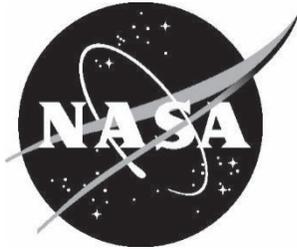


NASA/CR-20210009973



Bell Unmanned Aircraft Systems Integration and Operationalization (SIO) Demonstration: Final Report, Summary of Research

*Bell Textron Inc.
Fort Worth, Texas*

March 2021

NASA STI Program . . . in Profile

Since its founding, NASA has been dedicated to the advancement of aeronautics and space science. The NASA scientific and technical information (STI) program plays a key part in helping NASA maintain this important role.

The NASA STI program operates under the auspices of the Agency Chief Information Officer. It collects, organizes, provides for archiving, and disseminates NASA's STI. The NASA STI program provides access to the NTRS Registered and its public interface, the NASA Technical Reports Server, thus providing one of the largest collections of aeronautical and space science STI in the world. Results are published in both non-NASA channels and by NASA in the NASA STI Report Series, which includes the following report types:

- **TECHNICAL PUBLICATION.** Reports of completed research or a major significant phase of research that present the results of NASA Programs and include extensive data or theoretical analysis. Includes compilations of significant scientific and technical data and information deemed to be of continuing reference value. NASA counter-part of peer-reviewed formal professional papers but has less stringent limitations on manuscript length and extent of graphic presentations.
- **TECHNICAL MEMORANDUM.** Scientific and technical findings that are preliminary or of specialized interest, e.g., quick release reports, working papers, and bibliographies that contain minimal annotation. Does not contain extensive analysis.
- **CONTRACTOR REPORT.** Scientific and technical findings by NASA-sponsored contractors and grantees.

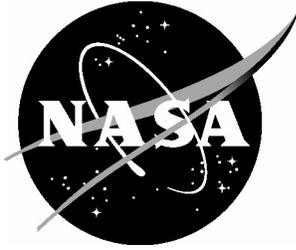
- **CONFERENCE PUBLICATION.** Collected papers from scientific and technical conferences, symposia, seminars, or other meetings sponsored or co-sponsored by NASA.
- **SPECIAL PUBLICATION.** Scientific, technical, or historical information from NASA programs, projects, and missions, often concerned with subjects having substantial public interest.
- **TECHNICAL TRANSLATION.** English-language translations of foreign scientific and technical material pertinent to NASA's mission.

Specialized services also include organizing and publishing research results, distributing specialized research announcements and feeds, providing information desk and personal search support, and enabling data exchange services.

For more information about the NASA STI program, see the following:

- Access the NASA STI program home page at <http://www.sti.nasa.gov>
- Help desk contact information:
<https://www.sti.nasa.gov/sti-contact-form/>
and select the "General" help request type

NASA/CR-20210009973



Bell Unmanned Aircraft Systems Integration and Operationalization (SIO) Demonstration: Final Report, Summary of Research

*Bell Textron, Inc.
Fort Worth, Texas*

National Aeronautics and
Space Administration

Langley Research Center
Hampton, Virginia 23681-2199

Prepared for Langley Research Center under
Cooperative Agreement 80AFRC19M0004

March 2021

The use of trademarks or names of manufacturers in this report is for accurate reporting and does not constitute an official endorsement, either expressed or implied, of such products or manufacturers by the National Aeronautics and Space Administration.

Available from:

NASA STI Program / Mail Stop 148
NASA Langley Research Center
Hampton, VA 23681-2199
Fax: 757-864-6500

18-SIO-0007: Bell Unmanned Aircraft Systems Integration and Operationalization (SIO) Demonstration

Final Report, Summary of Research

**Period Covered by Report
10/29/2018 – 10/31/2020**

Bell Textron Inc.
3255 BellFlight Blvd
Fort Worth, Texas
76118

Cooperative Agreement Number
80AFRC19M0004





Document Change Record

Version Number	Date	Reason for Change	Sections Affected
1.0	10.22.2020	Original Release	-



