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Employment of Unmanned Aircraft Systems for Canadian Forces Anti-Submarine Warfare

by

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A Research Report Submitted to the Faculty

In Partial Fulfillment of the Graduation Requirements

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Appendices

Biography

Captain Joseph W. Lisenby, Jr. entered active duty in 1984 after graduating from the University of Alabama. He completed flight training in Pensacola, Florida and Corpus Christi, Texas and was designated a Naval Aviator in June 1986. After initial Fleet Replacement Squadron training in the P-3C *Orion*, he served consecutive flying assignments as an Aircraft Commander, Mission Commander, and Instructor Pilot in Patrol Squadron ONE, NAS Barbers Point, Hawaii; Patrol Squadron THIRTY ONE, NAS Moffett Field, California; BUPERS Sea Duty Component, Dallas, Texas; and Patrol Squadron ONE, Whidbey Island, Washington. He also served as the Assistant Chief of Staff for Operations for Commander, Patrol and Reconnaissance Force Pacific, and as Commanding Officer of Patrol Squadron FORTY SEVEN in Kaneohe Bay, Hawaii. During his command tour, VP-47 deployed to Iraq and Afghanistan flying missions in support of operations *Enduring Freedom* and *Iraqi Freedom*. Additionally, CAPT Lisenby commanded Air Test and Evaluation Squadron ONE from 2008-2010, conducting integrated Operational Test and Evaluation for Navy rotary-wing, large fixed-wing, and unmanned aircraft systems. Captain Lisenby has flown more than 5000 hours in Navy aircraft and holds Masters Degrees from Embry-Riddle Aeronautical University and Naval War College.

Introduction

Fixed-wing Unmanned Aircraft Systems (UAS) technology has experienced exponential growth over the past 10-15 years and is now employed as an intelligence, surveillance, and reconnaissance (ISR) asset by virtually every modern military force in the world, as well as by civil law enforcement agencies. Currently, more than 30 nations are developing or manufacturing more than 250 models of UAS.[1] Substantial commercial market growth and competition in fixed wing UAS platforms for military and law enforcement applications resulted in a wide variety of UAS platforms from small, hand-launched aircraft that operate at low altitudes for short-duration, to large, complex turbo-prop and jet powered aircraft capable of long-endurance operations at medium and high altitudes.[2] Dramatic increases in UAS platform performance and payload capacity in recent medium and high altitude, long-endurance designs permitted customers to add more systems and capabilities to their UAS design requirements. These advances resulted in UAS platform capabilities that meet or exceed legacy manned fixed wing ISR and maritime surveillance platform capabilities.

Employment of Medium-Altitude, Long-Endurance (MALE) and High-Altitude, Long Endurance (HALE) UAS in the anti-submarine warfare (ASW) role is rapidly becoming feasible through emerging technologies and expanded payload capacities, the most significant of which are secure high-bandwidth Beyond Line of Sight (BLOS) satellite datalink communications, miniature light-weight sonobuoys, and real-time shore-based acoustic processing. As a result, UAS may be a technically feasible future Canadian Forces (CF) ASW capability as a complementary or stand-alone alternative to manned fixed-wing and rotary-wing maritime ASW platforms.

UAS Employment in Canadian Forces

Canadian Forces are currently employing the Israel Aerospace Industries fixed-wing MALE *Heron* UAS in Command, Control, Communications, Computers, Intelligence, Surveillance and Reconnaissance (C4ISR) roles both domestically and internationally.[3] According to the Canadian Forces Joint Unmanned Aerial Vehicle Surveillance Target and Acquisition System (JUSTAS) concept of operations, MALE UAS operates domestically in support of defense requirements and other government departments, providing domestic surveillance of Canadian waters and land territory. MALE UAS also supports CF internationally in combat operations, peace support and stabilization missions, maritime interdiction operations, peacekeeping observer operations, humanitarian assistance missions, and personnel evacuation missions.[4] Although the current CF *Heron* is not configured for weapons delivery, a precision strike targeting and weapons delivery capability has been identified as a requirement for future Canadian Forces MALE UAS procurement.[5]

