than the decision loop of the adversary. UXVs integrated with sensors and extensive communications links (e.g., in-air telemetry for USVs and UAVs and combined acoustic and in-air communications for UUVs as shown in CFJAE12) and advanced on-board data processing results in an increased information flow rate. However, this can also lead to information overload where the information is not properly used or interpreted for the *decision* part of the loop.

Autonomy provides UXVs with some decision-making ability which is how autonomy-enabled UXVs could participate in the *decide* step – to mitigate information overload. Humans should be part of the tactical decision-making however, there are circumstances where the human and UXV cannot communicate so the autonomy must be capable of taking on a decision-making and acting role. The UXV should limit decisions to the rules provided to it prior to deployment and provide the humans complete details of its OODA loops upon its recovery. It is likely the UXV's decisions will be limited to positioning sensors and its own movements.

The difference between a UXV controlled by autonomy (e.g., IVER2 UUV) and a remote controlled (e.g., USV-HH) one is the on-board processing power. For these reasons, future CFJAEs should consider some focus on the *orient* step of the OODA process and its impact on the *decide* step and how autonomy might be applied to assist with decision-making.

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Annex F Lessons Learned - Details

#1: Legislative, Policy, Legal, CF Orders and procurement processes that need to be considered in developing future CF Joint Arctic Experiments

- Federal and Territorial permits to allow experimentation in the Arctic (Land use permits)
  - Indian Northern Affairs Canada (Federal) - Land Use Permit (12 month process time)
  - Nunavut Water Board Permit (Territorial) – Land Use Permit (12 month process time)
- Environmental Assessment’s for all pieces of equipment (12 month process time)
  - A total of 49 pieces of equipment were assessed
    - Project Activity or Component (s)
    - Valued Ecosystem Component(s) Affected
    - Description of the Effect
    - Mitigation Measures
    - Residual
- Procurement – PWGSC contracts to purchase equipment (24 month led time for contract, delivery, set to work, trial of equipment, training, SOP development and integration into the experiment)
- Process to allow UAV operations
  - Selection of UAV area of operations
  - Special Purpose Flight Permit (this includes - RARM – Risk Assessment, Frequency Allocation and Mutual Interference Plan, Technical Air worthiness, Operational Air Worthiness and Air Control Plan)
  - 1 CAD message to fly
  - NOTAM
  - Marking of Aircraft
  - Class F airspace or Class F waiver
  - Reference - B-GA-100-001/AA-000 *National Defence Flying Orders* 2001-05-25, Change 8
- Legal considerations
  - AJAG provided two legal opinions on UAV operations in the North and USV/UUV operations in the North
  - Nunavut Liquor Control Act (no transport of liquor through certain Arctic communities which includes personal alcohol in suitcases)

        - Use of Alcohol at Gascoyne Inlet Camp
        - Recreational Fishing Licence (if individuals intend to fish)
- Submission of Request for DRDC Support document (24 month led time)
- CHIEF SCIENTIST ORDERS Q346 – command and control structure that the CFJAE 2012 fell under while at sea.
- Gascoyne Inlet 2012 Deployment Orders - command and control structure that the CFJAE 2012 fell under while on land.
- Documentation/preparation of personnel for safe entry into the Arctic
    - Wilderness and Remote First Aid training
    - Medicals (9 month process through HR and Health Canada for civilian CF employees)
    - Sleeping Bags (must be carried by each person in order to fly on PCSP aircraft in the Arctic)
    - Floater Jackets (safety item, water temperature was 1 degree Celsius)
    - Guide for Seagoing personnel - explains safety considerations when onboard CFAV QUEST. On joining QUEST personnel were briefed on procedures for fires, floods, operation of hydraulic emergency doors, immersion suits and abandon ship drills.
    - Gascoyne Inlet Standing Orders - explains safety items related to fires, muster areas, medical support and polar bear intrusions into the camp. Note polar bears got inside the camp perimeter prior to the arrival and just after the departure of the CFJAE team.
    - Next of Kin - up to date list was kept at both the Gascoyne Inlet camp and onboard QUEST.
    - Families were given an emergency contact document that provided options for contacting members deployed in the Arctic.

#2: Effect of magnetic north fluctuations on magnetic north-based navigation systems.

The negative effects of the fluctuating magnetic field on magnetic navigation systems had been researched prior to the deployment. It was assessed that the impact would be substantial and options were selected to compensate for this negative impact. On example was the implementation of DGPS for the USV navigation systems. Another example is the purchase of fibre optic gyros for the UUVs to improve their inertial navigation when submerged. However, the fibre optic gyros did not arrive in time to be integrated into the vehicles.

The negative impact on the magnetic compass navigation systems that were employed was substantially greater than anticipated for this area. Magnetic north based navigation systems should not be employed in future northern operations/experiments at this latitude.

Magnetic north-based navigations systems should still be considered for operations in lower latitudes to provide an option for navigation in GPS denied environments.

#3: Universal command and control unit for operation of UXV platforms and their payloads.

The various UXV control stations used during CFJAE12 were unique (or proprietary) with their individual strengths and weaknesses. Since each system was unique there was a large training /operation load on the operators. This reinforces the need for a longer term approach to develop the NATO 'Multi Domain unmanned Control System (MDCS)' to support future CF experiment/operations in the Arctic and other areas.

Ref [7] concluded that "it is technically feasible and advisable to design and build a single Multi Domain unmanned Control System (MDCS) for all of the [UAV, UGV, USV, and UUV] vehicle domains". Based on that finding, together with the strong US DoD support [8] for this type of interoperability, it is likely a MDCS-like control system will be fielded in the next few years. This type of control system should be considered for experimentation in future CFJAEs.

#4: A time line of 24 months is recommended for the preparation, work-ups, and execution of future CFJAEs.

To effectively prepare and mitigate risk for future Arctic experiments it is recommended that a 24 month planning/development/execution time line be allocated. A number of items were listed in summary #1 with lead times. The 24 month time frame will allow parts of the experiment to be built into unit budgets, programs of work and development of teams, etc. Specifically two items are identified as needing this amount of time:

- PWGSC procurement with enough time after delivery for systems integration, training, development of maintenance capability, mitigation of risk and safety issues, vetting SOPs and work-ups, etc.
- "Request for DRDC support" document to be processed and resources assigned. This is required for their business planning cycle which will allocate resources to future CFJAEs.

#5: Autonomy – this technical component of future UXV systems must be considered and examined for its ability to deliver efficiency, effectiveness and economy to future capability. It is linked to the personnel costs associated with the future UXV system.