Table of Contents

DOCUMENT CHANGE RECORD	1
TABLE OF CONTENTS	2
LIST OF FIGURES	4
LIST OF TABLES	6
INTRODUCTION	9
SIO DEMONSTRATION CONCEPT OF OPERATIONS (CONOPS) OVERVIEW	10
BELL APT 70 OVERVIEW	14
COMMAND AND CONTROL (C2)	16
Radio Performance	16
C2 Testing Results	17
APT 70 C2 Flight Testing	18
Scalability	19
Safety and Cybersecurity	20
C2 Technology Gaps.....	20
DETECT AND AVOID	21
Airborne Detect and Avoid System	21
Radars	22
Electro-Optical (EO) Cameras.....	22
ADS-B Receiver	23
DAA Supporting Hardware	24
DAA Installation for SIO	24
DAA Software and Performance	25
DAA Targets Observed during Demonstration Flight.....	26
Demonstration DAA Information	31
DAA Technology Gaps.....	32
<i>Limits of Camera Detection Capabilities</i>	33
CASA WEATHER AVOIDANCE SYSTEM	34
System Testing.....	35
Flight Weather Display and Alerting Console (FlightDAC).....	35
CityWarn™ Hazard Notification System	38
SAFETY AND CERTIFICATION	39
Airworthiness Artifacts.....	39



CONCLUSIONS42



List of Figures

Figure 1. Bell SIO Demonstration Mission Profile.	11
Figure 2. APT 70.	14
Figure 3. Sample GCS Display with C2 Link Highlighted.	17
Figure 4. ABDAA System Architecture.....	21
Figure 5. DAA Radar Horizontal View of Field of Regard.....	22
Figure 6. DAA Radar Isometric View of Field of Regard.	22
Figure 7. FLIR Camera Specifications.	23
Figure 8. DAA Camera System Horizontal View of Field of Regard.....	23
Figure 9. uAvionix EchoUAT Receiver.....	24
Figure 10. DAA Pod Assembly (before paint).	25
Figure 11. DAA Components Installed in Pod.....	25
Figure 12. DAA Target Information.	27
Figure 13. DAA ADS-B Targets on DFW International Final Approach.	28
Figure 14. DAA ADS-B Target at Floyd Carlson Field.....	28
Figure 15. Ghost Radar Track.	29
Figure 16. Multiple Ghost Radar Tracks.	30
Figure 17. APT Portable GCS.	30
Figure 18. GCS Display with DAA Specific Information Highlighted.....	31
Figure 19. Demonstration Aircraft Tracks on GCS.....	32
Figure 20. Weather Display Monitor at the Ground Station.	34
Figure 21. CASA D/FW UAS Weather Display.	35
Figure 22. CASA UAS Weather Tool Closeup.	36
Figure 23. CASA Weather Tool with Local Precipitation.	36



Figure 24. UAS Risk Classes (from FAA Draft AC 21.17-XX)41



List of Tables

Table 1. Air Logistic Missions Details.....	10
Table 2. C2 Test SNR & Throughput Summary.....	18
Table 3. DAA Supporting Hardware.....	24



Acronyms

ABDAA	Airborne Detect and Avoid
ADS-B	Automatic Dependent Surveillance-Broadcast
AGL	Above Ground Level
ASOS	Automated Surface Observing System
ATO	FAA Air Traffic Organization
BVLOS	Beyond Visual Line of Sight
C2	Command and Control
CASA	Collaborative Adaptive Sensing of the Atmosphere
CNPC	Command and Non-Payload Control
COA	Certificate of Waiver or Authorization
COTS	Commercial off-the-shelf
DAA	Detect and Avoid
DFW	Dallas/Fort Worth International Airport
D/FW	Dallas - Fort Worth metropolitan area
EMI	Electromagnetic Interference
ES	Extended Squitter
EO	Electro-Optical
FAA	Federal Aviation Administration
FCC	Federal Communications Commission
FPV	First-Person View
FRC	Bell Flight Research Center
GCS	Ground Control Station
HITL	Hardware-In-the-Loop
INS	Inertial Navigation System
IP	Internet Protocol
LOS	Line of Sight
LTE	Long Term Evolution
MCS	Modulation Coding Scheme
MOPS	Minimum Operational Performance Standards
NASA	National Aeronautics and Space Administration