The vast majority of current MALE UAS platforms used by the United States, Canada, Australia, Great Britain, and other western nations, are equipped with color electro-optical and infrared (EO/IR) camera capabilities with Full Motion Video (FMV) datalink and, in some cases, specialized radar, Electronic Surveillance Measures, (ESM) and communication relay capabilities. Most current UAS platforms and tactical capabilities were designed to meet overland ISR requirements, but have also been employed effectively in the open-ocean and littoral maritime surveillance roles by the United States Navy (USN) and others.[6] In order to fully realize an effective ASW capability, UAS platforms will need payload capacity and capability to carry, deploy, monitor, and process ocean acoustic data from air deployed sonobuoys. With the recent invention of miniature light weight sonobuoys, a payload of air deployable sonobuoys adequate for open ocean ASW is now within the payload capacity of several currently available medium and high-altitude, long-endurance UAS.[7] Additionally, the reduced personnel risk realized through elimination of onboard crew manning, and superior range and endurance, makes a UAS ASW platform a practical choice for consideration as a future complementary tactical capability or stand-alone alternative to legacy manned ASW platforms for Canadian Forces.

Legacy Fixed Wing Long Range ASW Capabilities

Canadian Forces currently employ the Lockheed CP-140 *Aurora*, a manned long-range, medium-altitude aircraft, operated by a crew of 10-12 for maritime surveillance, Anti Surface Warfare (ASUW) and ASW. The *Aurora* is a derivative of the USN Lockheed P-3C *Orion*, equipped with similar, but not identical, ASW, ASUW and maritime surveillance capabilities and systems compatibility. *Aurora* airframe performance and range are virtually identical to the Orion.[8] Both the *Aurora* and *Orion* are capable of transiting 1000 nautical miles while carrying a payload of more than 80 “A”-size sonobuoys (5” diameter x 36 inches long), loitering at low altitude for four hours while deploying and monitoring the sonobuoy payload, and transiting 1000 nautical miles back to base with a 1.5 hour fuel reserve remaining.[9] The *Aurora* and *Orion* acoustic processors are capable of monitoring over 30 passive sonobuoys continuously and over 60 passive sonobuoys non-continuously. *Aurora* and *Orion* are both equipped with radars designed and tailored to maritime surface surveillance, ASUW, and ASW. Some aircraft are equipped with Inverse Synthetic Aperture Radar (ISAR) and/or Synthetic Aperture Radar (SAR). Both *Aurora* and *Orion* are also equipped with an ESM suite capable of detecting and classifying surface, subsurface and shore based electronic emitters, an Electro-Optical/Forward Looking Infrared (EO/FLIR) camera suite, and magnetic anomaly detection (MAD) systems.[10]

Next Generation ASW and C4ISR Capabilities

The United States Navy has procured the Boeing P-8A *Poseidon*, a derivative of the Boeing 737-800, as the next generation manned ASW and maritime surveillance platform to replace the aging P-3C Orion beginning in 2013. *Poseidon* is equipped with state of the art avionics and sensor suites that include SAR/ISAR radar with overland and maritime capability, color electro-optical/FLIR camera suite, an ESM suite, advanced acoustic processors with color displays, and both Line-of-Sight (LOS) and BLOS satellite communications and datalink capabilities. The acoustic and non-acoustic capabilities of the *Poseidon* surpass those of the *Aurora* and *Orion* in every category except magnetic anomaly detection (MAD). The *Poseidon* is not equipped with a MAD system. *Poseidon* is designed to be fully integrated and electronically compatible with the Navy's Broad Area Maritime Surviellance (BAMS) medium and high-altitude UAS, including a future Pre-Planned Product Improvement (P3I) program that will enable *Poseidon* tactical control and employment of BAMS sensors in flight for coordinated C4ISR operations.[11]

The U. S. Navy procured the Northup-Grumman RQ-4N BAMS UAS, a derivative of the RQ-4D *Global Hawk* (Navy Variant). BAMS UAS is currently undergoing developmental testing for a planned 2014 fleet introduction. Designed to perform long-duration independent and coordinated C4ISR operations in both the overland and maritime operating environments, BAMS will have an endurance of over 28 hours and a ferry range of more than 10,000 nautical miles.[12] The BAMS sensor suite consists of a multi-function electronically steered array radar with maritime and ground modes, a multi-spectral targeting system, a high resolution EO/FLIR system with target tracking and Full Motion Video (FMV), an ESM system with Specific Emitter Identification (SEI) and an Automatic Identification System (AIS) for identification of maritime vessels.[13]

Current and Future ASW Threats

"Undersea warfare remains a tough business where the only acceptable position is one of absolute operational primacy . . .against a full spectrum submarine threat which is increasingly diverse and technologically sophisticated"

