Integration of a Miniature Synthetic Aperture Radar (MicroSAR) on the Aerosonde UAV

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***Abstract*—Project RAVEN is a research project at Memorial University of Newfoundland, whose aim is to establish an Uninhabited Aerial Vehicle (UAV) presence off the Eastern coast of Canada in support of maritime surveillance operations conducted by manned aircraft. Until recently, the use of radar on the small low altitude long endurance (LALE) class of UAV being considered for this role was thought impossible due to restrictive payload size and weight limits. However, RAVEN has acquired the use of a small Synthetic Aperture Radar (MicroSAR) that will be integrated onto the Aerosonde UAV, through a cooperative research project with Brigham Young University (BYU) in Utah, and the University of Colorado at Boulder. The intent is to use the MicroSAR system on an Aerosonde to take high-resolution imagery of sea ice off the Newfoundland Coast in 2007. The end application for such technology includes monitoring of sea ice changes in the Arctic, support for the Iceberg Patrol in the North Atlantic, and target detection and characterization. This paper presents the work done to date to integrate the MicroSAR onto the Aerosonde UAV in preparation for this mission and initial test results.**

***Index Terms* — Aerosonde, Ice Patrol, MicroSAR, Maritime Surveillance, Project RAVEN, Synthetic Aperture Radar.**

I. Introduction

THE MicroSAR system was developed at the Brigham Young University (BYU) Microwave Earth Remote Sensing Laboratory, with the specific intent to image sea ice using a small UAV flying at low-level [1]. Table I gives a summary of the characteristics of this miniature Synthetic Aperture Radar (SAR) system. A full description of the details of this system is provided in reference [2]. The current paper will deal primarily with the physical integration of the system on the Aerosonde UAV.

The MicroSAR system is shown in Fig. 1. The System consists of an electronics package (RF module), two patch antenna arrays, and a set of cables, which may be extended up to 1.82m (6 ft) in length to allow flexibility in positioning the antenna arrays. Including cables and antennas, the mass of the system is less than 2 kg. The RF module consists of a stack of circuit boards, which includes an integral A/D data collection board (topmost board as shown in Fig. 1). Lower boards control power levels, transmit and receive antennas and the overall operation of the SAR. A set of 4 DIP switches located on the digital synthesizer board is used to select the appropriate PRF to use for the planned flight altitude and speed of the UAV.

TABLE I
SUMMARY OF MICROSAR SYSTEM [2]

Frequency: 5.56 GHz
Bandwidth: 80 MHz.
Signal Type: Linear frequency modulated continuous wave (LFM-CW)
Oscillator Type: 100 MHz stable local oscillator (STALO)
PRF: 128 to 2880 Hz (selectable through DIP setting)
Transmit Power: 28 dBmW (total less then 1W)
Power Supply: 18 VDC (1.1A steady state, 1.5A peak)
Power Consumption: Approximately 18W
Beam Pattern:
Azimuth 3dB beam width: 8.8 deg Elevation 3dB beam width: 50 deg
Maximum resolution:
Azimuth: 0.15m x Range: 1.85m
Maximum swath size (at 344m altitude): 1024m
Data Recording Rate: 0.67 MB/sec to pair of 1 GB CompactFlash cards (1 GB = 25 minutes of data)
Physical Characteristics: RF electronics module: 127mm cube envelope, mass 900g Antennas: 2 patch antenna arrays, each 127 x 330 mm, 150 to 175g. Full System, including cables: less then 2 kg

When power is supplied to the system, the MicroSAR conducts a 24 sec boot/self-check sequence then proceeds to collect data. Raw SAR image data is recorded on one of the pair of CompactFlash cards at a rate of 0.67 MB/sec. Each 1 GB CompactFlash card holds up to 25 minutes of data, for a total recording time of approximately 50 minutes. When one card is full, recording automatically switches to the other card. Once this card is filled, the system reverts back to the start of the first card and begins overwriting previous data. Data recording terminates when power is turned off. For practical use on the Aerosonde, a means of remotely controlling the MicroSAR power supply is necessary. On the Mk4 Aerosonde a conditioned 18 VDC bus supply is available which may be controlled through the built-in avionics [3].

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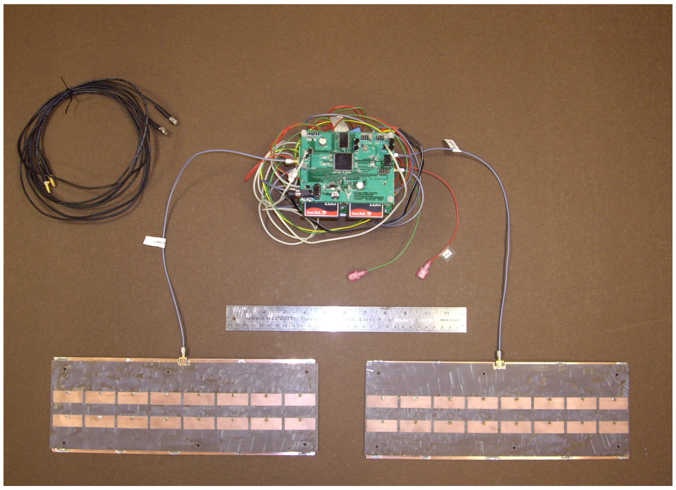


Fig. 1. MicroSAR System with 6' extension cables (upper left). Note 12" steel rule for size reference.

