

AUTONOMOUS AIRSPACE AWARENESS SYSTEM (A3S)

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Public Final Report

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Project Partners

Transport Canada and the National Research Council through the LOOKNorth Project, provided testing support and feedback. Helping to ensure the development of safe DAA technology for commercial use here in Canada. This development will help us to continue to reduce GHG emissions while continuing to provide data that is required for environmental monitoring.

Executive Summary

The following final report will summarize the objective, key developments and learnings, as well as recommendations for next steps regarding the advancement of technology for Beyond Visual Line of Sight (BVLOS) with unmanned aircraft being used for environmental monitoring. This project was funded by Alberta Innovates through the Land and Biodiversity fund and executed by Pegasus Imagery. Supporting research partners included Transport Canada and the National Research Council (NRC) outlined in the report.

Inside of this project, Pegasus Imagery was able to advance the technology of its proprietary Detect and Avoid (DAA) sensor, testing it in partnership with the NRC in an operational environment. This DAA system which will enable safe BVLOS and help advance the commercialization of low GHG emitting unmanned aircraft for aerial environmental monitoring.

Results

- The project was successful in defining the selection of tools, how to successfully integrate the radar for best results, and best practices for flight tests.
- Conducted in-flight testing of the system in both simulated and operational environments.
- A3S software was able to detect, track and avoid intruder aircraft during flight.
- Simulation suite was created to show the custom Pegasus aircraft 'Eos', which was built to hold the A3S sensors and the sensor simulation of intruder aircraft.
- The simulator suite can now allow for training of scenarios through machine learning algorithms.

- The sensors validation testing resulted in better performance than anticipated. A3S detected and tracked intruder aircraft at double the expected range.

Next Steps

- (1) Continued flight testing in more complicated scenarios to train the on board artificial intelligence. These flights will be to ensure that A3S is capable of conducting the safest avoidance maneuvers;
- (2) Continued demonstrations and trials in operational and real-life conditions to build the data to demonstrate reliability;
- (3) continued discussions with regulatory bodies to ensure full and safe compliance with all applicable rules and regulations.

The DAA technology has significantly progressed over the duration of this project, with the support from AB Innovates, Transport Canada, and the NRC. The progress made during this project and the required next steps will help to enable the future use of BVLOS with uncrewed aircraft, which will be key to decreasing the environmental impact of monitoring the environment. The project completed on time, in budget, while advancing the Technology Readiness Level (TRL) rating.

Introduction

Pegasus Imagery has partnered with Alberta Innovates and Transport Canada's LOOKNorth Project to develop DAA technology to help enable commercialization of BVLOS flights in Canada. This new technology helps unlock the use of autonomous systems for use in data collections for environmental monitoring using drones or remote piloted autonomous systems (RPAS). This technology will use 90% less GHG emissions than current options. Drones are currently only able to fly within visual line of sight, which would not allow for drones to replace high emitting alternatives for environmental monitoring collections of data. Some of the key technology Gaps that would enable the regulator, to allow for drones to fly beyond visual line of sight (BVLOS) are addressed through this project. The technology gaps include the ability to fly RPAS in an integrated airspace with manned aircraft; the ability to perform autonomous Detect and Avoid (DAA) maneuvers without pilot intervention; and autonomously remaining well clear of airborne obstacles, compared to existing last-minute collision avoidance systems.

Pegasus' project helps solve the technology and regulatory barriers to commercialization of Beyond Visual Line of Sight (BVLOS) operations. Critical to this is a demonstrable, a reliable Detect and Avoid (DAA) system to ensure safe integration between manned and unmanned aircraft. Pegasus' Autonomous Airspace Awareness System (A3S) comprises an airborne radar system and other onboard sensors to detect, track, and autonomously avoid potential airborne hazards, enabling commercialization of autonomous data collection at scale. Through this project, Pegasus will accelerate development and testing of A3S-enabled autonomous aircraft, working closely with regulatory stakeholders to deliver real-world testing and feedback of this transformational technology.

Project Description

Technology Description

This project is focused on the safe integration of RPAS using Pegasus' Autonomous Airspace Awareness system (A3S). A3S fuses different sensors together including airborne radar, GPS, and Inertial Measurement Units (IMU) data to safely operate RPAS beyond visual line of sight (BVLOS) in any airspace. By actively scanning the RPAS' environment 20 times per second, A3S has the capability to detect, track and autonomously avoid potential airborne hazards, such as birds, drones and most importantly, manned aircraft. A3S is integrated with edge AI or a deep learning framework. Edge AI is the process where Artificial Intelligence (AI) algorithms are processed locally, either directly on the device or on the server near the device. In this case on board the aircraft. The algorithms utilize the data generated by the devices themselves. Devices can make independent decisions in a matter of milliseconds without having to connect to the internet or the cloud. This process is what enables A3S to make autonomous decisions to avoid airborne obstacles even in the rare event of lost communications. Using onboard AI also removes risks associated with human factors and data links from the decision-making cycle while providing safe, all-weather navigation to every mission. Key considerations for why Pegasus chose an onboard A3S system to solve the technology gap is multifaceted: communications from the ground could be interrupted, resulting in not receiving information fast enough to perform an avoidance maneuver. As A3S is an onboard system, if communications are lost it still has the ability to avoid obstacles without pilot intervention. This also eliminates any latency associated with a communications system. This enables the A3S decision cycle to be measured in milliseconds rather than seconds.

During this project the objective is to move the technology from a technology readiness level of 5 (basic technology components are integrated for testing in a simulated environment) through 6 (model or prototype that represents a near desired configuration in a simulated environment) to 7 (prototype at planned operational level and is ready for demonstration in an operational environment). Planned objectives during the project will include successful use of radar data to detect airborne obstacles, to fully integrate A3S software and hardware package onboard a RPAS, to successfully test A3S onboard a UAV in a controlled environment, autonomously avoid intruder aircraft, to complete field testing to confirm safety systems of RPAS of avoiding airborne obstacles, and to successfully fly a mission with airborne obstacles, detect-avoid-resume mission.

Updates to Project Objectives

DAA Radar Simulator User Interface: The Pegasus radar simulator is a piece of software that emulates the radar sensor used on the drone. The radar simulator allows for a full simulation environment by integrating with the existing UAS simulation software. Aside from the radar simulator, all Pegasus software components used in simulation are the same as those used for hardware testing on an airborne UAS. Having the radar simulator user interface separate from the ground control station allows for enhanced debugging and display of information that is only useful in a testing or debugging context and may be confusing or misleading in an operational environment.

Performance Metrics

Pegasus has defined project specific metrics to determine whether this project is a success.

Technology Readiness Level Advancement

At the inception of this project, A3S was completing component validation. The project tasks and objectives will result in the technology advancing from validation of components, to integration of components in a simulated environment, to prototype configuration, to prototype testing in an operational environment. Success would include the first round of advance flight tests being completed (TRL 7). We could consider the advancement of the technology successful when completing successful initial field testing of A3S integrated on a RPAS.