Autonomy observation/assumption and recommendation:

- Without autonomy future UXV systems will be unmanageable due to the required personnel costs to support a labour intensive system.
- Without autonomy future UXV systems will fail to deliver timely data. The complexity and volume of data within the UXV C4 part of the system needs to be assessed on how autonomy can be utilized/leveraged in future CFJAEs. Operations research should be employed to apply cost-effective analysis to compare relative costs and outcomes (effects) to various courses of action.

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Annex G Details of Technical Recommendations

This annex provides technical recommendations for topics that should be pursued for future CFJAE deployments.

UUV Engineering:

- An upward looking Doppler velocity log (DVL) is required on the UUVs to perform rudimentary mapping of ice keels from below the ice keels. As well, the ability to transmit this information back to the ship via acoustic modem, which is at safe stand-off range, on the traversability of the ice for ships with ice-breaking capability.
- Purchase long base line (LBL) transponders for UUVs to perform under-ice navigation.
- The SeeByte NEPTUNE tool (adaptive to the environment, changes in assets, mission objectives, etc.) be integrated onto USV-2600 and the UUVs to integrate above and below water (or ice) picture and facilitate collaboration between multiple UXVs.

USV Engineering:

- For USVs to navigate broken ice waters, two on-board cameras are required. One for USV navigation and the other to profile the ice, provide ISR, etc. As well, on-board radar would assist with ice detection and monitoring. The USV-2600 would benefit from a forward look sonar to detect the below-water extent of ice visible on the surface.
- Developmental work with the USV-HH, consider installing improved video and IR cameras, an echo sounder, and the ability to transmit the on-board bilge pumps status to the operator console on-board QUEST through telemetry for leak detection.
- The ability to recover USVs without deploying a manned RHIB in the water is investigated. One approach uses a long pendant with an open eye attached to the USV lift lug. The length of the pendant depends on the reach of the crane hook above the USV lift lug. The idea is that a ship-bound crew member release the pendant with a boat hook when the USV is within reach. The pendant eye is hooked onto the crane by the crew member with the boat hook. The USV would be piloted to maintain tension on this line as needed. Tag lines are inserted by deck crew using a happy hooker with a boat hook.
- The good USV-2600 command and control system highlights that an operator console is useful for mission planning, integrating sensor measurements, and overall situational awareness. However, an additional portable wireless controller, that the operator can use for manual control, and carry out to the Aft Deck, was invaluable for launch and recovery from a high freeboard vessel like QUEST. This is clearly where the USV-HH is lacking. Such a portable controller for the USV-HH does not currently exist.
- Another goal is to integrate a higher quality bathymetric sonar than the Teledyne ES3M multi-beam sonar used to better assess the stability of catamaran platforms like the USV-2600 as a hydrographic platform.

UAV Engineering:

- GPS-based navigation be implemented in UAVs that fly in the Arctic. This requires development work with Aeryon Labs and Copterworks. As well, UAVs are not marinized for the maritime Arctic environment. They have no reserve buoyancy and are not waterproof. The UAV-QUAD control station tablet be able to load geo-referenced maps and represent ship superstructure to assist with UAV-QUAD recovery from a ship.
- Further, the UAV-QUAD control station tablet is ill equipped to the task of controlling the final recovery. The operator cannot simultaneously control both UAV altitude and position relative to the ship at any one time. The operator can only do one or the other alternately. When the UAV was driven upward in a turbulent eddy, the operator had no recourse except to ride it out and try again. In hindsight, the flight deck should have been cleared to allow for crosswinds on final approach in the event of an overshoot.
- A possibility to consider to demonstrate UAV capabilities in the Arctic is to deploy the DRDC Suffield APHID UAV from Resolute Bay and fly it to Gascoyne Inlet. The range is within the capability of the APHID.

Heads-up display:

- There was a requirement during CFJAE12 to build a near real-time display where QUEST, USV-HH, USV-2600, IVER2 UUV, and the UAV positions are displayed on one geo-referenced screen. The IVER2 position would be relayed by the USV-2600 underwater modem/Freewave radio transmitting IVER2 position as determined by the LBL transponders. This display would be used by QUEST to monitor the location and missions of off-board autonomous systems. The display requires ADS-B transmitters for the UAVs that CFJAE12 could not secure in time. The range of speeds in the UXVs (2, 4, 15, 30) kt made it difficult for QUEST and the Lead Scientist to track and monitor. This was evident on days when there were 3 platforms simultaneously deployed. This UXV situational display remains an objective for future activities.

UXV communications:

- The capability for submerged UUVs with micromodems to provide their in-situ situational awareness to QUEST via the USV-2600's underwater micromodem / in-air Freewave ethernet radio was demonstrated. Further work looks at refining the quality (minimize packet loss) and throughput of information sent in such data transfers.
- As well, further work considers using a UAV as a relay to extend the range of signals transmitted from the USV to the ship.
- The capability to deploy sonobuoys autonomously with the USV-2600 at pre-determined locations and have it and the ship monitor the sonobuoys was shown. What was not demonstrated was the ability of the USV-2600 to re-transmit the sonobuoy signals to QUEST if the sonobuoys are deployed over-the-horizon from the ship. Stealth buoys acquired for long endurance ISR with communications back to the RJOC in Halifax.

Annex H Detailed Experimentation Plan

Table 6: CFJAE Experimentation Plan Summary.

<table>
<tr><th colspan="4">CFJAE12 Experimentation Plan Summary</th></tr>
<tr><th>mission</th><th>vignette / task / overall capability</th><th>specific capability / experimentation plan</th><th>scientific objectives</th></tr>
<tr><td>1. Humanitarian and Disaster operations</td><td>1. CONFIRM APPROACHES FOR RCN SHIPS IN THE AFTERMATH OF A DISASTER

vignette: - On 01 July 20XX a natural disaster (earth quake followed by a tsunami) struck the North East portion of the Canadian Arctic in the region of 75 North.

task: Confirm harbour approaches and anchorage area are safe for an RCN ship to transit into harbour and anchor within the anchorage area. In addition, provide overall situational awareness of the Gascoyne Inlet area including port, port facilities and facilities ashore.

capability: A UXV system capable of confirming safe entry and anchorage for CFAV QUEST as well as overall SA.