ADM Jay Johnson, USN, CNO 1997[14]

The fall of the Soviet Union and subsequent decline of Russia's Navy significantly reduced the world-wide blue water nuclear submarine threat that existed during the Cold War. The list of nuclear powered submarine operators in the world today is mercifully short and the threat from these boats has not proliferated to the same degree as diesel-electric submarines. Other than the United States and a limited number of NATO allies, only Russia and China continue to produce nuclear powered submarines.[15] Modern nuclear powered submarines are quiet, making them hard to detect and track via acoustic detection means. Additionally, nuclear submarines have the ability to travel submerged for thousands of miles at high speeds without the need to come to the surface or stop for refueling. This freedom of movement, combined with the ability to remain submerged and undetected for long periods, allows countries who operate nuclear submarines to threaten surface ships and other submarines in virtually any accessible and navigable body of water world-wide.[16]

The proliferation of diesel-electric submarines continues to pose a significant threat to the security of sea lanes in the littorals and freedom of navigation in Sea Lines of Communication (SLOC) in blue water oceans. Diesel-electric submarines can have the same lethal effect on surface ships as nuclear powered submarines--when operated on battery power alone at low speeds they can be more difficult to track and attack than nuclear submarines. This is especially true of ASW in littoral environments, commonly acknowledged by naval tacticians as the most difficult environment for acoustic ASW. Russia, China, Germany, France and Spain are the primary producers of new construction diesel-electric submarines, but many diesel submarines are operated by minor powers. Since 1980, Germany alone has exported more than 50 diesel-electric submarines to more than 10 countries worldwide.[17] Some of these minor naval powers are very proficient submarine tacticians and operators posing a tactical threat to opposing naval forces, particularly when operating in familiar bodies of water. One of the most graphic modern examples of the diesel-electric submarine threat was the complete failure of the British Royal Navy to detect, localize and successfully attack the single Argentine submarine during the Falkland Islands Conflict of 1982.[18]

Blending Legacy and Next Generation ASW Tactical Solutions via Datalink

The CF *Aurora* is equipped with Link 11, a secure half-duplex Tactical Digital Information Link (TADIL) radio datalink used by NATO and Pacific Rim allies that receives or transmits, but not both simultaneously, a sequential data exchange digital link.[19] Link 11 exchanges digital information among airborne, land-based, and ship-board tactical data systems, and it is the primary means to exchange data such as sensor tracking and contact information BLOS. Link 11 can be transmitted on either high frequency (HF) for BLOS communications, or ultrahigh frequency (UHF) for LOS communications. Although Link 11 is still in use, its capabilities have been surpassed by more capable datalink architectures. Modern current generation and next generation tactical communication systems utilize more capable and flexible datalink systems such as Link 16.[20] Link 16 is a Time Division Multiple Access (TDMA) based secure, jam-resistant high-speed digital data link which operates in the UHF spectrum. This frequency range limits the exchange of information to users within LOS of one another, or may be used to transmit BLOS via satellite utilizing long-haul protocols such as Transmission Control Protocol and Internet Protocol (TCP/IP). Link 16 is the design standard for current modern and next generation NATO and Pacific Rim allied airborne platforms. Although some NATO ships and ground stations have the capability to share tactical datalink information between Link 11 and Link 16, the two systems are not directly compatible.[21]

The BAMS communication suite represents state of the art LOS and BLOS capabilities for medium and high altitude UAS. For the purposes of this research, BAMS/*Global Hawk* represents a known and proven capability that could be leveraged for use in a CF ASW-capable UAS. The BAMS communications suite uses wideband satellite communications in the Ka/X bands (50 Mbps) and narrow-band satellite communication via Integrated Marine/Maritime Satellite (INMARSAT) /Demand Assigned Multiple Access (DAMA), Common Data Link (CDL) 2 channel, full duplex X/Ku bands (45Mbps), and Link 16.[22]

Lack of datalink communication between Link 11 and Link 16 prevents a next generation Link 16 capable ASW UAS from sharing direct line of sight tactical datalink information with *Aurora's* legacy Link 11 system. Although not technically insurmountable, it would likely require the *Aurora* Link 11 and ASW UAS Link 16 tactical information to be transmitted from the originating unit via BLOS means to a Canadian Forces shore-based tactical mission support facility. The information is then electronically combined and retransmitted in a near real-time blended tactical solution back to the *Aurora* and ASW UAS via Link 11 and Link 16, respectively—a current solution in select NATO ship and shore installations. A complete compatibility solution could be achieved by converting legacy *Aurora* aircraft to Link 16, a solution that has already been fielded and proven in select USN *Orion* aircraft.[23]