Albertan Jobs

Pegasus' location of headquarters is at regional airport in Villeneuve, Alberta with a population of 136 (2011 Census) which is located approximately 30km northwest of Edmonton, Alberta. The A3S project has generated increased need for Software Engineering and Electrical Engineering personnel within Pegasus Imagery. These positions require a high degree of qualifications and would bring economic growth to a rural area of Alberta. Success would include growing the Pegasus engineering team by at least two highly qualified individuals.

Innovation Ecosystem

To ensure there is market readiness and need for this technology advancement Pegasus has determined that success would include signing Memorandum of Understandings to prepare for commercialization of this technology. A demonstration of the interest around the technology being developed by

Pegasus is reflected through the partnerships that have been created around this technology during this project. MOU's have been signed with Kongsberg Geospatial and Stantec. Pegasus is currently moving forward in discussions on additional agreements with Boeing, GKN Aerospace, Thales Canada and CP Rail.

Policy Influence

BVLOS technologies will need to conform with Transport Canada regulations and policies to be commercially viable. Pegasus has established early partnerships with Transport Canada including partnering in the development of this technology. Ongoing discussion include a potential joint effort between Pegasus, Transport Canada and Boeing Research and Technology (BR&T) to recommend updates to RTCA aviation standards. These changes will support new standards for autonomous DAA systems. The recommended changes for the RTCA standards will help enable regulatory change allowing for commercialization of this technology.

Methodology

Pegasus Imagery's Autonomous Airspace Awareness System (A3S) requires the integration of flight hardware, computing hardware, firmware, and software to deliver on its goal of autonomously controlling a drone and avoiding airborne obstacles, while also ensuring that the drone hosting the system flies its original mission. Key aspects of the methodology include the facilities, personnel required, the accuracy and integration of components, simulation of technology, and flight testing.

Facilities

The work to complete the project was conducted at three separate locations: The design, engineering, and manufacturing portions of the project will be performed at Pegasus' main hangar at the Villeneuve Regional Airport in Sturgeon County, Alberta. The flight testing for A3S will be conducted in the restricted airspace above a Canadian Forces Base and at Pegasus' testing site in rural Alberta.

Personnel

Integrating these components will require a multi-disciplinary team of electrical, mechanical, and software engineers. Testing and deploying the A3S system will require supporting personnel for logistics, resource management, flight operations, mission control, technical leadership, and team leadership responsible for coordinating testing and operational activity with external organizations with access to flight testing resources and legal oversight over the project. Based on the Pegasus' team size at the start of the project, it was determined a new software engineer and electrical engineer would be required.

Equipment

Key to the performance of testing is the in-house developed RPAS that can safely and reliably carry the A3S software and hardware components. Other key equipment is the sensors, and communication equipment required to integrate with the software components.

Simulation & Radar Simulator

Advanced flight simulation will be conducted to demonstrate A3S's ability to perform in multi-threat environments.

One piece of flight simulation is an RPAS physics simulator to ensure that the RPAS is not pushed beyond the bounds of its flight envelope, causing a potential failure or crash. By simulating the physics of the airframe used in field testing, simulations are able to better predict the outcome of field tests.

Simulation of radar contacts allows for A3S's core functionality of avoiding aviation traffic to be tested. By supporting multiple flight envelopes and concurrent threats, complex conflict simulations can be performed to ensure A3S performs acceptably before being subjected to field conditions.

Radar detection

Air-to-Air developmental radar licenses are required to continue the testing of the radar, which will need to be obtained from Industry, Science and Economic Development Canada (ISED). In Canada, Air to Air radars have not been used by civilian companies. As such, there are currently no paths for obtaining commercial licensing for this technology. Pegasus will work with the ISED, Western Operations group to create a development air to air radar license. This first of its kind developmental license will allow for development of technology and will set the stage for the creation of a commercial license for the use of this technology.

Key to the technology is determining the accuracy of the radar unit. While the selected radar has already been validated in testing with the FCC and FAA, because it is a critical component its accuracy and reliability must be verified inside of this project. Pegasus obtained partnerships with Transport Canada and the National Research Council to validate both the range and accuracy of the radar. Inside of this project the NRC provided testing advice and assistance, and Transport Canada provided procedural advice for the testing of the radar and A3S. This partnership also benefited the regulator by allowing Transport Canada early access to developing technology that will influence regulatory change.

As a partner, the NRC was able to provide in-kind support to help facilitate the in-flight testing of A3S. The NRC provided an Inertial Measurement Unit (IMU) that allowed for the testing of the accuracy of A3S while in flight. The IMU was utilized on the intruder aircraft and its precise position was measured and compared against the locations provided by the radar through A3S. This essential piece of technology provided by the NRC demonstrated A3S' ability to detect and track Cessna sized aircraft up to 5km away.

Ground Control Station (GCS)

A Ground Control Station (GCS) is used by the Pilot in Command (PIC) to communicate with an RPAS while it is airborne. Although A3S operates autonomously, it is important to relay flight information to the Pilot-In-Command (PIC). From the GCS, the PIC can view the location and attitude of the RPAS overlaid on a Geographic Information System (GIS) showing satellite imagery and the RPAS's mission plan. Additional features added to the GCS included the ability to modify flight parameters and review previous flight logs. Sensors views, such as a map of contacts from the radar, will also be added to the view of the GCS to provide the PIC for better situational awareness.

Integration

High level methodology outlined to allow for full integration of the technology with a RPAS included: develop and bench testing the software components required to implement the A3S; design, manufacturing, and functional testing the electrical components required; design, manufacturing, and flight testing the mechanical components required; assemble and integration testing of all the electrical, mechanical, and software components.

A3S will be integrated onto Pegasus Imagery's experimental fixed-wing VTOL airframe. This involved selection of peripheral components such as networking

switches and storage devices which have suitable weights and physical dimensions to fit into the RPAS's fuselage.

Flight Testing

Remote A3S Configuration & Collision Avoidance

Initial flight testing performed with a simulated radar contact being fed into A3S from the ground while the system is in flight. This input created the illusion of an obstacle in the path of the A3S equipped RPAS. This allowed for basic testing of the systems integration and ensured that the system responded in flight to the message that would be produced by the radar. The ideal avoidance maneuvers for the testing performed was predetermined by the Chief Pilot prior to the flight and was compared to autonomous actions of A3S to determine that the correct decisions were being made by the AI. The tests were repeated multiple times in order to ensure reliability and predictability.

Subsequent flight testing saw the A3S flown against non-A3S equipped RPAS. This testing showed the ability of A3S to avoid non-cooperative aircraft in an operational setting. Following the same methodology, the Chief Pilot determined what the optimum avoidance should have been in the anticipated encounter, and this was compared to the decisions made by A3S. This test was repeated multiple times in order to ensure reliability and predictability.

Project Results

Pegasus has completed individual component validation including testing of the radar unit, companion computer, and software modules responsible for collaboratively executing avoidance maneuvers in response to radar contacts.

This includes in-flight validation of the radar and flight testing in cooperation with Transport Canada and the NRC.