• deploy UxV's in the order of:
o UAV fixed wing
o USV Hammerhead
o UAV rotary wing
o UXV system - comprised of USV & UUV's (3)</td><td>V1-A: Launch fixed wing UAV's with ISR/sense payload to conduct airborne reconnaissance to confirm safety and provide SA.

expt plan: Launch fixed wing UAV with ISR/sense payload to conduct airborne reconnaissance of Gascoyne Inlet to confirm safety and provide SA.</td><td>E1–A1: Capture of knowledge for future UAS autonomy development and experimentation for 2014. Understand current technology limitations and capabilities and develop enhancements through automatic mission planning and execution. Output: data set for base line and future understanding of COIs (MOEs and MOPs).
1. Validate SOPs;
2. Launch and recovery in austere environments, simulated ship deck area;
3. Aircraft able to fly desired route, accuracy;
4. Ability of imaging systems to gather appropriate data set;
5. C2 with a moving GCS;
6. Adequacy of communications links.

V1-A2: Capture of knowledge and data set for future research in situational awareness (sense / ISR). Gather data to advance development of aided target detection algorithms. Build a knowledge base to build automated data analysis tools.
1. Validate the ability of imaging systems to gather appropriate data set;
a. e.g., detection of polar bears for situational awareness
2. Investigate the capability to develop mosaicked, high-res imagery
3. Validate ability to geo-reference targets of interest

V1-A3: Capture of knowledge and data sets to support airspace integration and interoperability studies.
1. Provide Situational Awareness through ADS-B
2. Investigate interoperability of different systems</td></tr>
</table>

CFJAE12 Experimentation Plan Summary			
mission	**vignette / task / overall capability**	**specific capability / experimentation plan**	**scientific objectives**
1. Humanitarian Assistance & Disaster Operations			through accepted communication/data package standards (e.g., NMEA, ADS-B) 3. Validate ability to hand off detected target locations to other UXVs 4. Gather data to develop the ability to detect and identify targets in real time
			V1-A4: Capture of knowledge and data set to coordinate optimization of multiple UXV systems. Demonstrate the concept of cooperative detection, identification and location of threats. 1. Fly fixed-wing UAV for threat detection; 2. Pass areas of interest (AOIs) to rotary-wing UAV; 3. Fly rotary-wing UAV for threat identification and localization **V1-A5**: This includes all events within E1. Prepare and conduct a brief for the Master of QUEST on whether it is safe to enter Gascoyne Inlet and proceed to the anchorage area. Include any sea surface and shore-based threats. Provide SA on Gascoyne Inlet and the infrastructure ashore including Force Protection issues related to polar bears.
		V1-B: Launch USV Hammerhead with ISR/sense payload to conduct surface recon to confirm safety and provide SA. **expt plan**: Launch the USV-HH with ISR/sense payload to conduct surface reconnaissance to confirm safety and provide SA.	**V1-B1**: Capture of knowledge for future USV autonomy development and experimentation 2014. Understand current technology and develop enhancements through autonomous mission management. Output: data set for base line and future MOP/MOE. 3 elements of autonomy with the goal of achieving a baseline data set for future MOP's: - Sense (leading to control)

CFJAE12 Experimentation Plan Summary			
mission	**vignette / task / overall capability**	**specific capability / experimentation plan**	**scientific objectives**
1. Humanitarian Assistance & Disaster Operations			- Control (leading to action – achievement of the task) - Actuate (action) Operational requirements 1. Validate SOPs; 2. Launch and recovery in austere environments, simulated ship deck area; 3. Autonomous navigation accuracy; 4. Ability of sensor systems to gather appropriate data set; 5. C2 with a moving GCS; 6. Adequacy of communications links **V1-B2**: Capture of knowledge and data set for future research in situational awareness (sense / ISR). Look at areas where you have no true autonomy - current technology and then insert additional autonomy in the future. SA related to: - Ice, ice cover, Ice Growlers - Detection capability & Detection Range - Control of a UXV system (multiple platforms) - Selection of alternate route **V1-B3**: Capture of knowledge and data set to analyse optimum approach in the future to sweep transit route and anchorage area for hidden obstructions e.g., new uncharted obstructions. **V1-B4:** Capture of knowledge and data set to analyse optimum approach in the future for maintaining situational awareness using combination of multiple UXVs deployed relative to the ship. - Formation or flocking movement of UXVs

CFJAE12 Experimentation Plan Summary			
mission	**vignette / task / overall capability**	**specific capability / experimentation plan**	**scientific objectives**
1. Humanitarian Assistance & Disaster Operations			**V1-B5**: Capture of knowledge and data set to analyse optimum approach in the future for C2 and communications between UXVs in different environments. Areas of interest: - exchange individual UXV status between the hive and control platform - overall mission status (abort, continue, move to next phase, etc.). **V1-B6**: Capture of knowledge and data set to analyse future optimums for launch and recovery of USV's. Compare: - L&R via ships RHIB - L&R via cocoon Collect metrics on time and personnel manning – total personnel hours.
		V1-C: Launch rotary wing UAV with ISR/sense payload to conduct airborne reconnaissance to confirm safety and provide SA. **expt plan:** Launch rotary wing UAV with ISR/sense payload to conduct airborne reconnaissance to confirm safety and provide SA.	**V1-C1**: Capture of knowledge for future autonomy development and experimentation 2014. Understand current technology and develop enhancements through autonomy.
			V1-C2: Capture of knowledge and data set contributing to SA. Stitch and geo-reference imagery to produce a coherent tiled view. This includes the collection of both on shore and sea surface imagery, potentially imaging subsurface targets. **V1-C3**: Investigate existing targets provided by a fixed wing UAV asset. **V1-C4:** This includes all events within E1. Prepare and conduct a brief for the Master of QUEST on whether it is safe to enter Gascoyne Inlet and proceed to the anchorage

CFJAE12 Experimentation Plan Summary			
mission	**vignette / task / overall capability**	**specific capability / experimentation plan**	**scientific objectives**
1. Humanitarian Assistance & Disaster Operations			area. Provide overall SA on Gascoyne Inlet and the infrastructure ashore including Force Protection issues related to Polar Bears.
		V1-D: Launch U×V system (comprised of USV Catamaran and three UUV IVER2's). The four platforms with ISR/sense payloads create a U×V system to conduct underwater reconnaissance to confirm safety and provide SA. • beyond-line-of-sight comms UUV to USV to UAV to QUEST **expt plan**: Launch U×V system (comprised of USV-2600 and three Iver 2 UUVs). The four platforms with ISR/sense payloads create a U×V system to conduct underwater reconnaissance to confirm safety and provide SA.	**V1-D1**: Capture of knowledge for future autonomy development and experimentation 2014. Understand current technology and develop enhancements through autonomy. Output: data set for base line and future MOP. Three elements of autonomy with the goal of achieving a baseline data set for future MOP's: - Sense (leading to control) - Control (leading to action – achievement of the task) - Actuate (action) **V1-D2**: Capture of knowledge and data set for future research in situational awareness (sense / ISR). Look at areas where you have no true autonomy - current technology and then insert additional autonomy in the future. SA related to: - Ice - ice cover, keel depth of ice - Underwater obstructions (relationship to mine warfare) - Control of a UXV system (multiple platforms) - Selection of alternate route **V1-D3**: Capture of knowledge and data set to analyse optimum approach in the future to sweep transit route and anchorage area for hidden obstructions e.g., flipped over boats and uncharted obstructions. **V1-D4**: Capture of knowledge and data set to analyse optimum approach in the future for maintaining situational awareness of all types of UXVs that are deployed relative to the ship. - ADS-B transponders onboard each UAV & USV (link