Miniature Sonobuoy Technology

Emerging miniature sonobuoy technologies (USN designation MJU-10) with significantly less size and weight than current Canadian Forces/USN size "A" Directional Frequency Analysis and Recording (DIFAR) sonobuoys may permit UAS designers to modify current medium and high altitude long-endurance UAS designs to carry avionics and sonobuoy payloads capable of conducting ASW missions. MJU-10 sonobuoys are currently under vendor development and testing as part of USN led Small Business Innovative Research (SBIR) projects. The MJU-10 sonobuoy external dimensions and weights are contained in Appendix D. MJU-10 design represents a substantial reduction in size and weight when compared to current size "A" sonobuoys which have external dimensions of 5 inches in diameter x 36 inches long, and individual buoy weights that vary from 20-39 lbs depending on model.[24]

Like current size "A" DIFAR sonobuoys, MJU-10 DIFAR sonobuoys provide a magnetic bearing to the acoustic signal of interest and can be used for search, detection, and classification of submarine targets. Using the magnetic bearing capability, it is possible to fix the location of a submarine contact with as few as two sonobuoys. DIFAR sonobuoys are the buoys of choice for acoustic ASW search and localization because they utilize a hydrophone with directional detection capabilities, as well as an omnidirectional hydrophone for 360-degree acoustic monitoring.[25] The MJU-10 DIFAR sonobuoys are designed to float and self activate on contact with sea water and deploy the hydrophone package to a preselected depth of up to 400 feet. The ASW capable fixed-wing, rotary-wing, or UAS platform receives the sonobuoy signals for recording, processing, and analysis.[26]

Although MJU-10 sonobuoys are still under development, preliminary testing indicates that they will have similar frequency response and directional capabilities as size "A" DIFAR sonobuoys. Sonobuoy battery life estimates for the MJU-10 are between 2.0 hours to 5.0 hours while transmitting a continuous .25 watt Very High Frequency (VHF) telemetry signal. MJU-10 sonobuoys can be designed to transmit either a digital or analog VHF telemetry signal and will have the capability to select three preset hydrophone sensor depths between 90-400 feet.[27]

Do Current UAS Platforms Have Payload Capacity and Range to Perform ASW?

As previously discussed CF *Aurora,* USN *Orion,* and *Poseidon* are all capable of transiting 1000 nautical miles while carrying a payload of over 80 air launched sonobuoys, loitering at low altitude for four hours while deploying and monitoring the sonobuoy payload, and transiting 1000 nautical miles back to base with 1.5 hours fuel reserve remaining.[28] These distances and loiter times are representative of the current standard for NATO allied manned fixed-wing, long-range ASW aircraft, and they are also achievable goals for a currently produced medium and high altitude ISR UAS. Using two UAS platforms currently in production for comparison, the range and payload data for BAMS and *Predator B* is presented in Appendix B.

ISR versus ASW Flight Profiles

When attempting to make direct operational range and payload capacity comparisons between proposed ASW-capable UAS and current production medium and high-altitude ISR UAS, it is essential to consider that the operating altitudes and maneuvers required for ASW are different than those required for ISR. Therefore, manufacturer's estimates for UAS range and payload may not be applied in a linear relationship when the aircraft is employed in the ASW role. The data published by UAS manufacturers assumes optimum cruise altitudes for transit to and from the operating area. The two UAS platforms listed in Appendix B cruise between 30,000 feet and 60,000 feet above Mean Sea Level (MSL) depending on aircraft gross weight and current outside air temperature.[29] Both UAS examples listed in Appendix B are turbine powered: BAMS is powered by a turbofan engine and *Predator B* is powered by a turbo-prop engine. Turbine powered aircraft are less efficient when operated at low altitudes (below 10,000 feet) rather than at higher altitudes, (30,000-60,000 feet MSL) resulting in increased fuel consumption at lower altitudes.[30]