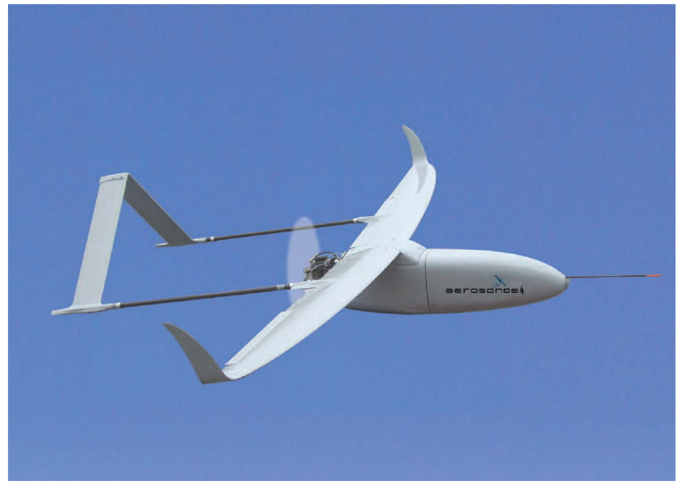


Fig. 3. Aerosonde Mk4.2 UAV

II. INTEGRATION ON AEROSONDE

A. *Aerosonde UAV*

The MicroSAR was designed for use on the Aerosonde UAV. This is a low altitude long endurance (LALE) UAV with a proven track record for exceptional endurance and operability in harsh environments including over 1000 flight hours in the Arctic during missions operated from Barrow, Alaska [1]. Fig. 2 shows the Aerosonde UAV used during the Alaska tests in 2004, and provides a sense of the scale of this UAV. An Mk4 Aerosonde (similar to that shown in Fig. 3) will be used during the ice surveys planned for March 2007. A summary of the specifications and performance of this UAV is provided in Table II [4].

Fig. 2. Aerosonde UAV following completion of a mission over the Beaufort Sea in 2004 [1].

TABLE II
Specifications of the Aerosonde Mk4.1 UAV[4]

Specification	
Weight	13 – 15 kg
Max Take-off Weight	33 lb
Wing span	2.9 m
Engine	24 cc, Avgas, 1kw, Single Cylinder, Fuel Injected, Premium Unleaded Gas
Fuel Consumption	180g/hr level flight
Min/Max Fuel Weight	2.2 / 12.1 lb 0.33 /1.8 Gal
Navigation	GPS/DGPS
Communication Range via UHF	200 km depending on height and terrain
On board power generation	40 Watts continuous, 75 Watts peak. 18V DC
Payload Computer	Supports Serial, Interface Input
Main Payload Bay Area (can be adapted)	100mm Length, 120mm Width, 180mm Depth
Performance	
Speed, Climb	18 – 32 ms^{-1}, Climb > 2.5 ms^{-1} (49 to 62 Knots)
Endurance, Range	~ 30 Hrs (All Fuel Payload)
	~ 5 Hrs (Max Payload, Min Fuel)
Max Range	~ 2000 NM (All Fuel Payload) ~ 300 NM (Max Payload, Min Fuel)
Altitude Range	100 m to > 6000 m
Payload Maximum	5 kg (gives approx 10-hour flight)
Mk 3 Variant	Up to 8.8 lb
Mk 4.1 Variant	Up to 12.1 lb
Landing & take off distance	Less than 300 m
Take off speed	Average 90 km/hr
Launch	Vehicle Roof Rack & Catapult
Recovery	Skid
Temperature	+110°F to -30°F
Operation	
Staff for Launch and Recovery	3 ~ Controller, Engineer, Pilot/Maintenance
Staff for Flight Command	1 Person for several aircraft
Ground Equipment	Proprietary Staging Box, 2 PC's, GPS
Flight	Fully autonomous, or under Base Command.
Communications	UHF or Satellite (Iridium)

Initial integration efforts will use the first Aerosonde UAV vehicle available to the project, an Aerosonde R/C Trainer. This is an Mk2 with the GPS-based autopilot and avionics removed, and replaced by standard line of sight radio control (R/C) aircraft equipment. Once the airworthiness of our configuration is confirmed via flight test in November, we plan to fit the MicroSAR on the Mk4. Note that the remotely operated payload power supply available on the Mk4 is not present on the Trainer. Instead, a spare channel of the R/C control will be used to control the function of a small relay board to provide remotely switched power.