CFJAE12 Experimentation Plan Summary			
mission	**vignette / task / overall capability**	**specific capability / experimentation plan**	**scientific objectives**
			to UUV) **V1-D5**: Capture of knowledge and data set to analyse optimum approach in the future for USV(cat) controlling UUV's. The UXV system must be capable of determining and transmitting via the USV the optimal route to a surface ship through uncharted waters. **V1-D6**: Capture of knowledge and data set to analyse optimum approach in the future for C2 and communications between UXVs in different environments. Areas of interest: - exchange individual UXV status between the hive and control platform - overall mission status (abort, continue, move to next phase, etc.) **V1-D7**: Capture of knowledge and data set to analyse future optimums for launch and recovery of UUV's. Compare: - L&R via ships RHIB - L&R via cocoon Collect metrics on time and personnel manning – personnel hours.
2. HADO	**2. DETECTION, LOCALIZATION, AND SA FOR SAR (MID-AIR COLLISSION)** **vignette**: CFAV QUEST safely anchored in Gascoyne Inlet. QUEST finished off loading and landing 50 tons of supplies to community. At 1300 ships lookout reports a mid-air collision between 2 twin otter aircraft to the East.	**V2-A:** Army detachment launch fixed wing UAV's with ESM, communications relay and ISR/sense payload to conduct airborne reconnaissance to detect (emergency position indicator), locate and provide SA of primary SAR crash site to the East. **expt plan**: Launch fixed wing UAV with	**E2-A1:** Capture of knowledge for future UAV autonomy development and experimentation for 2014. Understand current technology limitations and capabilities and develop enhancements through automatic mission planning and execution. Output: data set for base line and future understanding of COIs (MOEs and MOPs). 1. Validate SOPs; 2. Launch and recovery in austere environments, simulated ship deck area;

<table>
<tr><th colspan="4">CFJAE12 Experimentation Plan Summary</th></tr>
<tr><th>mission</th><th>vignette / task / overall capability</th><th>specific capability / experimentation plan</th><th>scientific objectives</th></tr>
<tr><td>2. Humanitarian Assistance and Disaster Operations</td><td>First aircraft trailing smoke and in a steep dive to the West impacts the water in Gascoyne inlet. On impact A/C flips over and sinks. No survivors were recovered by the ships rescue boat.

Second aircraft is seen to conduct a rapid but somewhat controlled descent to the East trailing smoke. A/C declared in an in-flight emergency and then mayday on 126.7 MHz air common chat. No further communications.

task: Conduct SAR

capability: A UXV system capable of conducting SAR.
• primary SAR location
o deploy UXV's in the order of:
▪ UAV fixed wing (land launch)
▪ UAV rotary wing (land launch)
• secondary SAR (recovery) location
o deploy UXV's in the order of:
▪ USV HH
▪ UAV fixed wing (simulated ship launch)
▪ UAV rotary wing (simulated ship launch)
▪ UXV system - comprised of UUV's (3) & ROV</td><td>ISR/sense payload to conduct airborne reconnaissance of eastern (land) and western (water) Gascoyne Inlet crash sites to provide SA of sites and surrounding areas (ie. Polar bears and other threats to potential survivors). Provide site coordinates to other UXVs.</td><td>3. Aircraft able to fly an area survey around a given coordinate;
4. Ability to detect an emergency position indicator beacon;
5. Ability of imaging systems to gather appropriate data sets (e.g., floating and semi-submerged targets, personnel, polar bears);
6. Adequacy of communications links.

V2-A2: Capture of knowledge and data set for future research in situational awareness (sense / ISR). Gather data to advance development of RF-aided target detection algorithms. Build a knowledge base to build automated data analysis tools.
1. Validate the ability of imaging systems to gather appropriate data set;
a. state of crash site, e.g., survivors
b. detection of polar bears for situational awareness
2. Investigate the possibility of communicating with survivors
a. e.g., drop a communication device or alert survivors to presence (engine noise)
3. Validate ability to geo-reference targets of interest.

V2-A3: Capture of knowledge and data sets to support airspace integration and interoperability studies.
1. Provide Situational Awareness through ADS-B;
2. Investigate interoperability of different systems through accepted communication/data package standards (e.g., NMEA, ADS-B);
3. Validate ability to hand off detected target locations to other UXVs;</td></tr>
</table>

CFJAE12 Experimentation Plan Summary			
mission	**vignette / task / overall capability**	**specific capability / experimentation plan**	**scientific objectives**
2. Humanitarian Assistance and Disaster Operations			4. Gather data to develop the ability to detect and identify targets in real time. **V2-A4:** Capture of knowledge and data set to coordinate optimization of multiple UXV systems. Demonstrate the concept of cooperative detection, identification and location of crash site. 1. Fly fixed-wing UAV for detection; 2. Pass areas of interest (AOIs) to rotary-wing UAV; 3. Fly rotary-wing UAV for identification and localization. **V2-A5:** This includes all events within E2. Prepare and conduct a brief for the Master of QUEST on the state of the crash sites and possible survivors. Provide SA on crash sites including issues related to polar bears or other threats.
		V2-B: Army detachment launch rotary wing UAV's with ISR/sense payload to conduct airborne reconnaissance to detect (based on queuing from UAV fixed wing), locate and provide SA of primary SAR crash site to the East and secondary crash site to the West. **expt plan:** Launch rotary wing UAV with ISR/sense payload to conduct airborne reconnaissance to detect, locate and provide SA of crash sights.	**V2-B1:** Investigate a rotary wing UAV's capability to provide SA in a SAR operation, both over water and land, with queuing from a fixed wing UAV asset. Stitch and geo-reference imagery to produce a coherent tiled view. **V2-B2:** Investigate route planning based on imagery derived from the Scout. **V2-B3:** This includes all events within E1. Prepare and conduct a brief for the Master of QUEST with regard to the disposition of SAR targets, survivors, etc. Provide overall SA of the crash sites.