RF	Radio Frequency
RPIC	Remote Pilot in Command
SA	Signal Analyzer
SIL	System Integration Lab
SIO	Systems Integration and Operationalization
SNR	Signal to Noise Ratio
SWaP	Size, Weight and Power
TRB	Trinity River Bottom
TSO	Technical Standard Orders
UA	Unmanned Aircraft
UAS	Unmanned Aircraft System
UASSC	Unmanned Aircraft System Standardization Collaborative
UAT	Universal Access Transceiver
UAV	Unmanned Aerial Vehicle
VFR	Visual Flight Rules
VMC	Vehicle Management Computer



Introduction

National Aeronautics and Space Administration (NASA) initiated the Unmanned Aircraft Systems Integration and Operationalization (SIO) demonstration as a partnership between NASA and Industry with the goal of accelerating routine unmanned aircraft systems (UAS) operations in the national airspace (NAS). In order to accomplish this goal, NASA partnered separately with Bell and two other industry teams each pioneering the development, integration, and testing of their UAS, with the intent to make progress towards type certification. The program culminated in flight demonstrations representing future commercial operations by each partner.

Bell's team along with its teammates, Xwing, and University of Massachusetts at Amherst's Collaborative Adapting Sensing of the Atmosphere (CASA), demonstrated on September 28, 2020 an urban mission profile representing the flight environment of potential commercial missions using the APT 70 in the National Airspace System (NAS) to advance the technologies required for autonomous beyond visual line of sight (BVLOS) flight operations over people in urban environments through uncontrolled (Class G) and controlled (Class B) airspaces. The APT 70 gained approval to fly 500-1,000 ft above ground level.

The BVLOS technologies examined were Airborne Detect and Avoid (ABDAA) and Command and Control (C2). Various test methods were utilized at a component, system and aircraft level in build up to the flight demonstration. Supporting a step-by-step approach, these methods included lab and bench testing, hardware in the loop (HITL) testing, system level ground testing, airborne test beds and aircraft integration testing. Tests addressed operational capabilities necessary for flight operation in urban environments as well as preparatory flights for and execution of the NASA SIO demonstration.

This effort also explored airworthiness required to complete the SIO mission and certification requirements for future type certification of the aircraft for urban missions. A formalized concept of operations was developed for the urban mission. From that mission profile, a risk-based safety assessment was derived. The assessment included risk levels and mitigations. These documents formed the basis for discussions with the Federal Aviation Administration (FAA) on airworthiness and flight approvals and submission of airworthiness artifacts.

While much remains to be completed for routine flight operations in urban environments, the Bell SIO demonstration is a stepping stone towards that future. Data collected and lessons learned during the demonstration will support future standards development and FAA certification guidelines.



SIO Demonstration Concept of Operations (CONOPS) Overview

The APT 70 is an air logistics platform. With a payload capacity up to 70 lb (31.2 kg), its vertical take-off and landing (VTOL) capability makes it ideal for routine transportation missions with a small ground operating footprint.

Bell examined three different, low altitude, logistic mission scenarios for implementation as SIO demonstrations with the APT 70: urban critical medical transport, disaster relief support and offshore cargo transport. Each mission was envisioned to employ vertical take-offs and landings, operate at altitudes between 500-1,000 feet above ground level (AGL), include challenging C2 requirements, and have payload requirements of up to 70 pounds. Each of these three scenarios presents its own unique challenges and risks; each is an economically viable commercial mission. Of the three, the urban critical medical transport was selected for the demonstration. The mission represents the most challenging of the command and control system requirements due to the noisy radio frequency (RF) environment and the challenges of radio line-of-sight due to infrastructure obstacles. In addition, the DAA system had to accommodate the complications of an urban environment at low altitudes. The urban mission captured valuable data to enable a pathway for future routine UAS operations in metropolitan areas.