B. *Installation of Electronics Module*

Including room for wiring, cables and mechanical supports, the RF module fits in a 127 mm (5 in) cubic volume. Integration into the Aerosonde will be fairly straightforward, as the RF module was designed to fit within the payload bay of the Aerosonde. Fig.4 shows the payload bay room available on the trainer versus the situation on the Mk4. The RF module will be placed inside the payload compartment and high density (non-conductive) foam will be used to protect the module plus hold it firmly in place during flight. On the Trainer, the 18 VDC power for the RF Module will be controlled using a custom power control board, which will take its control signal from a spare channel of the R/C receiver, a Futaba 9 channel synthesized receiver (model R319DPS). On the Mk4, there will be no need for this power control board.

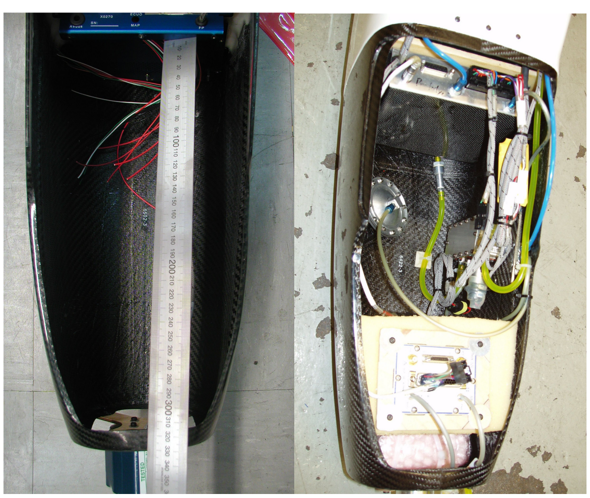
C. *Installation of Antenna Arrays*

The integration of the antenna arrays has been the most challenging aspect of this project. Each antenna array is approximately 127 x 330 mm (5 x 13 inches), with the pair installed in tandem along the long axis. The pair must be spaced in Azimuth, the ideal spacing being between a wavelength and ½ of one antenna length. A compromise distance of 75mm (~3 in) has worked well. Thus, the minimum installed area required is a flat rectangular area at least 127 x 736 mm (5 x 29 inches) positioned down the side of the aircraft. Due to range/swath geometry and assuming typical flight altitudes of 300 m, the ideal normal pointing angle of the array is 45 degrees down from horizontal.

The original concept of mounting the antennas on a support structure built on the side of the Aerosonde fuselage was abandoned, primarily due to lack of sufficient longitudinal area, and concerns about interference with the Aerosonde launch mechanism which clamps onto the fuselage. An alternative arrangement was developed to attach the antennas to one of the tail booms. The antennas were installed inside a custom-build planar radome. This was essential to provide both mechanical support and weather protection.

The radome was of simple design, as shown in Fig. 5. Main shape and structure was provided by 1 inch thick high density pink Styrofoam insulation. This was attached to a ¼ inch plywood back plate using standard construction adhesive. The edges of the Styrofoam were carved and sanded into a rounded shape to reduce drag. The antennas were nestled within the

Fig. 5. MicroSAR Antenna Radome with covered "dummy" version above.



(a) (b)

Fig. 4. Payload Bay available on (a) Trainer, and (b) Mk4 Aerosonde (photos courtesy of Aerosonde AAI)

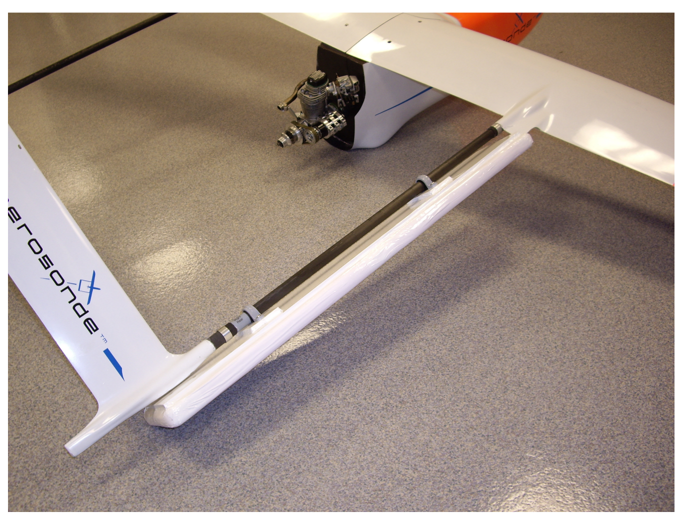


Fig. 6. Radome installation on Right Tailboom of Aerosonde.

Styrofoam, and attached to the plywood using ½ inch nylon standoff hardware. The RF cable connection locations were sealed using silicone sealant.