CFJAE12 Experimentation Plan Summary			
mission	**vignette / task / overall capability**	**specific capability / experimentation plan**	**scientific objectives**
2. Humanitarian Assistance and Disaster Operations		**V2-C:** Launch USV Hammerhead with ISR/sense payload to conduct surface reconnaissance of crash site to the West and provide SA. **expt plan**: Launch the USV-HH with ISR/sense payload to conduct surface reconnaissance of crash site to the West and provide SA.	**V2-C1**: Capture of knowledge of autonomy on optimal search pattern for detection of floating material from crashed aircraft. Understand current technology and develop enhancements through autonomy for experiment 2014. **V2-C2**: Capture of knowledge of payload capabilities. Try to get the best out of present payload and develop future enhancement of payload capability (sense / ISR). **V2-C3**: Capture of knowledge and data set to analyse optimum approach in the future for SAR using combination of multiple UXVs that are deployed relative to the ship. Ex. UAV finds some floating debris and geo-locates them, USV confirms the target, and use RHIB or USV recover targets on surface water
		V2-D: Launch UUV's and ROV's with ISR/sense payloads to conduct underwater reconnaissance to detect (emergency position indicator), locate and provide SA of secondary SAR crash site to the West. Conduct recovery with ROV. **expt plan**: Launch U×V system (comprised of USV-2600 and two UUVs). The three platforms with ISR/sense payloads create a U×V system to conduct underwater reconnaissance to search an area of X × Y to localize a downed aircraft whose black box transponder should still be working.	Did not get black box transponder from CF.

CFJAE12 Experimentation Plan Summary			
mission	**vignette / task / overall capability**	**specific capability / experimentation plan**	**scientific objectives**

3. Humanitarian Assistance and Disaster Operations	**3. RE-ESTABLISH COMMUNICATIONS NETWORKS**
	
	vignette - 01 July 2025 - A natural disaster (earth quake and tsunami) has struck the East coast of the Canadian Arctic at 75 North.
	
	The community of Gascoyne Inlet has suffered major infrastructure damage and the loss of 80% of their accommodations. A whole of government approach is being employed to respond, support, stabilize and re-establish the necessary infrastructure for life to continue.
	
	The whole of government approach including Federal, Territorial and Municipal governments, First Responders (Fire, Police and Medical) as well as NGO's has been hampered by the lack of simple reliable communications. Communication requirements include 24/7 access to both the local area as well as long distance access
	
	task: conduct and support communications (C2) with OGD's and NGO's
	
	capability: deploy a cell phone network with local area coverage
		V3-A: deploy a cell phone network with local area coverage
		• QUEST:
		  o Antenna
		• Army Detachment ashore:
		  o Conduct training to OGD and NGO staff
		  o Pass out cell phones
		  o Liaise with QUEST ref problems and effects ashore
		  o Confirm footprint of coverage
		
		expt plan: Provide cell phone coverage over the areas of interest in and around Gascoyne Inlet. Install cell phone base station STAR inc. CDMA – 2000 system on the QUEST (Wet Lab – second deck) and antennae on railing of flight deck. Use broadband spectrum analyzer to map power levels of cell phone reception areas to validate RF propagation models in the Arctic environment. Distribute handheld cell phones to NW commanders and Army detachment.
			E3–A1: Capture knowledge for future installation and operation of communication networks in austere and harsh environments. Understand current technology limitations and capabilities and develop enhancements through analyzing environmental impacts on RF communications. Output: data set for base line and future understanding of environmental effects.
			1. Adequacy of communications links;
			2. Heat map of RF communication powers.
			
			V3-A2: This includes all events within E3. Prepare and conduct a brief for the Master of QUEST on the state of the communication infrastructure within the area of interest.

4 . HADO	**4. SAFE PASSAGE FOR RCN SHIPS IN UNCHARTED AND BROKEN-ICE WATER** **vignette**: Infrastructure has been repaired and day to day activities have been stabilized at Gascoyne Inlet. QUEST is preparing to return to Halifax.	**V4-A:** when transiting in non-ice covered inadequately charted waters employ a USV system for safe transit (bottom depth). In this case transit is to a SAR location. **expt plan** - Use a USV equipped with a	**V4-A1**: Autonomy algorithms for the USV to best survey the water underway with the ship following at some stand-off. **V4-A2**: Perform limited processing of ES3-M sonar on-board. Send back depth soundings as a minimum to the ship?

CFJAE12 Experimentation Plan Summary			
mission	**vignette / task / overall capability**	**specific capability / experimentation plan**	**scientific objectives**
4. Humanitarian Assistance and Disaster Operations	A CF Hercules aircraft has made an emergency landing on a remote island 100 nm to the south of Gascoyne Inlet. A/C has received moderate damage and will not be able to take off. RCC has good communications with the crash site. A total of 35 crew and passengers are safe with the necessary supplies to last 10 days. Weather is poor, low ceiling, icing, reduced visibility and temperature of minus 10 to plus 10. Rescue by air is not an option due to other high priority air tasks and continued poor weather. CFAV QUEST is tasked to proceed south and conduct the SAR. **task:** SAR **capability**: safe transit within the Arctic	bottom-looking multi-beam scanning sonar (Teledyne ESM-3) to transit ahead of a high valued asset (QUEST). The USV would do some on-board processing of the sonar data to radio back to the high valued asset the best path through the water. What we can achieve to date is to send the depth sounder measurements back to Quest for consideration.	**V4-A3**: Ability to radio back to the ship situation awareness of what the bathymetry is ahead of the ship using a low value asset.
		V4-B: when transiting in ice covered & inadequately charted waters employ a UUV system for safe transit (bottom depth and ice depth). In this case transit is to a SAR location. **expt plan**: Deploy a UUV to map ice keels to determine their thickness and whether a select ice breaker could transit through. The UUV shall be equipped with a depth sensor, DVL to determine altitude, and an upward looking sonar to determine ice depth. The UUV is supported by a USV to serve as a gateway buoy in order to allow QUEST to operate from a larger stand-off from the ice field.	To occur during CFJAE14.
		V4-C: when transiting in ice covered & inadequately charted waters employ a UAV system for safe transit (leads through ice). In this case transit is to a SAR location. **expt plan**: Launch rotary wing UAV with	**V4-C1** - Investigate a rotary wing UAV's capability to provide ice survey looking for leads in the ice and surface manifestations of possible deep ice keels. Stitch and geo-reference imagery to produce a coherent tiled view. **V4-C2**- Investigate correlation of Scout imagery with ice depth provided by an UUV.