Table 1. Air Logistic Missions Details.

Mission	Cruise Altitude (ft, AGL)	Landing Zones
Urban Critical Medical Transport	500-1,000	Hospital Helipads & airports
Offshore Cargo Transport	500-1,000	Existing flight operations centers
Disaster Zone Relief	500	Non-standard zones

The Bell team consulted with multiple medical entities within the Dallas–Fort Worth (D/FW) area to discuss potential applications of the APT 70 platform for their operations. Several applications were found to reduce the time for organ transplants or blood transport. Possible flight paths were identified and examined for safe operations. The business case mission selected was the transportation of a blood sample from a donor location to the blood analysis center. In the D/FW area, a flight path from near downtown Fort Worth to the facility north of downtown Dallas was identified. This flight path drove the requirement for transition into and out of controlled airspace with flights over people which would represent operations in many metropolitan areas. Discussions with the FAA determined that a type-certified aircraft would be required to accomplish this future mission.



The future mission profile evolved utilizing feedback from both NASA and FAA to a selection that could be accomplished within the period of performance. For the SIO demonstration, a reduced portion of the proposed future medical mission was generated. As illustrated in Figure 1, the SIO flight path was 8.2 nautical miles long over unpopulated and undeveloped areas in the Dallas/Fort Worth metroplex in Texas. It included uncontrolled (Class G) and controlled (Class B) airspace. The shaded area is the flight area as defined in the approved Certificate of Waiver or Authorization (COA). The flight path is depicted by the red curve.

The flight path was planned to begin at the at Bell Training Academy's Floyd Carlson Training Field in Fort Worth, Texas, in Class G airspace and to transition into and out of Class B airspace near the Dallas/Fort Worth International Airport (DFW). The entire flight path was west of the DFW arrival and departure flight patterns with approximately 1 mile of lateral separation from the DFW traffic patterns. Additionally, flight path in Class B space was flown at 500 ft AGL to maximize both the lateral and vertical separation from the DFW traffic pattern.

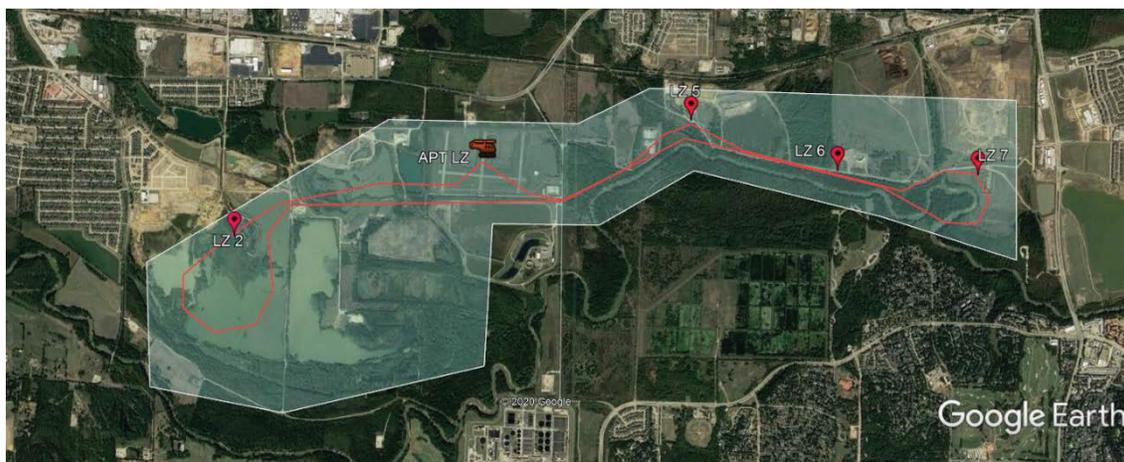


Figure 1. Bell SIO Demonstration Mission Profile.

Through the evolution of the mission profile, mitigations and requirements were identified to maintain ground and air safety for an experimental aircraft. Some of the requirements were driven by the limitations of the airworthiness approvals. Others were identified as part of the operational risk assessment. Much of the focus of the mitigations related to preventing flight over non-participating people, flight in controlled airspace, spectrum, lost link procedures, and DAA mitigations.