Once the antennas and cables were installed the radome was covered using heat-shrink Monokote covering as used on R/C model aircraft. This provided weatherproofing and also improved the drag characteristics. The radome was then clamped to the tail boom of the Aerosonde using tube clamps with rubber gaskets (Fig. 6). Small spacers were used on the back plate to provide the clearance needed to avoid the Aerosonde tail section.

Routing of the RF cables back to the RF module will be done in the following manner. Along the tail boom they will be held in place using wire-ties. The cables will then be routed inside the wing through a small hole at the base of the tail boom attachment pod and sealed using silicone seal. Routing of the cables to the root of the wing and into the fuselage will be done in a similar manner to existing cable routing for the tail-mounted iridium antennas on the Mk4 Aerosonde.

D. Computer Simulations Checks

The attachment of the MicroSAR radome will have obvious aerodynamic impacts on the Aerosonde. Before putting any real hardware at risk, a detailed computer simulation of the modified Aerosonde was developed based on the AeroSIM Aeronautical Simulation add-on library for Matlab. This add-on is available from Unmanned Dynamics and includes aan accurate Aerosonde simulation as an example [5].

The effect of adding a single Radome on the right hand tail boom and also adding a second "dummy" Radome were considered. Besides balancing the aerodynamics, there is a potential to add a second set of antennas, as the latest version of the MicroSAR can operate with 2 channels [2]. The additional drag, mass, inertia and shifts in center of gravity and center of pressure were considered for the two cases. Fig. 7 shows the basic Aerosonde geometry, locations of the MicroSAR components, and the estimated shifts in center of gravity (CG) and center of pressure (CP).

For the single Radome case, the additional mass of the Radome was compensated for by installation of the RF module in the payload bay. The backward shift in CG was estimated to be 11.5 – 16 mm (empty to fully fueled vehicle). The backward shift of CP was more dramatic (65 mm) which in theory actually increases the longitudinal stability margin. However, the rightward CG and CP shifts tends to cause the UAV to turn to the right, which the autopilot must now constantly correct. It was also noted that the UAV was more susceptible to crosswind conditions, with an increased tendency to "weather-cock" into the wind. However, even a rudimentary PID-based autopilot was able to control the UAV properly during a typical orbital circuit around a target even in the presence of high winds (40 km/hr).

For the two radome case, left-right aerodynamic balance is restored. The rearward CG/CP shifts are also increased, although CP (105.5mm) moves back more then CG (28.5 mm),