CFJAE12 Experimentation Plan Summary			
mission	**vignette / task / overall capability**	**specific capability / experimentation plan**	**scientific objectives**
		ISR/sense payload to conduct in stride airborne reconnaissance to survey ice conditions in front of the ship.	
5. CAN Arctic Patrol Sovereignty	**5. AUTONOMOUS UNDERWATER BATHYMETRIC MAPPING SURVEYS** **vignette:** During the Canadian Forces Joint Arctic Experiment 2012- The CFJAE team in conjunction with CHS hydrographers will chart Gascoyne inlet. The charting will be accomplished by employing a CF USV equipped with new state of the art bathymetry equipment provided by CHS R&D section. Autonomous unmanned systems are potentially one means of providing data to generate charts to modern standards. This would allow the Canadian Forces Arctic Offshore Patrol Vessels of the future to move safely and effectively in the Canadian Arctic. **task**: Support OGDs like the Canadian Hydrographic Service **capability:** conduct comprehensive survey work with the Canadian Hydrographic Service (CHS) Department in the Canadian Arctic	**V5-A:** conduct a survey of Gascoyne Inlet by employing a Canadian Forces, USV catamaran and a CHS - Odim ES3-M multibeam • QA/metrics for this experiment will involve the comparison of collected data against current CHS data. **expt plan**: With QUEST anchored at the north end of the inlet, deploy USV-2600 performs a hydrographic survey of Gascoyne inlet.	**V5-A1**: Feasibility of autonomous surveys given a 4 kt speed. Stability achieved on a catamaran-like vessel to produce reasonable data?

CFJAE12 Experimentation Plan Summary			
mission	**vignette / task / overall capability**	**specific capability / experimentation plan**	**scientific objectives**
6. CAN Arctic Sovereignty Patrol	**6. ASSIST WITH FORCED SHIP BOARDING** **vignette:** HMC Ship is conducting a Canadian Arctic Sovereignty Patrol. Ship is tasked to conduct a boarding of a Vessel Of Interest (VOI) which is believed to be carrying illegal immigrants. Naval Boarding party is to be put onboard to confirm the identity of all persons onboard and to conduct a thorough search of the vessel. No helicopter for this deployment **task:** Support OGDs - CBSA **capability:** conduct boarding of VOI in support of OGD mandates. In this case illegal immigration which falls under CBSA	**V6-A:** Employ UAV rotary wing Copterworks for boarding op. **expt plan**: Fly Copterworks rotary-wing UAV with high-res digital imaging capability, simulating transit from own ship to VOI. Upon arrival at VOI, gather imagery of human faces as a function of range, 10-100m ranges expected. Demonstrate the ability to monitor the VOI for the duration of a boarding mission with either the Copterworks rotary-wing UAV or the fixed-wing UAV.	**V6-A1**: Capture knowledge for future investigation of the ability of small UASs to gather high-res imagery for facial recognition studies. Understand current technology limitations and capabilities and develop enhancements to existing facial recognition software. Output: image data set for algorithm development and performance predictions. 1. Ability to gather appropriate imagery from small UAS; 2. Ability to maintain safe operations while flying close to target vessel; 3. Ability of a small UAV to station keep while tracking a moving platform; 4. Demonstrate the ability of a small UAV to maintain SA for boarding party operations. **V6-A2**: This includes all events within E6. Prepare and conduct a brief for the Master of QUEST on the suitability of a small UAV for this mission.
	Employ UXV's in advance of the boarding (preparation of the battle space) and during the boarding (force protection). ▪ prior to boarding: • UAV rotary wing to collect imagery for facial recognition • UAV rotary wing to collect imagery for SA ▪ during the boarding: • UAV rotary wing to cover blind side of VOI	**V6-B:** Employ UAV Aeryon Scout for boarding op. **expt plan**: Fly small rotary wing UAV with high resolution digital imaging capability, simulating transit from ship to VOI. Upon arrival at VOI, gather imagery of human faces as a function of range, 10-100m ranges expected. Demonstrate the ability to monitor the VOI for the duration of a boarding mission.	**V6-B2**: Investigate ability of the Aeryon Scout to capture imagery of human faces for subsequent facial recognition. **V6- B2:** Investigate the ability of the Scout to contribute to SA before and during boarding of the VOI, including viewing the blind side of the VOI.

CFJAE12 Experimentation Plan Summary			
mission	**vignette / task / overall capability**	**specific capability / experimentation plan**	**scientific objectives**
	• UAV fixed wing to cover blind side of VOI • USV to cover blind side of VOI	**V6-C**: Employ USV for boarding op **expt plan**: Launch USV Hammerhead with ISR/sense payload to conduct staring operation to cover blind side of VOI during the boarding procedure.	**V6-C1**: Capture of knowledge of autonomy on optimal station keeping capability of USV. Understand current technology and develop enhancements through autonomy for experiment 2014. **V6-C2**: Capture of knowledge of payload capabilities. Try to get the best out of present payload and develop future enhancement of payload capability (sense / ISR). **V6-C3**: Capture of knowledge and data set to analyse optimum approach in the future for using combination of multiple UXVs for conduct boarding of VOI in support of OGD mandates.

CFJAE12 Experimentation Plan Summary			
mission	**vignette / task / overall capability**	**specific capability / experimentation plan**	**scientific objectives**
7. CAN Arctic Sovereignty Patrol	**7. ASW - AUTONOMOUS SONOBUOY DEPLOYMENT AND MONITORING** **vignette:** HMC Ship is conducting a Canadian Arctic Sovereignty Patrol, no helicopter embarked. Indications are that a submarine may be transiting Arctic waters. HMC Ship is tasked to conduct ASW operations. Specifically, conduct underwater surveillance operation at choke point in Barrow Strait. MPA resources are limited. MPA resources will be released for 24/7 operations once contact is gained. UXV detachment is onboard with a mix of UXV's which include: USV capable of deploying sonobuoys and stealth buoys **task:** conduct ASW **capability:** detect, identify, and track underwater contact	**V7-A:** employ UXVs to detect, identify and track underwater contact. • deploy sonobuoy field and barrier of stealth buoys. o employ USV catamaran capable of deploying sonobuoys and stealth buoys • monitor sonobuoy field **expt plan**: With QUEST anchored at the north end of the inlet, deploy USV-2600 then transits and stops at 2 locations south of QUEST to deploy 53-G sonobuoys. The USV-2600 loiters in the area of the 2nd sonobuoy to monitor. After 2 hours have elapsed, QUEST will task the USV-2600 to come back to the ship.	n/a