Simulation

Rather than using a default “out-of-the-box” model, our simulation suite has been customized to reflect the Pegasus’ Eos airframe that would be carrying the A3S DAA system. Having the simulator reflect real-world performance as closely as possible is important so that results of field testing could be better predicted before being performed. Analyzing the effect of A3S inputs into airframe stability in simulation is only possible with a realistic simulation model and helps improve the safety of field tests. The original airframe used for simulation was smaller than Eos which resulted in simulated behavior diverging from the physical behavior witnessed in field testing. Simulation allows for hundreds of flights to be flown in the time that one flight would have taken in physical flight testing. This simulator will be an enduring part of this project. It will be instrumental in testing future upgrades’ effects on the RPAS. Inside of this timeline, this simulator was able to identify issues inside of a third-party firmware upgrade. This issue would have undoubtedly caused a crash of the RPAS had it been on a physical flight.



Figure 1. Simulated Flight of Eos

Radar Simulator

The radar simulator complements the existing simulation suite by interfacing directly with the A3S system as if it were a physical radar sensor. Aviation traffic can be configured for testing A3S avoidances for all directions, speeds, angles of approach, etc. With the radar simulator fully implemented, the Pegasus simulation environment was completed, and allowed for A3S reliability without necessarily performing physical flights.

Rather than sending an empty radar contact message, messages now include configurable position and velocity information, allowing for A3S to make context-specific decisions about avoidance maneuvers. Pegasus was able to plan, perform, and document unique aerial encounters through simulation testing including static, moving contacts, various closure angles, and varying alignment of contacts. As the technology progresses the frequency and complexity of simulation testing is increasing.

The simulator also supports complex – multi contact and oblique – conflict scenarios. Testing of the multicontact simulator occurred after initial flight testing results and will influence future in-flight testing.

The simulator has shown the ability to simulate specific airborne encounters. This enables testing of A3S against encounters specified by RTCA in the DO-386 standard on ACAS Xu detect and avoid systems. Training sets for AI and ML algorithms can also be processed using this context-specific feature of the radar simulator. These AI and ML algorithms will be incorporated into future versions of A3S.

Radar Detection of Intruder RPAS and Light Aircraft

Several tests were performed to verify the selected radar's ability to detect airborne contacts.

Initial testing was conducted with the radar on a tripod on the ground and flying a small RPAS target within the radar's field of regard (FOR). Results of these tests were used to verify sensor range when detecting small RPAS (Figure 2).

To better test the radar's ability to filter ground clutter, airborne tests were conducted with the radar mounted beneath a midsize RPAS and again using a small RPAS target as the airborne contact (Figure 3).

The final stage of radar testing was to detect a light aircraft (Figure 4). For these tests, the radar was stationary on the ground and a light aircraft was used as the airborne contact. Flight maneuvers were designed to assess the range and FOR of the radar to be compared against the manufacturer's specifications. Range testing was done by having the light aircraft approach the radar directly from 5km away, well outside the radar's advertised range of 2.5km, and then fly away from the radar back out to 5km. The FOR of the radar unit was tested by having the light aircraft perform a serpentine maneuver in front of the radar, designed to exceed the radar's FOR.



Figure 2. Small RPAS Track from Radar



Figure 3. Midsize RPAS Carrying A3S Hardware and Radar as Seen From Small RPAS



Figure 4. Testing Radar with Light Aircraft

Ground Control Station

In most cases, GCS is the only form of communication between the PIC and the RPAS. Information sent from the GCS to the RPAS included commands used for altering flight modes and alterations to mission plans. It is these messages that informed the RPAS where to go and whether to progress to its next mission waypoint or to perform a manual maneuver as dictated by the PIC. Information sent from the RPAS to the GCS included positional data which informed the PIC of the RPAS's current location, altitude, attitude, etc. The GCS allowed the PIC to interface effectively with A3S by providing the ability to enable or disable A3S functionality and to observe whether the A3S was actively executing an avoidance maneuver.

The GCS showed RPAS position and orientation overlaid on satellite imagery which enabled visual georeferencing. The GCS interface also supports mission planning and remote flight controller configuration (Figure 5).

At the beginning and end of each A3S maneuver, an audio alert was used to notify the user. There is also a visual prompt on the screen throughout the duration of A3S control of the RPAS. It is important to keep the PIC informed on A3S's current state and operational intentions so that any manual actions taken by the PIC are appropriate for the conditions.

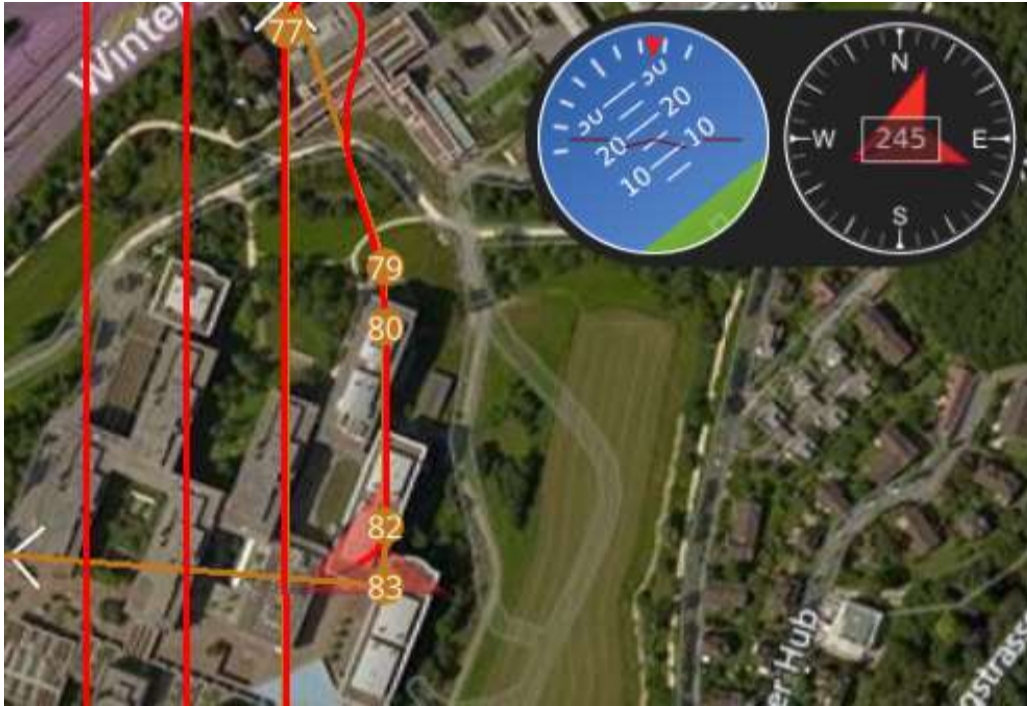


Figure 5. GCS Relaying Flight Information Overlayed on Planned Mission and Satellite Imagery

Post-mission data collected from A3S was analyzed to provide mission statistics and virtually replay mission data for quantitative and qualitative analysis. This was necessary functionality for debugging during the current and future development of A3S and essential for operational situations for flight review. Flight review will be required before resuming operations after any operational disturbance, whether that be a near-miss or a crash. In depth analysis of flight data using manually and automated tools assisted in assessing and improving the reliability of A3S.