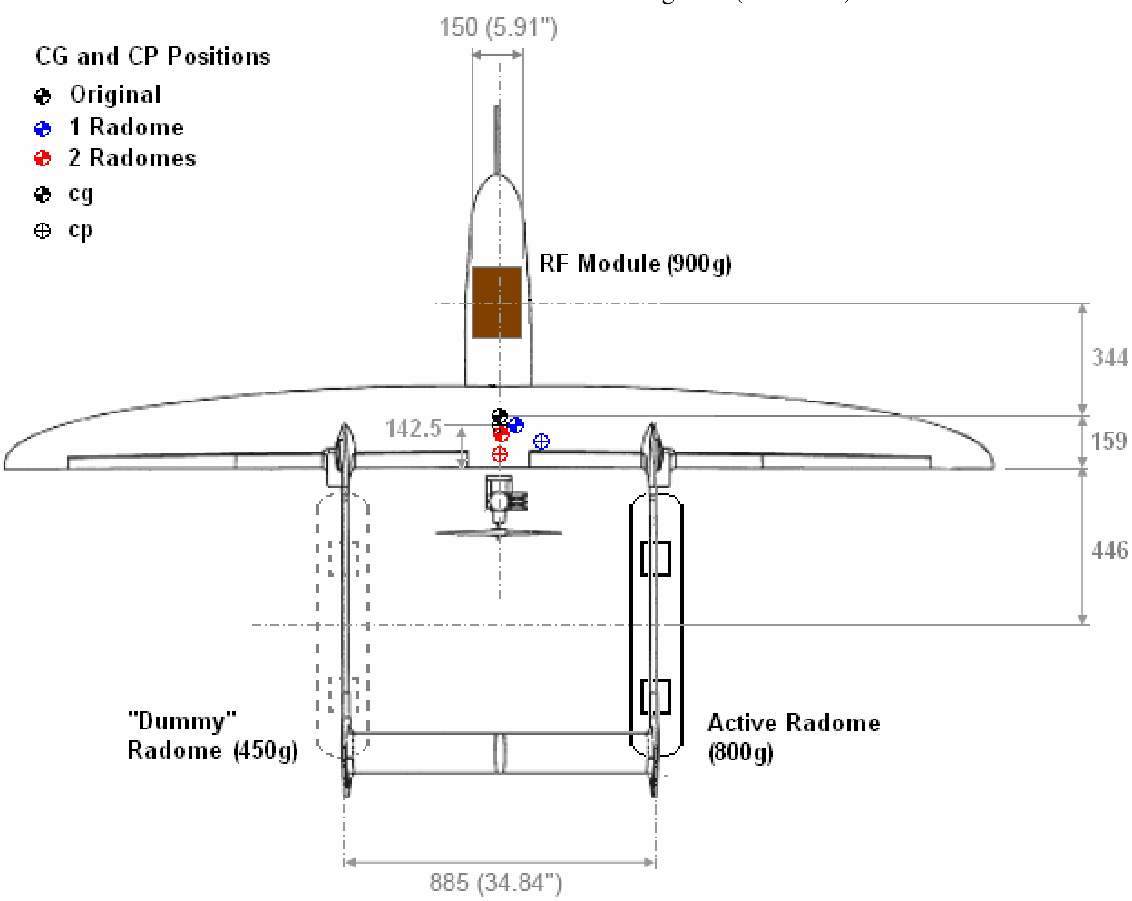


Fig. 7. Aerosonde Geometry and Effect of Adding MicroSAR Components (figure courtesy of AAI).

resulting in greater longitudinal stability margin. Simulation results with the 2 radome configuration showed that the weather-cocking behavior is now more prevalent, although the tendency to turn right is gone. The increasingly tail-heavy Aerosonde was less responsive in pitch without adjustments to the autopilot. The standard autopilot (tuned to the basic "clean" Aerosonde) now has a tendency to over-control in pitch, leading to some oscillating behavior after sharp turn maneuvers or during climb-out. However, it is likely that a suitable adjustment to the gains could be made to bring the UAV pitch control back into trim. How controllable this configuration would be under manual pilot control remains to be seen.

III. MICROSAR TESTING

Fig. 8 MicroSAR installed on a Cessna 175 during flight testing over sea ice near Barrow, Alaska.

In preparation for the flights tests on the Aerosonde UAV, the three research collaborators on this project have been conducting a number of preliminary tests.

A. Barrow, Alaska Tests(March 2006)

Flight testing of the MicroSAR was carried out by University of Colorado (U.Col) personnel with the unit installed on a Cessna 175 (Fig. 8) during flights over sea ice near Barrow, Alaska in March 2006. A sample of the imagery obtained can be seen in Fig. 9. During this scan, the altitude was 150 m (~500 ft) at a speed of 38 m/s (72 kts). Image resolution obtained was approximately 2m. This testing confirmed the operation of the MicroSAR in very cold conditions, as would be expected during winter or high arctic testing. The antennas were exposed to temperatures as low as -43 ºC during the flights, with no problems encountered.

B. Logan, Utah Airborne Tests (September 2006)

Recent flight tests were conducted by BYU over agricultural areas near Logan, Utah. The purpose of these flights was to confirm the correct MicroSAR settings and the expected

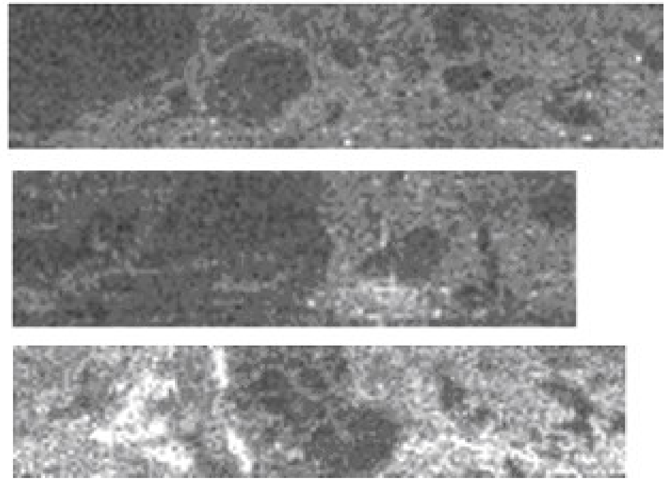


Fig. 9. Examples of microSAR imagery acquired during Barrow area flight testing. Imagery was acquired from a flight altitude of 500 ft. and show small floes, ridges and rubbled ice within shore-fast ice.

MicroSAR imagery that is to be expected once we flight test the Aerosonde-MicroSAR configuration. The Logan tests were conducted using a Piper Cub as the carrier aircraft. Scans were made while the aircraft flew in a straight path in a similar manner to the Alaska tests, at 150m (500 ft) altitude and slightly higher speed of 110-120 MPH (93-102 kts). A sample of the imagery can be seen in Fig. 10.