As noted in Appendix C, fuel flow data collected by a USN test pilot flying a notional ASW flight profile in the BAMS simulator using initial on-station loiter altitudes between 500-1500 AGL resulted in on-station fuel flow 2.47 times greater than typical BAMS ISR profile loiter fuel flow at FL570. When loiter altitude was increased to 10,000 MSL, fuel flow was 1.91 times greater than FL570 loiter fuel flow.[31] Accordingly, UAS operators can expect a substantial decrease in available on-station loiter time when employing turbine powered UAS platforms in ASW flight profiles. Additionally, increased maneuvering at low altitudes to facilitate accurate deployment of sonobuoys for ASW search and tracking will also result in increased fuel flow.[32] However, both BAMS and *Predator B* have range performance (operational radius) and on-station loiter endurance margins that substantially exceed the range and loiter capabilities of current and future manned fixed-wing ASW platforms: *Aurora*, *Orion*, and *Poseidon*.[33]

Sonobuoy Payload Capacity and Loiter Endurance

Any ASW UAS platform will need payload capacity and systems capability to carry and deploy a payload of MJU-10 air launched miniature sonobuoys for acoustic search, identification, and localization of submerged submarine targets. Preliminary MJU-10 acoustic detection and performance data indicates sonobuoy acoustic sensor performance similar, but not identical, to legacy size "A" SSQ-53 DIFAR sonobuoys. However, MJU-10 battery performance is limited to approximately two to five hours, which is inferior to size "A" DIFAR sonobuoys with selectable battery life that can be preset from 1 to 8 hours.[34] Considering the long range ASW mission example of 1000 nm transit to operating area, with a four hour loiter for ASW search, the number of MJU-10 buoys required to conduct the search is up to twice that of the legacy manned platforms using size “A” DIFAR sonobuoys. Accordingly, assuming a worst case two hour battery life for the MJU-10, a 30 buoy search pattern would need to be deployed, monitored and recorded for two hours, and reseeded by deploying 30 more buoys in the same search pattern, to accomplish the requisite four hours of continuous pattern monitoring and recording of subsurface ocean acoustic data. MJU-10 sonobuoys weigh a maximum of 3.5 lbs. each, therefore a sixty buoy payload could weigh up to 210 lbs, not including the additional weight required for a sonobuoy carriage and launching system.[35] Comparing the internal and external payload capabilities of both BAMS and *Predator B* listed in Appendix B, it appears that both BAMS and *Predator* would be capable of carrying the requisite load of sonobuoys to accomplish a four hour ASW search approximately equal in size to a legacy *Aurora* or *Orion* search area. However, this does not take into account the weight of the ASW avionics package required to conduct the ASW mission.[36]

Balancing Future CF ASW Requirements and Fiscal Realities

Operational requirements and fiscal constraints join together to inform and shape defense acquisition processes that ultimately determine future weapon system capabilities. According to the Department of Defense Unmanned Systems Roadmap 2005-2030, aircraft empty weight is a commonly utilized cost metric in the defense aviation industry because it remains relatively constant across a variety of aircraft types. In 2010 dollars the price is approximately $1,600 per pound of empty weight and $8,500 per pound of payload capacity.[37] As UAS BLOS technology has advanced and platforms have grown in size and payload capacity, substantial increases in range, endurance, and weapon system capabilities have resulted. As noted previously, both

BAMS and *Predator B* have the payload, range, and endurance capabilities that would allow them to be adapted and reengineered to carry and deploy sonobuoys and requisite avionics to perform the ASW mission role. However, CF will need to carefully prioritize requirements against fiscal constraints to determine which UAS capabilities and vendors are capable of best meeting their future ASW needs.

CF legacy *Aurora* and *Heron* platforms share many of the ISR mission capabilities of both *Global Hawk*/BAMS and *Predator B*, and those capabilities are generally complimentary to both ASW and SUW mission sets. Incorporating additional ASW avionics and sonobuoy deployment capabilities will add additional weight to any ISR focused UAS unless compromises are made in the airframe and/or mission systems to limit weight. As noted by a U.S. Navy test pilot currently assigned to BAMS developmental testing, "Even on a UAS platform as large as the *Global Hawk*/BAMS, every pound of additional weight has a calculable negative impact on mission range and endurance."[38] Accordingly, any UAS ASW solution will be a compromise between cost and capability.