Flight controller logs are stored separately from A3S logs and analyzed graphically to assess flight performance (Figure 6). These logs can also be used to diagnose erroneous behavior following a crash or unanticipated underperformance which enables more efficient debugging. Figure 6 depicts correct and expected operation of the flight controller and A3S override, with near-zero velocity during vertical take-off and landing, and a constant fixed-wing airspeed. The observation that measured airspeed closely matches the

airspeed setpoint whereas ground speed (from GPS) varies, likely due to wind conditions.

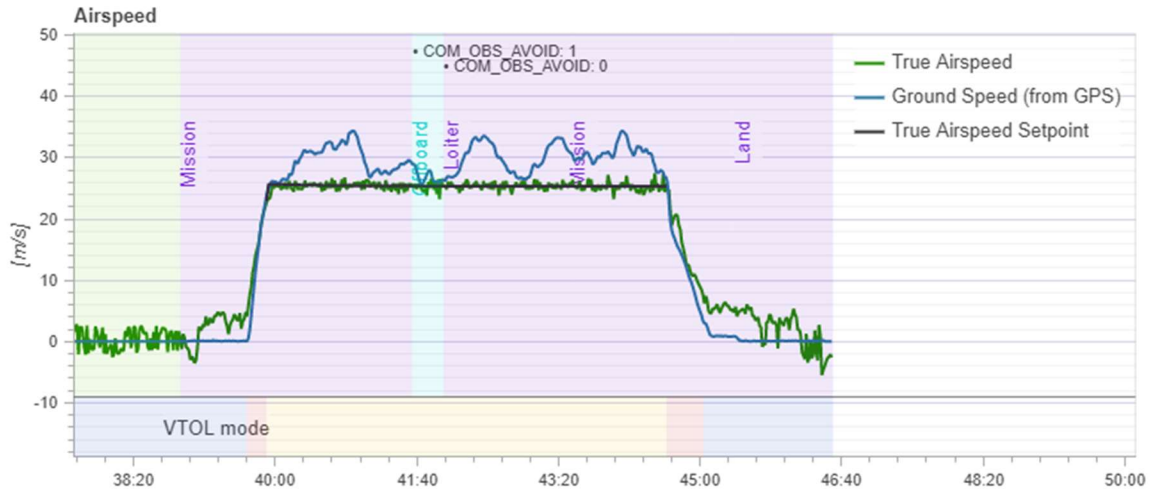


Figure 6. Airspeed Analysis Plot From Successful Flight Showing A3S Mode in Light Blue (Labelled “Offboard”).

Airframe Integration

A3S was integrated onto 3 different airframes. Two of these airframes were VTOL fixed-wing aircraft and one is a multi-rotor. For each integration, selections of peripheral components such as radios were based on the weight limitations of the aircraft versus performance of available peripherals. These additional integrations were performed to mitigate scheduling constraints caused by limited availability of the target RPAS. The multirotor was used due to its ability to carry the full A3S system with the radar sensor, and the additional fixed-wing VTOL RPAS was used to simulate the flight envelope of the other VTOL RPAS.

Automation of flight-testing processes and successful completion of flight tests have allowed A3S flight testing to be performed without any members of the A3S team being present. This allows for additional verification hours of the A3S system to be collected any time flight operations are taking place.

Remote A3S Configuration

The Drone Config Command Line Interface (CLI) was developed to enable remote configuration and monitoring of A3S and the sub-components that comprise A3S. This tool was later used to de-risk initial testing by enabling avoidance maneuver execution without a physical airborne intruder. Rather than using a physical airborne intruder, the Drone Config CLI can be used to send a radar message, prompting avoidance maneuvers.

Partial Integration Flight Testing

During this development cycle, a new step was added preceding fully integrated airborne testing. Previously, Individual software component testing would be followed by full system simulation testing (with simulated sensors), followed by fully integrated airborne testing where all sensors and systems are on board the RPAS. After simulation, an additional testing step was completed of an airborne test but still using simulated sensors. Removing the requirement to carry the radar unit allows for these tests to be completed on smaller airframes not capable of carrying the radar. Testing a partially integrated system also de-risks full integration testing with a more costly large airframe and expensive sensors such as the radar. To enable partial integration testing, a scale model aircraft was developed to carry the A3S system, depicted in Figure 7. All of this effort ensured that in-flight radar validation was able to be completed safely.



Figure 7. Small RPAS unit carrying A3S software package in fuselage over farmers field with small layer of snow on ground. Aircraft ready to perform avoidance maneuvers once Drone Configured Command Line Interface sends simulated contact to A3S.

Collision Avoidance Flight Testing

During flight testing, A3S was able to successfully perform avoidance maneuvers and de-conflict after receiving a radar message (Figure 8).

The success of this test is multi-faceted. The first success is the identification of a radar message as a threat that must be avoided. The second success was the timely calculation of an avoidance maneuver which avoided the contact and remained well clear of the contact after avoiding. The third success was communicating the avoidance maneuver to the flight controller and having the flight controller execute the avoidance maneuver. The avoidance conducted by A3S was in line with the optimal avoidance that the Chief Pilot had indicated. Multiple rounds of airborne testing of A3S have been completed with over a dozen successful avoidances and no unsuccessful avoidances. The successful completion of these tests confirms the successful integration of A3S software and hardware components to perform autonomous avoidance maneuvers.

Having successfully conducted this phase of testing and having analyzed test logs for erroneous behavior, A3S is ready for further flight testing in more complex operational environments.