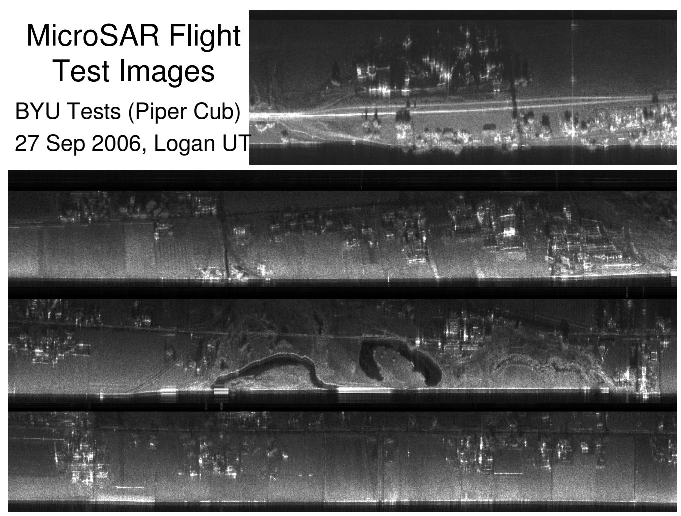


Fig. 10 MicroSAR testing over Logan, UT, carried at 500 ft on Piper Cub Aircraft

C. Local Ground Testing (August-September 2006)

When the RAVEN team first received the MicroSAR system, local ground tests were made to confirm basic functionality of the equipment. These tests were essentially a repeat of the "VanSAR" tests conducted in Utah by BYU [2]. Because of the very low elevation angle during these ground scans, the selection of a suitable "test range" was difficult, due to near-field obstacles and the need to maintain a steady speed and straight track during the MicroSAR recordings. Several

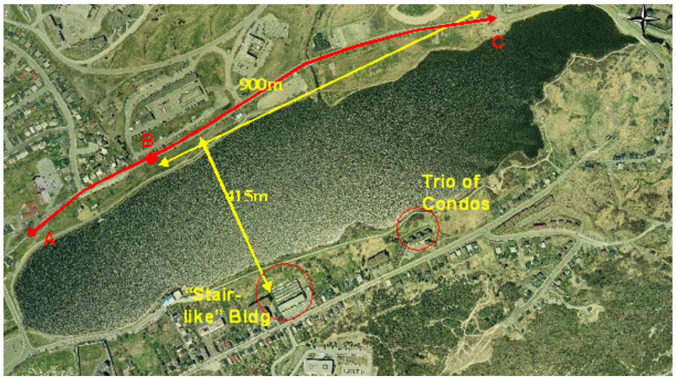


Fig. 12 Quidi Vidi Lake test site for "VanSAR" Tests (28 Sept 2006).

attempts were necessary before we found a suitable location that yielded credible SAR imagery.

Up to this point all MicroSAR tests were conducted with the antenna arrays mounted directly onto the vehicle exterior (as in Fig. 8) with no protective covering or radome. To verify MicroSAR operation with the custom Radome, the ground tests were repeated.

The Radome was mounted on a minivan as shown in Fig. 11. The "test range" used is a stretch of road along the north shore of Quidi Vidi Lake, located in the east end of St. John's, Newfoundland. Fig. 12 provides an aerial view of the test site. The road used is fairly straight and elevated slightly (20 ft) above the surface of the lake. The southern bank is at the base of a tall hill and rises very steeply (at least 150 ft) before the first major road. There is a variety of apartment buildings, houses and vegetation on this southern shore. Critical locations along the minivan's path are noted: (a) MicroSAR switched on, (b) +24 sec recording start location; and (c) MicroSAR switched off.

The results of the recent Radome ground tests were similar to those obtained previously. A sample of imagery that was obtained is given in Fig. 13. This has been rotated to match the same orientation as the test range figure. The top edge is North, with van traveling from left to right. The far lake shore is clearly visible, as are several buildings, in particular the key buildings noted in Fig. 12. Some of the near shore was also captured (top right edge). Objects with strong reflecting surfaces (e.g. windows) show clearly on these images.

IV. TEST PLAN FOR AEROSONDE

The original delivery date of the Aerosonde UAVs (mid-September) has been delayed until the second week of November, primarily due export/ITAR regulations. The following activities are planned to occur.

A. *Airworthiness Tests*

The MicroSAR will be installed in the Aerosonde Trainer aircraft. The Trainer is flown under R/C control and is used to practice the manual piloting skills needed during launch and landings. The launch sequence is identical to that of the Mk4, via a vehicle-top mounted launcher. This is expected to be one of the two crucial test phases (the other being the landing) for the MicroSAR configuration. The results of the Computer Simulation results indicated that the Aerosonde UAV can fly with either one or two radomes attached, but this must be confirmed through physical testing before risking the fully-equipped Aerosonde Mk4s.