To Weaponize or Not to Weaponize…That is the Question

As stated by RDML David Dunaway in his 2008 presentation on Navy war-fighter capability gaps in kill chain, "The ASW kill chain is composed of five basic links: 1. Detect, 2. Identify and Track, 3. Decide to Attack, 4. Attack/Launch Weapon, 5. Post-Attack Battle Damage Assessment (BDA)."[39] Accordingly, effective ASW weapons systems can be either lethal or nonlethal as long as they have the capability to integrate with other lethal ASW platforms to complete the kill chain when required. A CF ASW UAS could be designed and configured to perform some or all of the five basic links of the ASW kill chain, including attack/launch weapons, or could be employed in coordination with other CF airborne ASW weapons delivery platforms such as CP-140 *Aurora* or *CH-124 Sea King* helicopter. Alternatively, an ASW UAS could be configured solely as a flexible long-endurance ASW weapons delivery platform designed to be used in combination with other ASW sensors to complete only the critical attack/launch weapon link in the ASW kill chain.

Of the two UAS platforms listed in Appendix B, only *Predator B* currently has the capability to carry and employ weapons. *Predator B* is equipped with wing hard points for external carriage of weapons and is capable of launching both air to ground missiles and bombs.[40] CF employ the NATO standard MK-46 light weight torpedo as the air launched ASW weapon for *Aurora* and *Sea King*.[41] The MK-46 weighs 558 pounds, well within the external and internal payload capacities of both *Predator B* and BAMS, however externally loaded weapons induce additional aerodynamic drag that adversely affects aircraft range and endurance.[42] Installing an internal fuselage weapons bay can eliminate the drag penalty of externally loaded weapons, but requires tradeoffs in both additional airframe structure and reduced payload volume for mission systems. As discussed previously with regard to UAS sonobuoy carriage, adding additional capabilities to ISR mission based UAS platforms like *Predator B* and BAMS will require performance and weight tradeoffs in the airframe and compromises in mission systems to gain the capability and capacity to carry and deliver ASW weapons.[43]

Recommendations

Should Canadian Forces be the first medium/long range ASW capable UAS customer? Given the CF near-term need for a future UAS capability as a follow-on platform to *Heron* and the long-term need for a maritime capability to complement or replace the rapidly aging fleet of CP-140 *Auroras*, a sophisticated MALE or HALE UAS appears to be a very attractive option.

Combat proven UAS technologies such as the basic ISR capable *Predator B* and *Global Hawk*/BAMS airframes, ISR avionics, LOS/BLOS C4I connectivity, and shore-based Link 11/Link 16 data fusion have relatively low developmental risks for CF application. However, there are no easy or cheap solutions for full spectrum UAS ASW capability. Although this research suggests that UAS are technically feasible as future CF ASW capabilities either as complementary or stand-alone alternatives to manned ASW platforms, the engineering challenges required to adapt *Predator B* and *Global Hawk*/BAMS involve significant technical challenges.

Most significantly, miniature sonobuoy technology is still in the early developmental process and remains largely unproven. Additionally, development of first generation UAS sonobuoy deployment systems, shore-based acoustic processing, and ASW weapons delivery capabilities that would enable UAS platforms to act as stand-alone weapons systems will involve significant developmental engineering and fiscal risks.[44] These first of a kind UAS ASW capabilities involve complex acquisition issues that will require years of engineering design and development, as well as hundreds of flight hours of dedicated developmental and operational testing to perfect them for fleet operational use.[45] Accordingly, any CF effort to adapt a UAS platform for ASW will require a well organized and prioritized programmatic developmental approach with clearly delineated operational requirements and fiscal constraints.

Conclusion

While a full spectrum ASW capable UAS is technically feasible, the developmental and fiscal risks involved in fielding the capability remain high. The best compromise between operational UAS capabilities and ASW developmental risks for CF is a phased acquisition of MALE/HALE UAS capability that leverages proven ISR capabilities and adds C4I tactical datalink plot fusion to enable seamless tactical coordination with legacy CF and NATO ASW/SUW platforms. As pointed out in USN ASW doctrine, continuous awareness of a common tactical picture is essential in integrating and exploiting the capabilities of multiple allied air, surface and subsurface ASW weapons systems. Accordingly, the ability to blend legacy Link 11 tactical data with UAS Link 16 data is critical to exploiting the full potential of multi-platform CF ASW capability.[46] Secondly, CF should partner with USN and other NATO allies to continuously monitor and assess the capabilities and developmental maturity of MJU-10 or similar miniature sonobuoy technology for future use on CF ASW UAS. Finally, CF should replace *Heron* with a sophisticated MALE/HALE UAS with precision air to ground/surface weapons for use in the maritime SUW role in an effort to preserve the legacy *Aurora* fleet until a full-spectrum air ASW capability can be developed for CF UAS.