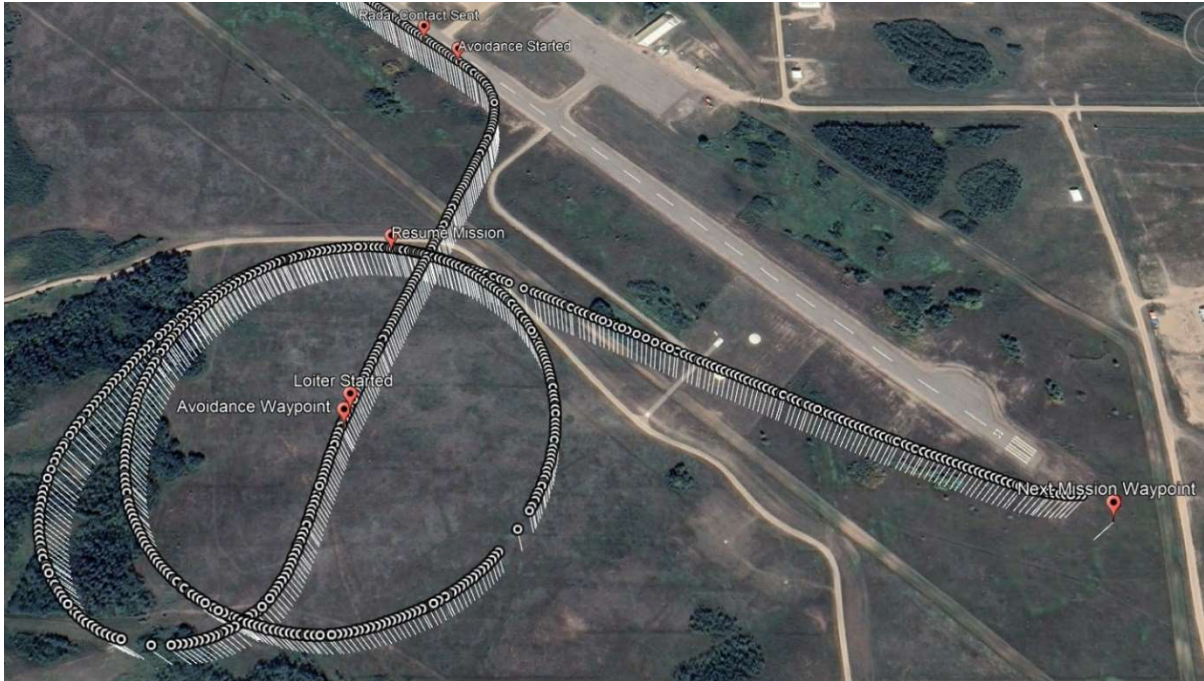


Figure 8. Map Showing Flight Path with Avoidance Maneuver Initiated by Radar Contact

The information that was gained from both the simulation and flight testing has allowed for the A3S algorithms used to determine avoidance maneuvers to be enhanced to handle multiple avoidances per flight and to intelligently select avoidance paths suitable for the position and velocity of radar contacts. This next step has been integrated into the system and has been successfully tested in our simulator (Figure 9). Flight testing with multiple airborne obstacles will be conducted in Spring 2022.

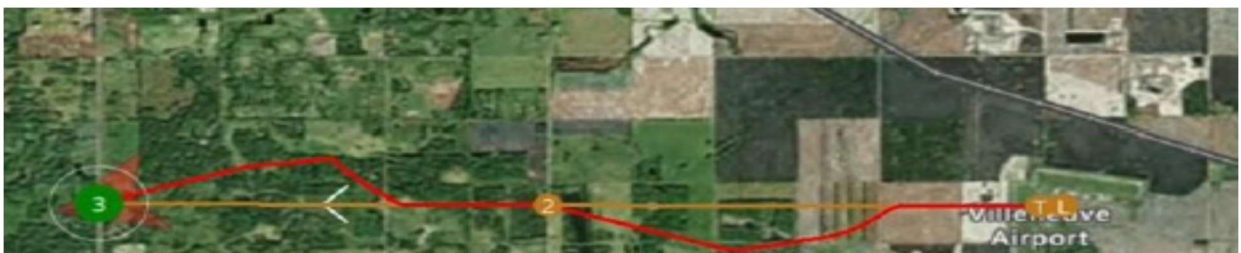


Figure 9. Flight log showing linear mission path in brown and actual flight path with 2 A3S avoidances in red.

A3S Testing Against Transport Canada Spec

As regulations for BVLOS are still in development, Transport Canada was not able to provide a list of standards that must be applied prior to a UAS DAA system would be allowed to operate in Canada. Due to this, Pegasus joined the global standards organization RTCA. As one of the few small businesses associated with this organization, Pegasus now has access to standards that have been developed by organizations around the world. In consultation with Transport Canada, ISED, the NRC, the Department of National Defence, and several Post-Secondary and industry partners. Pegasus has identified seven key standards that we are using to guide this technology development. As a member of the Canadian Drone Advisory Council's Task Group on RPAS Research and Development, Pegasus is monitoring other trends and standards and will incorporate that information as it becomes available.

- RTCA DO-178C – Software Considerations in Airborne Systems and Equipment Certification
- RTCA DO-365B – Detect and Avoid MOPS
- RTCA DO-366 – Air to Air Radar MOPS
- RTCA DO-386 – ACAS Xu Detect and Avoid MOPS
- ASTM F3442 – Detect and Avoid Performance Requirements
- Canadian Department of National Defense TAM – Technical Airworthiness Manual
- SAE EIA-649C – Configuration Management

Key Learnings

Radar Boresighting

Working in a partnership, the NRC provided valuable input and feedback on testing procedures and policies. One vital contribution was the suggestion to implement a boresighting calibration procedure to increase the reliability of positional data provided by the radar. Boresighting the radar helps account for small deviations in the relative mounting of the radar unit and Inertial Navigation System (INS) in the airframe. The INS is responsible for informing the radar of its orientation so accurate measurement of their relative position is vital to ensuring small mounting anomalies do not propagate to large errors when tracking far away objects. This will be especially important if multiple radar units are used in the future and are not aligned with cardinal directions on the airframe.

Field Test Planning and Preparation

Detailed planning and preparation of field tests is of utmost importance to ensure efficient and successful testing. Field testing has a high hourly cost both in man hours and equipment operational costs. Detailed testing plans and procedures helped ensure that field testing produced the required deliverables in a timely and efficient manner. Especially helpful was simulated and dry runs of tests to help inform the A3S team of expected behavior and results. Planning of testing contingencies in the case of reduced testing time availability or hardware failures enabled successful testing to occur following unforeseen issues that could otherwise derail delivery of key testing outputs.

An example of successful contingency testing was during the light aircraft radar detection tests. Earlier tests had indicated the potential of yaw drift in the flight controller and the potential for mis-calibration due to the flight controller being used in a static ground configuration. To mitigate this issue, some of the light aircraft radar detection testing was done with manually measured and inputted

location and orientation information. By manually inputting this data, it was possible to test the reliability of the radar unit without potentially introducing error from the flight controller being applied in a static setting.

Iterative Testing and Development

Built into our milestones was a task to make design revisions based on feedback from field testing. These design revisions were informed by both field testing and by internal design reviews. This step was essential in building a robust software product as it allowed for early mitigation of issues and better development practices for future enhancements.

Outcomes and Impacts

Project Outcomes and Impacts

Through this project's activities, objectives, and outcomes the detect and avoid technology A3S was able to be tested in an operational environment. This in-flight testing was completed in partnership with Transport Canada and the National Research Council. The NRC, providing equipment to verify the accuracy of A3S detections, showed that the system was able to accurately detect and track Cessna sized aircraft out to 5km. The decision cycle of A3S when making avoidance decisions is measured in milliseconds of time. The results of the testing with the NRC show that A3S is not only able to make decisions in time to meet collision avoidance standards, but also those standards that define "remain well clear". This increased safety standard will assist Transport Canada in defining future regulations that will guide the commercialization of DAA technology. The successful testing conducted during this project will guide additional flight testing to be flown in Spring 2022. During that testing we will see increased complexity of the testing environment that A3S will be exposed to. The development of this technology shows that an A3S

equipped RPAS would be able to operate BVLOS. This will enable the use of low GHG emission RPAS to conduct inspection and data collection that is currently conducted by high emission crew aircraft such as helicopters.