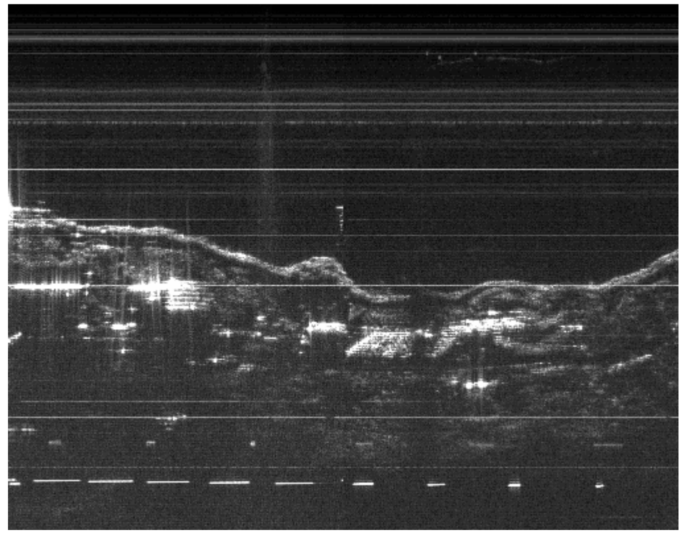


Fig. 13 MicroSAR image of Quidi Vidi Lake (28 Sept 2006).

Assuming that airworthiness of the MicroSAR-Aerosonde configuration is confirmed, the MicroSAR will be activated during manual R/C flight and scans of the launch area will be taken to test basic MicroSAR operation on the UAV. A spare channel of the R/C control will be used to remotely trigger the power-up sequence and to terminate recordings by the MicroSAR. It is expected that results will be similar to those obtained by the recent BYU flight tests over Logan, UT.

B. *Integration and Test on Mk4 Aerosonde*

Following successful completion of the airworthiness tests on the Aerosonde Trainer, the MicroSAR will be installed on an Aerosonde Mk4. Flight tests are planned as part of our acceptance tests for these aircraft. These acceptance tests will include autonomous flight along the coastal region of Trinity and Bonavista Bays in Newfoundland, as shown in Fig. 14, using the Clarenville airstrip (CCZ3) as our base of operations. The MicroSAR will be flown on at least one of these flights to capture imagery of ships and coastal areas remotely. This is an important step towards the Ice Survey mission planned for winter 2007.

C. *Ice Survey in 2007*

Accomplishment of the Ice Survey mission is a major goal of this collaborative research project. A mission for the

MicroSAR-equipped Aerosonde Mk4 is being planned for late winter (February-March) during the 2007 Ice Season off the north-east coast of Newfoundland. The goal will be to take high resolution sea ice imagery similar to what was previously done in Alaska in March 2006. Using this past year's season as a guide, it is likely that a variety of sea ice can be expected to appear off Fogo Island by mid-March 2007 (Fig. 15). It will be necessary to shift our base of operations from the Clarenville airstrip to a similar installation on Fogo Island. The cold weather operational experience of the U. Col team in Alaska, the demonstrated cold weather capability of the Aerosonde and our own experience from the off-shore acceptance tests in November will be valuable during this activity.

V. FUTURE WORK

The MicroSAR is a unique payload for the Aerosonde, and provides the basis for a range of radar-based payloads for small UAVs – a situation generally not considered possible just a year ago. In collaboration with our partners at BYU and U.Col several potential enhancements to the MicroSAR payload are being considered for future projects:

A. Geo-Referencing

Add geo-referencing to the recorded MicroSAR data through parallel recording of aircraft position and attitude data. This would enable the reconstruction of a scanned scene in global coordinates, and combination with other data such as Automatic Identification System (AIS).

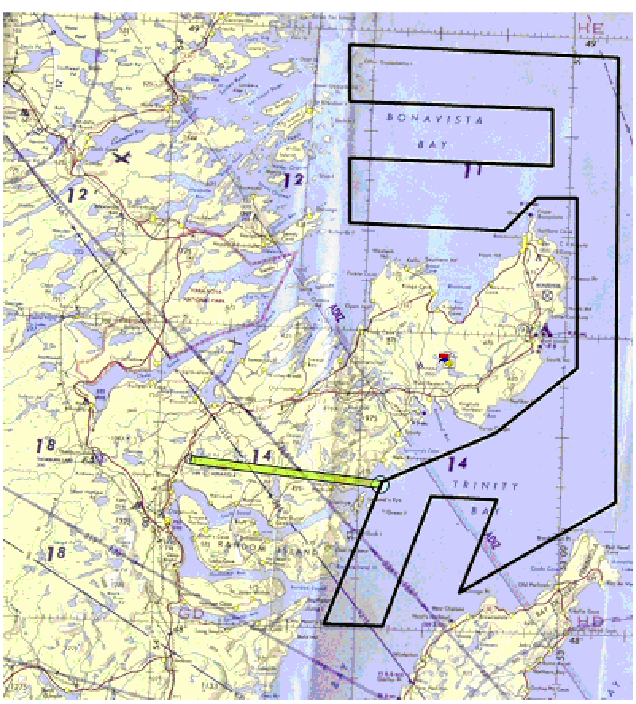


Fig. 14 Aerosonde test flight over Trinity and Bonavista Bays planned for November. (Courtesy of Provincial Aerospace Limited)

B. Motion Compensation

The MicroSAR system currently has no form of motion compensation (physical or electronic). Changes in vehicle attitude, especially roll and yaw, result in smearing and blurring of the images. It is proposed to add motion compensation to the scanned data, using vehicle attitude measurements from an Inertial Measurement Unit (IMU) to de-couple vehicle motion effects on the image data using well-known motion compensation algorithms [6]. This would allow flexibility in vehicle maneuvering during MicroSAR scans and improved image fidelity.