List of Acronyms and Abbreviations

“A” Sonobuoy	NATO standard dimensions (5 inches in diameter x 36 inches long)
AIS	Automatic Identification System
ASUW	Anti-Surface Warfare
ASW	Anti-Submarine Warfare
BAMS	Broad Area Maritime Surveillance
BDA	Battle Damage Assessment
BLOS	Beyond Line of Sight
CF	Canadian Forces
C4I or C^{4}I	Command, Control, Communications, Computers, Intelligence
C4ISR	Command, Control, Communications, Computers, Intelligence, Surveillance and Reconnaissance
DAMA	Demand Assigned Multiple Access
DIFAR	Directional Frequency Analysis and Recording
EO/IR	Electro-Optical/Infrared
EO/ FLIR	Electro-Optical/Forward Looking Infrared
ESM	Electronic Surveillance Measures
FMV	Full Motion Video (datalink)
HALE	High-Altitude, Long Endurance
HF	High Frequency
INMARSAT	Integrated Marine Maritime Satellite
ISR	Intelligence, Surveillance, and Reconnaissance
ISAR	Inverse Synthetic Aperture Radar
LOS	Line of Sight
MAD	Magnetic Anomaly Detection
MALE	Medium-Altitude, Long Endurance
MJU-10	USN designation for light-weight miniature sonobuoy
MSL	Mean Sea Level
NATO	North Atlantic Treaty Organization

P3I or P^{3}I	Pre-Planned Product Improvement

List of Acronyms and Abbreviations Continued

SAR	Synthetic Aperture Radar
SBIR	Small Business Innovative Research
SEI	Specific Emitter Identification
SLOC	Sea Lines of Communication
TADIL	Tactical Digital Information Link
TCP/IP	Transmission Control Protocol/Internet Protocol
TDMA	Time Division Multiple Access
UAS	Unmanned Aircraft Systems
UHF	Ultra High Frequency
USN	United States Navy
VHF	Very High Frequency

Comparison of BAMS and Predator B Range, Payload, GW and Cruise

	Operational Radius	External Payload	Internal Payload	Gross Weight	Cruise Speed
RQ-4N BAMS	3000 NM with 4+ HR Loiter	2400 lbs	3200 lbs	32,250 lbs	345 KTAS
MQ-9A Predator B	2000 NM with 4+ HR Loiter	3000 lbs	850 lbs	10,500 lbs	240 KTAS

Appendix B

BAMS SIMULATOR ASW PROFILE DATA TAKEN
FROM VX-20 SIMULATOR FLIGHT

	T/O CLIMB FL570	TRANSIT FL570	DESCENT 500FT AGL	500-1500FT AGL 1.5 HRS	10,000FT AGL 3 HRS	CLIMB FL570	TRANSIT FL570	DESCENT AIRFIELD
Time in route/On Station	0:50	3:00	0:40	1:30	3:00	0:40	3:00	0:40
Fuel Flow per hour	N/A	445	360	1100	850	N/A	413	360
Fuel Burned	1,500 lbs	1,335 lbs	200	1,650 lbs	2,550 lbs	1,115 lbs	1,240 lbs	200
Airspeed	N/A	345 GS/ 118 KCAS	N/A	145 GS	170 GS	N/A	344 GS/ 118 KCAS	N/A
Min airspeed	N/A	N/A	N/A	145 GS	160 GS	N/A	N/A	N/A
Max AOB	20	15	20	20	20	20	15	20