Certain exemptions to FAA regulations were required for flight operations. The exemption granted for the APT 70 by the FAA prohibited flight over non-participating people.. The first level of mitigation for this limitation was to select unpopulated regions within the urban environment. While much of the Dallas-Fort Worth Metroplex is built up, the river and flood plains near the Bell facility in Fort Worth remain unpopulated. These lands were either restricted access public lands for the City of Arlington and City of Fort Worth or private property. The next mitigation was to maintain a one-to-one separation from populated areas. Every foot of altitude (vertical) required at least one foot of horizontal distance from populated areas. This mitigates inadvertent flight over people in the event of a motor failure.



The flight path was designed to minimize road crossings. The flight path only crossed one public road in Fort Worth and flew near one service road on City of Arlington property. For safety, Bell elected to follow city procedures to close the public road during the flight. This was done utilizing off-duty city police officers, Bell security officers and visual observers located at the road crossing. Two-way radio communication between ground crew and visual observers was maintained to trigger traffic stoppage and to verify a clear road for vehicle crossing. While the service road has low traffic, the City of Arlington agreed to a temporary road blockage during flight operations. The city was also provided a 24-hour notice of the planned flight operations.

An additional layer of safety to mitigate inadvertent flight over people was the implementation of a geofence in the flight plan. If the geofence was crossed, the aircraft would initiate a hover hold maneuver and wait for further commands. The geofence boundary was programmed as part of the flight planning. The geofence was established at a minimum of 500 feet inside the boundary of the approved flight area. The functionality of the geofence was tested during remote testing phase.

The FAA scrutinized spectrum selection and the automated lost link procedures. Bell selected spectrum based on radio availability, required C2 data exchange rates to monitor the aircraft during flight, diversity of band selection and input from the FAA and NASA. For the SIO demonstration and part of the FCC license process, the FAA provided concurrence for temporary, experimental use of C band frequency.

Automated lost link procedures are critical to air safety. They define how an aircraft will behave if it loses communications with the ground control station (GCS) and is unable to reestablish communications within a given time. Since DAA maneuver execution required input from a pilot, Bell had to define additional lost link procedures to minimize the risk of a mid-air collision. One such example was pre-programmed emergency landing zones along the flight path. These locations were chosen to minimize the distance traveled and the exposure time in the air should the aircraft execute an emergency procedure. As part of the airworthiness discussions, Bell generated a white paper to provide additional clarity and documentation of the APT 70's lost link procedures.

As the airborne DAA system is a prototype, visual observers were used as a primary means of satisfying the see and avoid requirement. There were primary and secondary visual observers utilized during the demonstration. The primary visual observer was airborne on a Bell 407 chase helicopter. He was able to observe the aircraft the entire flight and was in radio communication with the remote pilot in command (RPIC) on the ground. The secondary visual observers were ground based. Two visual observers were stationed at each of the emergency landing zones. One to keep the landing zone clear and the second to observe the aircraft during its flight. They were in radio communication with the Test Director during the entire flight.

Each visual observer underwent Bell training before being allowed to deploy. Handoffs between visual observers were defined per established procedures and practiced as part of flight testing at the remote locations. At preflight briefings, the flight test engineer conducted a review of the required procedures and mission details. Information related to the training was shared with the FAA as part of the COA application process.



Transitioning in and out of Class B airspace required involvement and approvals from the FAA Air Traffic Organization (ATO). When the ATO was presented with an early version of the mission profile, concerns about the aircraft's proximity to the take-off and landing corridors for the DFW airport were identified. The team examined each of the concerns and modifications made to the flight path to address the concerns. The final mission profile was approved to allow entry into Class B airspace. The eastern portion of the flight path maintained a separation greater than 3,000 ft horizontal distance from the DFW 18R Departure Area.

The issued COA identified procedures and contacts for interactions with local DFW aircraft. This included pre-coordination requirements, identifying mission profiles, and points of contact for run-away or lost link events. Further coordination with the local ATO established the chase helicopter would provide an ADS-B signal and communications with the DFW tower during the demonstration.