Albertan Jobs

At the inception of this project, additional job positions were identified as needed for the continuation of the technology. At the beginning of the project Pegasus employed 2 software engineers. During the project the company hired an additional Software Engineer (June 11, 2021), who has taken Team lead role of this project, and two electrical engineers (May 31, 2021 and November 15, 2021). An Operations Manager was also used to assist in the planning and execution of project field testing. For a total of six full-time employees as a direct result of this project. We also saw some additional expertise from other projects in Pegasus to assist with integration into RPAS airframes and test flights. They're time on this project was not full-time however, the expertise in their respective areas was essential. In addition, Pegasus has created a strong bond with local Post-Secondary institutions in Edmonton. Creating a co-op program to work inside of this program, Pegasus took on four co-ops for full-time 8-month terms (April 2021 to December 2021).

Innovation Ecosystem

To understand customer needs and if there is market readiness for the technology, Pegasus was looking to sign at least one MOU with industry partners, instead Pegasus signed two with more to come in 2022. We have seen a significant interest for the technology in not only Alberta or Canada, but globally.

Boeing Aerospace Xelerated: Pegasus was selected as one of ten startup companies into a global accelerated program called Aerospace Xelerated.

Companies are selected by Boeing based on the transformational technology in development within that company in the fields of autonomy and AI. The program is designed to help startup companies grow into global aerospace ecosystems through supporting innovative technologies and business development. The 90-day program gives access to Boeing, its customers, business and technical specialists in our area of development.

Boeing: Boeing has further signaled their belief in the technology surrounding A3S by directly investing in Pegasus Imagery in Jan 2022. In addition, 6 different segments of Boeing are currently moving forward in different discussions about the opportunities that A3S opens up. These range from incorporating the Pegasus DAA system into Boeing unmanned systems to including it as a value add in future Air taxi technology that is in development.

Kongsberg Geospatial: During the project a MOU was established with Kongsberg Geospatial with the intention of integrating their IRIS Fleet Control Station following the completion of all AB Innovates Milestones. This integration has the potential to enhance A3S's Detect and Avoid (DAA) capabilities and introduce a more user-friendly interface for pilots.

Stantec: Stantec and Pegasus Imagery have an MOU outlining Stantec's interest in Pegasus Imagery's capabilities, providing market validation for their project and value-add options for their customers in environmental monitoring and wildlife surveys.

Thales Canada: Pegasus has signed a Teaming Agreement with Thales Canada. This agreement would see A3S equipped RPAS sharing sensor data across via the Thales Digital Platform (TDP) making this Pegasus technology to be one of

the first systems in Canada to be integrated with TDP. This system will allow for near real-time sharing of data collected by UAS operating BVLOS.

During this project Pegasus Imagery was partnered with Transport Canada and the National Research Council to develop a detect and avoid system for commercialization in Canada. The result of this partnership is the onboard autonomous DAA system A3S developed by Pegasus engineers.

Policy Influence

Pegasus Imagery has worked closely in partnership with Transport Canada and the NRC through the LOOKNorth project. This project was created by the regulator to help shape current and future regulations around commercial RPAS Beyond Visual Line of Sight (BVLOS) activities. Pegasus was one of three commercial organizations involved and was the only company offering an on-board Detect and Avoid (DAA) solution. Projects like LOOKNorth will set the stage for regulatory development to enable commercial growth in Canada. Separately, Pegasus provides input into various areas of both Transport Canada and Innovation Science and Economic Development (ISED) on policy development related to RPA use in Canada. In June, Pegasus provided input to the Transport Canada Regulations Department to support the development of regulations for Low-Risk BVLOS. Those regulations are due to be released in the Summer of 2022. In July 2021, Pegasus provided input on regulatory development to ISED on the rules and spectrum permitted for use by RPAS Command and Control systems. In 2022 Pegasus will participate in two separate TC Task-Groups. One for Advanced Air Mobility (Pegasus' COO) and the other on RPAS Research and Development (Pegasus' Senior Electrical Engineer)

Specific Metrics

Timeline

The timeline for the project was to be completed by November 30, 2021. Despite testing delays due to RPAS equipment availability and procurement delays caused by Covid, the project was completed on time.

Benefits

Successful use and knowledge generated from this technology could result in: Economic impacts like job creation, decrease of costs of data collection, and improved efficiencies on speed and access to data. Environmental impacts could include direct reduction of GHG's by replacing manned aircraft that require significant amounts of fuel to operate, and environmental benefits like wildlife monitoring. Social impacts include fostering industry leadership and entrepreneurial growth, increasing innovation capacity specialization and training abilities.

Economic

Job creation - Employment growth at Pegasus included recruitment of highly skilled positions such as engineering, technical support, and ground crews. Employment growth in supporting Alberta businesses related to drone construction, maintenance, and other specialized areas such as suppliers or companies whose specialize in data post-processing, machine learning, or artificial intelligence.

Decrease Cost of data collected - A reduction in the overall per hour or per area aerial data collection given that human pilots and manned aircraft cost more per hour of flight. These net savings will directly impact government, corporate, and private customers allowing for data to be collected more frequently (if required) or at a lower cost.

Improved efficiencies – Data collection being provided on a near real-time basis will allow for improve efficiencies of decision making. For example, early detection of fire monitoring will allow for faster response to fires, decreasing the potential size of the fire and decreasing the potential impact to forest. The decrease of forest being burned will allow increase of economic impact to lumber companies that will be allowed to harvest areas of the forest that have aged and are high risk for fast burning wildfires.

Direct Investment into Alberta Technology

Pegasus has seen investment into this technology from across Canada. The Boeing Company has also invested directly into Pegasus Imagery after due diligence that looked at the technology that is being developed by Pegasus in Alberta. Pegasus is now in talks with several areas of the Boeing Company to which would see A3S integrated into programs undergoing development.

Environmental

Direct GHG reduction

Comparing GHG emission of AStar 350 B3 (472.50kgCO₂/hr) and the Bell 206 (245.70kgCO₂/hr) helicopters that we've determine to perform a lot of the same services the RPAS with A3S onboard (2.32kgCO₂/hr) could perform; Helicopters emit 106 – 204x more GHG per hour than our solution which is the equivalent of 243 kg CO₂/hr to 470 kg CO₂/hr more emissions.

Pegasus RPAS with A3S onboard is equipped to fly approx. 8 hours, in comparison to helicopters which have to ferry to refuel approx. every 2-3 hours. The cumulative hours ferrying time is a direct reduction (as noted in above calculation) of GHG emission using a RPAS unit that does not required re-fueling as often. In other words, we could enable up to a 99.5% reduction of GHG

emissions by replacing general aviation for data collection tasks with unmanned aircraft.

Indirect GHG reduction

Through early detection of wildfire we can indirectly decrease the GHG emission of wildfires burning. Existing solutions for detecting fires rely heavily on visual observation, enabling wildfires to grow and spread quickly if they are not visible to the human eye. For example, the High-Level fire in 2019 went undetected for 24 hours because a regional fire tower was unoccupied. Our technology will allow for clean, affordable BVLOS detection with accurate wildfire size and rate of spread closing the “opportunity window” for wildfire. This early detection combined with a new level of responsible forestry management that A3S would help unlock would see overgrown forests identified as areas for forestry companies to focus their activities. This would allow for responsible forest management, reducing the opportunities for wildfire while increasing potential forestry company profits.