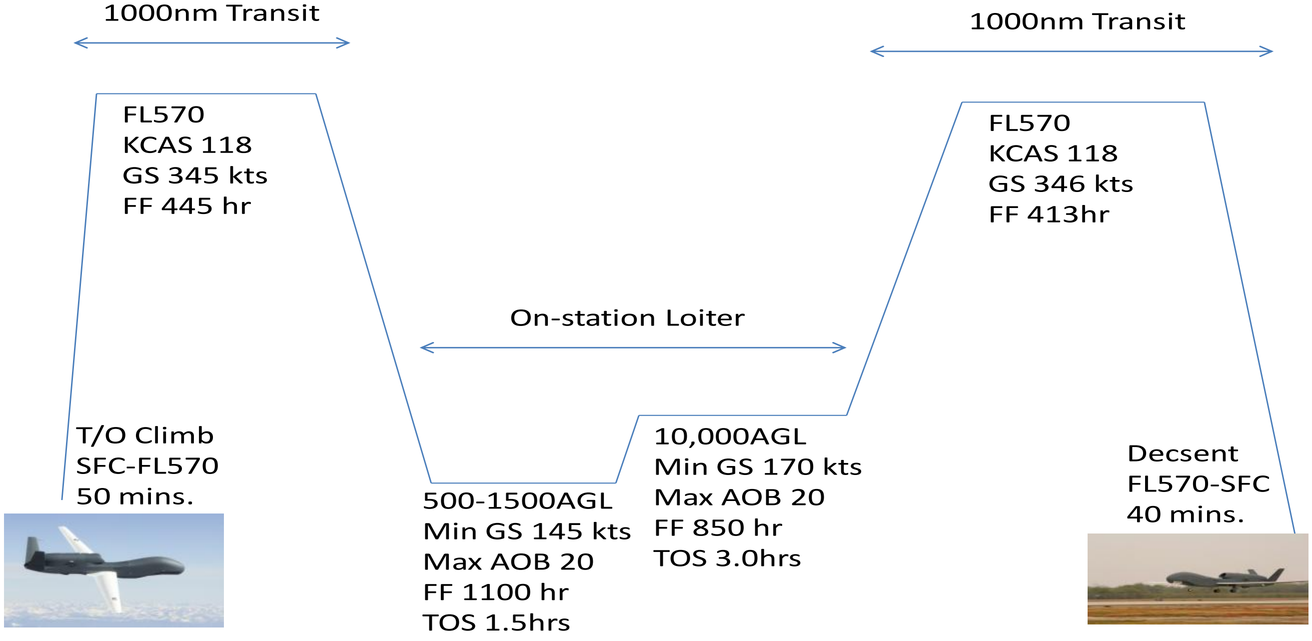
Total time of mission = 13:20

Note: All calculations were done with zero wind. Could not simulate extra wt/drag of sonobouys.

Total fuel burned = 9,790 lbs
Max fuel capacity = 15,400 lbs

Data collected by LCDR K. S. Matthew, VX-20 BAMS Test Pilot, NAS Patuxent River, MD

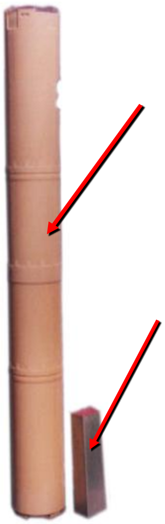
BAMS Simulator ASW Flight Profile Demonstrated by VX-20



MJU-10 Size Reduced Form Factor Sonobuoys

Technical Objective:

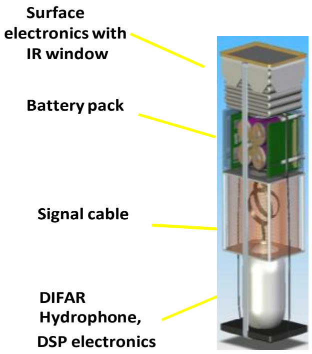
- Phase 1 - A directional sonobuoy capable of DIFAR performance in the MJU-10 form factor. A 20 to 1 reduction in size as compared to standard “A” sonobuoys
- Phase 2 - Prototype a directional sonobuoy capable of DIFAR performance in the MJU-10 form factor.



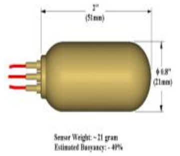
Standard
A-size pkg
5” dia. X
36” long

MJU-10 size pkg

2”x2.5”x8”



MJU-10 size



Miniature single crystal directional hydrophone

MJU-10 Vendor Technical Comparison

NAVMAR	SeaLandAire
Capabilities:	**Capabilities:**
• Frequency response covers EER, SQS-53C, ALFS, DICASS	• Frequency response covers Passive, EER, IEER
• Selectable frequency band	• Selectable frequency band
• RF Channels – 1 to 99	• RF Channel – single
• Maximum depth ~ 400 ft, single depth	• Maximum Depth – 400 ft, 3 depths
• Life ~ 2 hrs	• Life ~ 5 hrs
• 2.5 x 2 x 8 inch package; 2 – 3 lbs	• 2.5 x 2 x 8 inch package; 2 – 3 lbs
• Low sensor self noise 200 Hz to 13kHz	• Low sensor self noise 5 Hz to 2.4kHz
• Digital telemetry	• Analog telemetry

Appendix D

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