CFJAE12 Experimentation Plan Summary			
mission	**vignette / task / overall capability**	**specific capability / experimentation plan**	**scientific objectives**
8. CAN Arctic Sovereignty Patrol	**8. INDICATIONS AND WARNING OF SEA-GOING VESSEL OF INTEREST** **vignette**: HMCS conducting a Canadian Arctic Sovereignty Patrol CF has been asked to provide I&W of a Vessel Of Interest (VOI) should it depart Gascoyne Inlet. VOI is currently at anchor in Gascoyne Inlet. It is expected to leave within next month. There are indications that subject vessel has been conducting illegal fishing in Canadian Arctic waters. Once CF confirms departure, DFO will task PAL flights to conduct 24/7 surveillance for collection of data to support prosecution of VOI for illegal fishing. **task:** support OGD - DFO **capability:** conduct covert surveillance on a VOI (Quest)	**V8-A:** employ a UXV system to provide I&W of a VOI departing Gascoyne Inlet. • deploy barrier of stealth buoys across Entrance/Exit of Gascoyne Inlet. o employ USV catamaran to deploy stealth buoys o stealth buoys o report VOI only (sig in db) o call into DRDC(A), Halifax (RJOC) o conduct internal maintenance check and call in every 5 days. o on day 30 self-scuttle **expt plan**: QUEST is anchored or loitering not far from the mouth of the inlet. QUEST deploys the USV-2600 and transits north to a choke point where it deploys 1 stealth buoy roughly midway between the choke point and 1 sonobuoy 200 m south of the choke point. Various targets (USV-2600, USV-HH, then QUEST) are deployed and run over the location in an attempt to trigger the buoy.	n/a

Annex I NIIRS Measurement System

I.1 NIIRS Ratings for Target Detection and Target Tracking

The aerial imaging community utilizes the National Imagery Interpretability Rating Scale (NIIRS) [11] to define and measure the quality of images and performance of imaging systems. NIIRS is used by imagery analysts to assign a number which indicates the interpretability of a given image. The NIIRS concept provides a means to directly relate the quality of an image to the tasks for which it may be used. NIIRS provides a systematic approach to measuring the quality of digital imagery, the performance of image capture devices, and the effects of image processing algorithms.

A regression-based model relating aerial image quality, NIIRS, to fundamental image attributes has been developed. The General Image-Quality Equation (GIQE) treats: scale, expressed as the ground-sampled distance, GSD; sharpness, measured from the system modulation transfer function, RER; and the signal-to-noise ratio, SNR and relates these to the NIIRS rating. The GIQE will allow the determination of the NIIRS ratings for the detection and the classification functions from this experiment. The equation has the following form:

$$\mathrm{NIIRS} = 10.251\ 2\ a \log_{10} \mathrm{GSD}_{GM} + b \log_{10} \mathrm{RER}_{GM} - (0.656 * H) - (0.344 * G/\mathrm{SNR}) \qquad \text{(I.1)}$$

where the GSD, RER, H, and G/SNR are defined as: the GSD is the geometric mean of the ground sampled distance based on a projection of the pixel pitch to the ground; the RER is the slope of the system's edge response and is derived from the system MTF. Parts of the system MTF include optics, the environmental and boundary-layer MTF's, atmospheric effects, residual motion and detector characteristics. The RER is measured between two points that are 0.5 pixels from the edge. The RER is the slope of the system's edge response. The edge is normalized over the range of 0 to 1. The geometric mean of the X- and Y-axis RER is used. Since MTF compensation (MTFC) is commonly used with EO system post-processing, it is necessary to account for MTFC effects. The MTFC boosts both edges and noise; hence the overshoot and noise gain terms. Noise is modeled in terms of the noise gain derived from the MTFC and the SNR; a measure of contrast is captured in the SNR term. a equals 3.32 and b equals 1.559 if RER > 0.9, and a equals 3.16 and b equals 2.817 if RER < 0.9. RER_{GM} is the geometric mean of the normalized RER, the GSD_{GM} is the geometric-mean GSD (in inches), H_{GM} is the geometric mean-height overshoot caused by edge sharpening, and G is the noise gain resulting from edge sharpening. Details on the edge overshoot H and the gain G and signal to noise SNR can be found in [12]. These terms are small so they were ignored for the approximations in this report.

Based upon the imagery and the detection and classification thresholds available from the experiments, the following results are obtained using the GIQE:

NIIRS for Detection: 6.5
NIIRS for Classification: 7.5

These numbers are for the detection and classification of a human-size target.

I.2 Image Detection

The ground pixel resolution, target contrast against the background, etc. for UAV visual sensors is required to perform detection and classification from imagery for UAVs. This can be predicted using the National Image Interpretability Rating Scale (NIIRS) which is what the aerial imaging community uses. The NIIRS ratings are interpreted as follows: 6.2 detects individual not in a group, 7.7 detects outside mirrors on cars, and 8.2 identifies facial features on an individual. NIIRS ratings between about 6 and 8 are necessary to detect and classify targets.

These image resolution requirements impact the search swath, time and area. Measurements of the modulation transfer function of the Nikon D3X camera with a short focal length lens indicate a swath width of about 300 meters can be generated to meet these NIIRS requirements. A small UAV flying 100 km/hr requires 5 hours to survey a 10 km 10 km area allowing for turns and some swath overlap. Allowing for winds, launch and recovery, a system with a flight time of 10 hours would be required. Doubling the swath width by adding an additional camera would reduce flight time.

Annex J Path Loss in Air for Communications

Measurement Process and Results

Power measurements were taken in the area with an Anritsu spectrum analyzer with a 3 dB gain antenna. The results were compared to a simple prediction model. The difference between the transmitted signal power and the received power is defined as the path loss. The simplest propagation model, applicable in free space, states the path loss is proportional to the inverse square of frequency and to the square of distance. Higher frequencies have greater path loss, and signals attenuate linearly with distance. In realistic environments, however, two other l phenomena affect propagation: diffraction around obstacles and reflection off nearby surfaces. Reflected radio waves can "smear" or even cancel the primary transmitted signal, in a phenomenon called *fading* or *multi-path interference*.