Wildlife monitoring

Using RPAS for wildlife management has numerous benefits from a human, wildlife, and data quality aspect. One of the biggest advantages to collecting data with RPAS enabled A3S is the ability to perform data collection in remote locations safely, or BVLOS. It has been documented that light aircraft crashes are the top killer of wildlife biologists; in the United States, 66% of documented biologist and scientist field fatalities involved airplanes and helicopters conducting wildlife-habitat observation and radiotelemetry (Sasse, 2003; Audubon, 2014). RPAS are not only a safer method of data collection for humans, but for the wildlife being observed as well.

Widely used forms of wildlife data collection, including human ground survey, aerial fixed-wing survey, and helicopter survey, have high levels of disturbance to animals that impacts wildlife health (Brambilla & Brivio, 2018). RPAS have lower levels of disturbance because population data can be collected without directly entering breeding grounds and ecologically sensitive areas, and support more frequent monitoring due to a decreased resource requirement to perform data collection (Hodgson, 2018). Current RPAS technologies allow known herd sites to be easily mapped and remapped as required, making RPAS an efficient solution to current wildlife problems, such as poaching and herd tracking. A prominent application for drone monitoring in wildlife management is with woodland caribou (*Rangifer tarandus caribou*) populations. The woodland caribou are threatened by habitat loss across Western Canada and have a large indigenous cultural and spiritual importance (Borish et al., 2021; Nagy – Reis et al., 2020). Patterson (2015) has already conducted sample surveys demonstrating the effectiveness of using RPAS for detecting Caribou. A lack of updated, high-resolution data collected by remote sensing technology, specifically LiDAR, of caribou ranges in Western Canada is impeding the recovery and effectiveness of caribou monitoring efforts (Nagy – Reis et al., 2020). Pegasus' technology can easily meet all wildlife management needs of the woodland caribou, such as mapping herd sites, locating radio tagged individuals, and tracking herds as they migrate North.

Another benefit is the data that is provided by RPAS is of better quality than other forms of wildlife data collection, such as human ground survey. Hodgson et al. (2018) reported that data derived from RPAS are, on average, between 43% and 96% more accurate and precise than ground count methods. The mean absolute error of the results was significantly smaller for counts from RPAS imagery at all test heights. Using RPAS decreases the risk for human error and bias because, unlike traditional data collection methods, RPAS create a

permanent data record that can be recounted, error-checked, and automated with Artificial Intelligence (AI) to a high degree of accuracy. RPAS are a “scientifically rigorous data collection tool” that will assist in detecting population trends with more confidence in population estimates (Hodgson et al., 2018). The ability to replicate flights using autonomy provides spatial precision that increases the statistical power for detecting trends within populations from different surveys (Beaver et al., 2020). These results provide strong support for automating the current manual collection process that is reliant on eyesight and memory recall.

Pegasus' technology will be able to overcome short comings presented by current research involving wildlife management by using RPAS as the method of data collection. A3S, is Pegasus' Detect-And-Avoid (DAA) safety system which is assisting with overcoming the regulatory barriers of flying RPAS BVLOS. Pegasus' current sensors allow for an optical zoom of 30 times ensuring clarity of an image and allowing for longer range detection and identification of wildlife during the day. For nighttime applications, the same sensor incorporates an IR camera which allows for 4 times magnification and permits observing wildlife while bedding down, or the activities of nocturnal animals. Payloads can be altered easily in comparison to helicopters according to the task objective to ensure that the data provided meets the requirements of the research. With respect to disturbance, the volume of noise from Pegasus designed RPAS is perceived at 122m (400ft) away is two times less than the perceived sound volume from the average helicopter (Bauman, 2016; Cohen, 2011; Editorial Team, 2020). The Pegasus airframe and high capability sensors are a promising solution for widespread wildlife monitoring.

Thermal imaging is a simple solution to counting individual wildlife that can easily be paired with AI. Beaver et al. (2020) successfully demonstrated the ability for

RPAS thermal imaging to provide safe and cost-effective wildlife population surveys compared to other aerial survey methods. Currently, Pegasus has been able to use their operational camera to correctly identify various wildlife (Figure 10, Figure 11) while deployed for a separate project with Alberta wildfires in 2021.



Figure 10. Locating and identifying moose in Northern Alberta. IR showing moose feeding at night in a forested area at Martin Fire Base, Alberta. Two individual moose can be seen left and center of the frame.



Figure 11. Moose feeding at night in Northern Alberta. Three moose identified by IR in Northern Alberta at the Martin Fire Base during a night flight. The moose were undisturbed by the presence of the RPAS.

A3S allowing BVLOS RPAS flight will provide a method of data collection that is more efficient and precise while being less expensive with lower risks than traditional collection methods (Audubon, 2014). It is important to acknowledge that improving methods of data collection will increase the effectiveness of ecological management actions on the environment (Hodgson et al., 2018). Once the technology is completed Pegasus RPAS capabilities will permit the monitoring of almost any non-discreet species from both land and sea with the ability to effectively track migrating populations. As humans continue to encroach on wildlife habitats and alter their ecosystems, it is our responsibility to safely ensure that we are accountable to our actions and have the data to support actions to protect them.

Social

Industry Leadership – This project has led to the demonstration of DAA technology that in the short term will help with regulatory development through Transport Canada. With predictions of the drone market increasing by over \$5B each year until 2030, this project demonstrates a new area in Alberta where entrepreneurs can succeed. With over 90% of the design, development and manufacturing of this RPAS occurring here in Alberta, this project shows a clear benefit of diversifying our economy into the new aerospace sector.

<https://www.uasvision.com/2022/01/11/teal-group-predicts-worldwide-civil-drone-sales-will-surpass-120-billion-over-the-next-decade/>

Building Innovation Capacity

Specialization - The emergence of Alberta as a drone center of excellence that the global community will draw upon for expert guidance, goods, and services.

Training – Through this project we have grown our Engineering capacity by 50%. Our engineers have developed a high degree of understanding of advanced materials, manufacturing, aerospace and machine learning. Due to their detailed experience in aerospace standards and regulatory research our team is now sought after by Transport Canada. Transport Canada has recently requested the team participate in two separate task-groups (Advanced Air Mobility and RPAS research and Development). This will allow for Alberta voices to have a hand in regulatory development that will shape the industry.

Project Challenges

COVID19 Impact

Pegasus was fortunate because of the large manufacturing facility, strict guideline adherence to covid 19 protocols, early and high vaccination rates

within the company and enhanced sick leave to cope with any minor illness in the office allowed for the team to almost double in size.

The Pegasus engineering team established best practices for working together and built-in redundancy protocols if personnel had to leave on short notice. They advanced the technology despite the additional protocols and were in fact able to pull elements in the technology roadmap forward in the timelines.

While we were mostly insulated from the effects of COVID19, there have been some effects on the company. Covid 19 safety protocols at our testing locations reduced the opportunities for our crews to fly. While the quantity of flights was reduced, the team was still able to hit all the major milestones that the project had established. Including the inflight demonstrations of the technology.

Covid has reduced the company's ability to ad hoc bring in engineering advisors and specialized consultants due to the travel bans and gathering restrictions for in person meetings.