C. Remote Transfer of MicroSAR Data

The current system records data to on-board flash memory cards. The quality of collected data (and success of a MicroSAR scan) is determined well after the mission is completed and only after on-ground post-processing. It would be valuable to add the capability to transfer MicroSAR from the UAV to the ground in order to allow concurrent processing of the data during a mission. Initially, a line-of-sight RF link would be used to demonstrate the utility of this feature. Ultimately, it will be necessary to provide some sort of BLOS (Beyond Line of Sight) communication capability. This will require data compression or enhanced processing to permit transfer of data across BLOS satellite communication links.

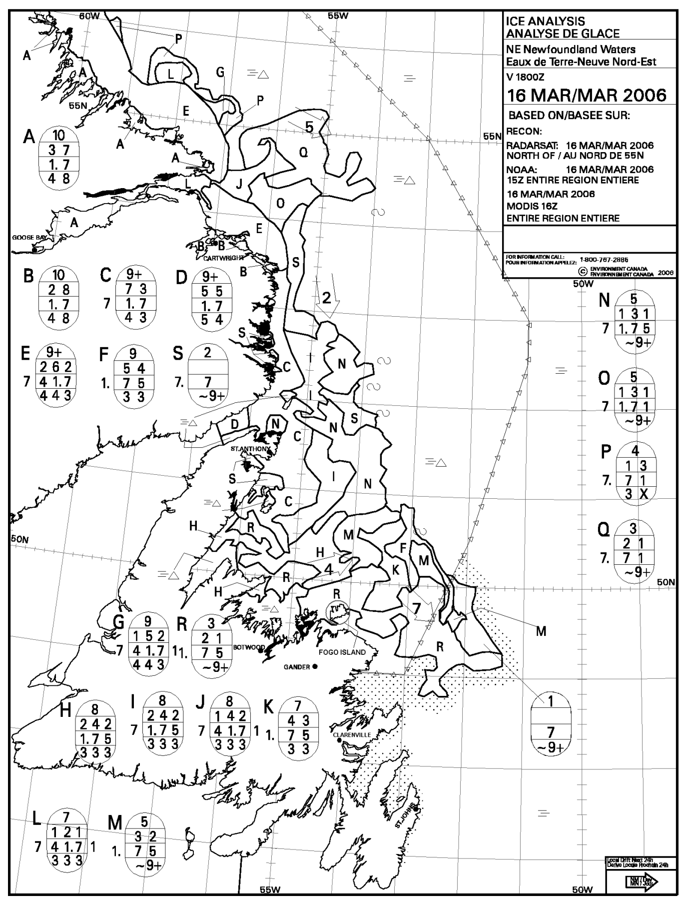


Fig. 15 Ice Chart for Newfoundland area, March 2006. (Environment Canada)

D. Enhanced Data Processing

Enhancements to the data processing algorithms may be possible to allow near real-time imaging, and possibly also onboard automatic target detection and classification. This could considerably help the situation with the BLOS satellite communications bottleneck.

ACKNOWLEDGMENTS

We wish to thank Aerosonde/AAI for their technical assistance and cooperation during this project.

REFERENCES

[1] Curry, J.A., J.A. Maslanik, G. Holland, J. Pinto, G. Tyrrell, J. Inoue, 2004. "Applications of Aerosondes in the Arctic", *Bull. Am. Met. Soc.*, 85: 1855-1861, 2004.

[2] E.C.Zaugg, , D.L. Hudson, and D.G. Long, "The µSAR: A Small, Student-Built SAR for UAV Operation", Proceedings of the International Geoscience and Remote Sensing Symposium, Denver, Colorado, August 2006.

[3] *Aerosonde UAV System Product Description,* Aerosonde Pty Ltd. Publication, March 2006.

[4] Glenn, Ian N. Canada. Defence Research and Development Canada. Department of National Defence. CR2006-109: UAV Jamming Missions & Technologies in Support of Canadian Forces Standing Contingency. Ottawa: DRDC, 2006.

[5] AeroSIM Aeronautical Simulation Blockset, Version 1.2, Unmanned Dynamics Inc., Hood River, OR, 2006 (www.u-dynamics.com).

[6] Horrell, M.J.M., Knight, A., Inggs, M.R., "Motion Compensation for Airborne SAR", Proceedings of the 1994 IEEE South African Symposium on Communications and Signal Processing, 1994.