Propagation models have as their central element the *path loss exponent*, which expresses logarithmic path loss as an exponential function of distance. A path loss exponent of 2 describes the free space model. The *plane earth* model for propagation over a surface has a path loss exponent of 4. Numerous empirical studies observe path loss exponents in a variety of environments and combine them in different ways to produce useful propagation models.

Our propagation model assume free space conditions apply very close (~ 1 meter) to the antenna and that propagation beyond follows a single path loss exponent, to be chosen based on experiments. The data gathered indicates that the path loss exponent of 2.3 produces a good fit to the line of sight signal strengths. Fig. 22 compares the measured attenuation to the theoretical prediction. Assuming a receiver minimum sensitivity of -85 dBm with a 0 dB gain antenna, the maximum line of sight range would be about ~4 km. This assumes line of sight can be maintained.

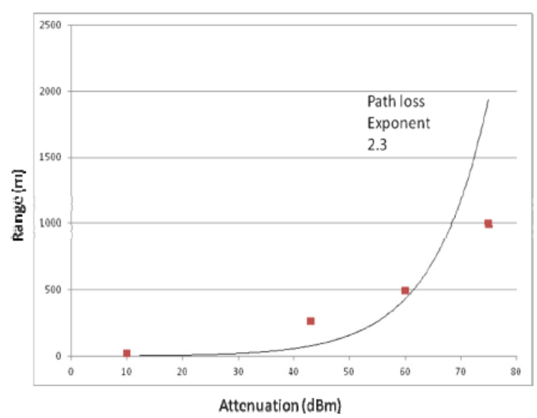

Fig. 22: Signal attenuation versus range.

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List of symbols/abbreviations/acronyms/initialisms

ADS-B	Automatic Dependent Surveillance - Broadcast
AIS	Automatic Identification System
AOI	area of interest
ASW	anti-submarine warfare
ATL	DRDC Atlantic
ATV	all-terrain vehicle
B	beam (as in ships)
BLOS	beyond line of sight
CBSA	Canada Border Services Agency
C2	command and control
C4	command, control, communications, computing
CD&E	concept development and experimentation
CF	Canadian Forces
CFAV	Canadian Forces Auxiliary Vessel
CFJAE	Canadian Forces Joint Arctic Experiment
CFAWC	Canadian Forces Aerospace Warfare Centre
CFMWC	Canadian Forces Maritime Warfare Centre
CFWC	Canadian Forces Warfare Centre
CHS	Canadian Hydrographic Service
COI	Critical Operational Issues
DFO	Department of Fisheries and Oceans
DLCD	Directorate of Land Concepts and Design
DND	Department of National Defence
DRDC	Defence Research & Development Canada
EO	electro-optic
ESM	electronic surveillance measures
GCS	ground control station
HADO	Humanitarian and Disaster Operations
HMCS	Her Majesty's Canadian Ship
H	height

HNeT	human and learning neural algorithm
I&W	indications and warning / intelligence and warning
IR	infrared
ISR	Intelligence Surveillance and Reconnaissance
L	characteristic length (usually longitudinal)
L&R	Launch and recovery
LBL	long baseline localization
LOS	line of sight
MMSI	Marine Mobile Service Identity
MOE	measure of effectiveness
MOP	measure of performance
NIIRS	National Image Interpretability Rating Scale
NGO	non-government organization
NOTAM	Notice to Airmen
NU	Nunuvut
NW	north west
OGD	other government department
OOTW	Officer of the Watch
OTT	DRDC Ottawa
OWTT	one way travel time
PAL	Provincial Airlines
PM	Project Manager
PTZ	pan-tilt-zoom (as in cameras)
PWGSC	Public Works and Government Services Canada
RCN	Royal Canadian Navy
RGB	red green blue
RHIB	rigid hull inflatable boat
RJOC	Regional Joint Operation Centre
ROC	receiver operating curve
SA	situational awareness
SAR	Search and Rescue
SEA	Strategic Experimentation Account

SOP	Standard Operating Procedure
SUF	DRDC Suffield
T	draft (as in ships)
TR	Technical Report
UAV	unmanned aerial vehicle
UAV-FW	UAV fixed wing (Caribou Cam)
UAV-HELO	UAV helicopter (Copterworks AF25B)
UAV-QUAD	UAV quadrotor (Aeryon Scout)
USV	unmanned surface vehicle
USV-HH	USV Hammerhead
UUV	unmanned aerial vehicle
uw	underwater
UXV	unmanned (X could be any combination of A,U, or S) vehicle
VOI	vessel of interest
XBT	expendable bathy thermograph

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Canadian Forces Joint Arctic Experiment 2012 (CFJAE12) was a joint capability development experiment conducted in and around Gascoyne Inlet, Nunavut from Aug 4-23, 2012. It was conducted in accordance with the Canadian Forces Strategic Experimentation Guidance and funded through the Strategic Experimentation Account. CFJAE12 was implemented by DRDC Centres – specifically, Suffield, Ottawa, and Atlantic. The maritime parts were based off CFAV QUEST (Atlantic) and the shore-based aerial parts (Suffield, Ottawa) were based at the DRDC Gascoyne Inlet Remote Camp. CFJAEA12 examined autonomous systems (UXV) such as fixed and rotary wing unmanned aerial vehicles (UAV), unmanned surface vehicles (USV), and unmanned underwater vehicles (UUV) as sensor platforms for future CF operations in harsh and remote environments like the Canadian Arctic. In such environments it can take days for external help to arrive in response to an incident or emergency. The focus of CFJAE12 was on Humanitarian and Disaster Operations (HADO) and Canadian Arctic sovereignty patrol missions. CFJAE12 showed that having UXVs on-board a nearby ship represents a lot of capability to initially respond to the incident or emergency. CFJAE12 demonstrated UXV capabilities towards: confirming northern anchorages and approaches for ships; detection, localization and situational awareness for search and rescue; providing safe passage for RCN ships in uncharted and broken-ice waters; detection and potential tracking of anti-submarine warfare targets; autonomous bathymetric surveys (especially in shallow waters); and support for ship boarding operations. With their inherent force multiplication, persistence, reach, and stealth, the UXVs gathered and transmitted back timely situational awareness to ships and ground personnel to assist with making decisions. Critical operational issues are briefly discussed. The impact of the harsh and rugged environment on UXV operations, implementation logistics for Arctic experimentation, and lessons learned from CFJAE12 are documented. A way-ahead is also provided as guidance for CFJAE14.

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UUV, USV, UAV, UXV, Canadian Arctic operations, CFJAE, Joint Arctic Experimentation, search and rescue, intelligence surveillance and reconnaissance, autonomous systems

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