Covid 19 has also impacted the supply chain for specific material required for testing. This has pushed back some testing dates and capabilities while waiting for supplies to arrive. Overall Pegasus was minimally impacted by COVID and was able to continue moving ahead with the project.

Recommendations and Next Steps

Next steps include: (1) The continued development of the A3S technology including continued prototype field testing and making any additional adjustments to prototypes to ensure safest avoidance maneuvers; (2) demonstrations and trials in operational and real-life conditions; (3) continued

discussions with regulatory bodies to ensure full and safe compliance with all applicable rules and regulations.

Continued Development of A3S

Continued testing of the A3S system onboard an RPAS and using smaller drones as intruder aircraft for A3S to autonomously perform avoidance maneuvers in operational environment (in airspace). Using these tests provided to Transport Canada to validate the effectiveness of the DAA system.

Advancing to commercialization will require additional considerations surrounding regulation and standards compliance. Additionally, extensive testing both in simulation and in operational environments will be required to advance to demonstrate the reliability of the technology.

Advanced field testing will include multi-threat avoidances and additional sensors beyond an air-to-air radar. One additional sensor will enable avoidances with cooperative aircraft in contrast to the avoidances completed thus far where traffic is assumed to be uncooperative. Further flight testing with the radar will help identify if any further integration work must be done, especially with respect to issues with ground clutter at large roll angles.

Pilot Situational Awareness: Although some data is already made available to the UAS pilot, further development of the ground control station will see additional features such as full motion video made available to assist the pilot in decision making when flying BVLOS.

Automated Simulation: The completion of the radar simulator allows for simple testing of A3S, but each test must be setup and analyzed individually. Automation of test suites and report generation will make the simulation environment currently in use much more powerful. Using automated simulation, the radar simulator can be used to process machine learning data sets for model training. Machine

learning can help to inform better collision avoidance strategies based on those encountered as part of the training set and any other testing.

Demonstrations and Trials

The success of this project has unlocked several partnerships and teaming agreements with global companies that are looking for this technology to help realize the potential of unmanned aircraft. A teaming agreement with Thales Canada is designed to lead to a demonstration of A3S incorporating additional technology developed by Thales. This joint effort has the intent of supporting Emergency Management personnel across Canada while also reducing the need for high emitting technology currently in use.

A research project funded by Agriculture and Forestry Alberta will begin in Jan 2022. This project is designed to identify the commercial opportunities for unmanned aircraft to support Emergency Management in Alberta. Pegasus has been selected as a research Partner in that study. This project will see demonstrations of Pegasus drone technology as part of the research.

Additional trials of A3S are planned through 2022 to bring the system through TRL 7 to 8 in preparation for commercialization. These trials will include the Government of Alberta, the Rural Municipalities of Alberta (RMA), Transport Canada, CP Rail, Thales Canada, among others.

Aviation Standards Compliance

The work completed to automate collision avoidance maneuvers on a UAS represents many novel technical and regulatory hurdles. The next step in the development of this system is to transition from simple heuristic-based collision avoidance algorithms to more complex algorithms laid out in DAA standards such

as RTCA DO-386 for ACAS Xu. Progress is also being made to achieve compliance with the following aviation standards:

- RTCA DO-178C – Software Considerations in Airborne Systems and Equipment Certification
- RTCA DO-365B – Detect and Avoid MOPS
- RTCA DO-366 – Air to Air Radar MOPS
- ASTM F3442 – Detect and Avoid Performance Requirements
- Canadian National Defense TAM – Technical Airworthiness Manual
- SAE EIA-649C – Configuration Management

Knowledge Dissemination

Current Status: As of December 20, 2021 the following A3S communications have been done in an effort to promote awareness of our technology and the development of the Detect and Avoid system.

Social media Post (Twitter, Facebook, LinkedIn, and Instagram – All are posted at the same time).

- Trade Commissioner Service – Indonesian Webinar, December 14, 2021 – Presented Technology to the Indonesian Military, Navy, Coast Guard, and Air Force.
- National Drone Safety Awareness Day, December 3, 2021 – Promoted the need for A3S for BVLOS safety.
- Promotion of technology from website – November 19, 2021 and continuous
- Promoting funding from AB Innovates and our technology to advance clean data collection methods.

Conference(s):

Rural Municipalities of Alberta (RMA) Trade Show was held on 23 Nov 21, This In person event in Edmonton Alberta, brought together approximate 500 people from the Province of Alberta and municipalities across the province. – Promoted A3S and other Pegasus technology and services.

Upcoming:

- More Social Media Posts throughout the year (minimum of 1/mo) for the foreseeable future.
- Press Release for accelerator program acceptance (international) called Aerospace Xelerated in January 2022.
- Press Release about this project supported through Alberta Innovates February 2022.
- In March 2022, Pegasus was invited to go to Galicia Spain to discuss the future of air space management. The Galician regional government has made the largest public investment in Europe towards the Civil UAV industry and houses the Rozas Aeronautics Research Center for testing of unmanned platforms.
- Attendance at the Alberta Aviation Conference date yet to be announced,
- AUVSI in Florida April 2022, is an Enterprise and Government Solutions (EAGS) is an educational opportunity to speak and feature Pegasus where we will talk about the challenge facing the industry and how our technology is part of the solution.
- RMA Spring 2022 and Fall 2022 conference, a previously attended event that we will continue to share information about our new technology and how it can benefit RMA members.

- Emergency Management Conference, All Hazards was identified put on by NAIT the date is yet to be identified as the February 2022 conference was cancelled due to covid-19.
- Attending a Helicopter Conference, the conference identified for attendance is in Austin Texas in March 2022, Pegasus' attendance is pending funding.

Conclusion

The development of A3S during this project has shown remarkable progress in a challenging Covid environment. The team was able to hit all major milestones. This included a successful demonstration of the technology to Transport Canada and the National Research Council of Canada. Considerable attention has been received by Pegasus from global companies such as Boeing, General Dynamics and GKN Aerospace, amongst others. These are organizations that realize the importance of the technology that is being developed in Alberta. A3S has the ability to unlock the true potential of uncrewed aerial vehicles. A potential where we see improved transportation of commodities; improved data collection to help secure our environment and provide critical information at an affordable rate; and potentially improved transportation of people. As per the goals of Advanced Air Mobility, A3S will assist in unlocking the GHG reductions that is possible with the implementation uncrewed systems. We are excited about this potential, and we are eager to continue pursuing it.

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Wildlife

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AI	Artificial Intelligence
A3S	Autonomous Airspace Awareness System
BVLOS	Beyond Visual Line of Sight
CLI	Command Line Interface
DAA	Detect and Avoid
EAGS	Enterprise and Government Solutions
FOR	Field of Regard
GCS	Ground Control Station
GIS	Geographic Information System
INS	Inertial Navigation System
IMU	Inertial Measurement Units
ISED	Industry, Science and Economic Development Canada
NRC	National Research Council
PIC	Pilot in Command
RMA	Rural Municipalities of Alberta
RPAS	Remote Piloted Autonomous System
TDP	Thales Digital Platform
TRL	Technology Readiness Level