Having specific objectives and clear definition of the mission concept of operations assisted with identifying and addressing concerns early in the SIO activity.



Bell APT 70 Overview

The Bell Autonomous Pod Transport (APT) program consists of a family of unmanned aircraft that Bell intends to bring to the commercial market as an unmanned logistics solution. The APT unmanned aircraft systems (UAS) are electric tail-sitter vertical takeoff and landing (VTOL) aircraft. The tail-sitter configuration gives the APT the hover maneuverability of a multi-copter, and the speed and range of a fixed wing aircraft. The aircraft are designed to autonomously take off and land in a vertical orientation and transition into a horizontal orientation for forward flight with autonomous waypoint following. Using its wings for lift, the APT reduces its enroute power consumption enabling increased speed and range compared to conventional VTOL aircraft. Currently, the APT family consists of two models: The Bell APT 20, which is a sub-55 lb gross weight (GW) aircraft designed to carry a 20 lb payload, and the Bell APT 70, which is a 320 lb GW aircraft designed to carry a 70 lb payload. The SIO activity utilized the Bell APT 70.



Figure 2. APT 70.

The APT 70 is nine feet wide and the height is six feet. The airframe structure consists of two wings and two pylons, four vectored thrust modules (VTMs) located at the wing tips and a cargo pod. The structure is made from metal, composites, and additive manufactured parts and components. The propulsion system for the APT 70 consists of four VTMs, each with an electric motor directly driving a 4-bladed fixed-pitch propeller. Each electric motor is powered by two lithium polymer (LiPo) batteries. The Flight Control Computer (FCC), sensor suite, and other flight control hardware are distributed about the airframe as necessary.



The cargo pod is positioned between two pylons which join the biplane wings. The cargo pod is adaptable to the customer's mission and payload requirements. This flexibility of design enables easy integration of the prototype DAA system hardware while accommodating the space required to simulate transport of medical cargo. The mission cargo considered was insulated boxes for transport of blood or tissue samples. As utilization of UAS increases for medical transport, pods could be designed to meet the specific requirements of organ transfers.

Command and Control (C2) is accomplished using two redundant and independent radios. The C2 links are managed by a proprietary system designed to provide data from the strongest link. The information provided through the C2 links is transmitted to the GCS.

The GCS provides the remote pilot information displays that include mission planning capability, mission progress information, aircraft status information, DAA information, and Datalink information. An additional display showing a weather application was used during the SIO demonstration.

A remote pilot conducted and monitored flight operations for the APT 70 during SIO testing and demonstrations. Although the demonstration was an autonomous flight, with the pilot using the ground control station to provide mission planning, the pilot had the ability to take over manual control of the aircraft at any time if necessary. During its autonomous flight, the APT 70 launched following a GCS command to initiate the mission. The UA continued the autonomous flight executing the pre-programmed mission profile and autonomously landing at the designated landing waypoint.

The SIO demonstration incorporated DAA capabilities into the APT 70 UAS to facilitate future integration into the national airspace system. The prototype DAA system was designed to provide air traffic information to the pilot as well as maneuver guidance for any conflicting flight paths with other aircraft. The APT 70 flew the SIO demonstration with the prototype DAA system integrated. The system collected data to assist in the performance evaluation of DAA systems for future applications. No encounters were planned for the SIO flight demonstration and no unplanned encounters requiring evasive maneuvering occurred. The DAA system detected commercial flights in and out of DFW airport during the demonstration flight however none of them were close enough to warrant an avoidance maneuver. The DAA system was programmed to ignore the chase helicopter with respect to maneuver alerting.



Command and Control (C2)

For the SIO demonstration, the UAS's dual RF links provided a robust command and control capability through datalink redundancy. Arbitration hardware and software were implemented in the system design to accommodate link failures and utilize the strongest C2 link.

The Bell SIO aircraft C2 datalinks consisted of two different and independent radios operating on different frequencies. Radio datalinks selected were a Persistent Systems MPU5 radio set and a Silvus StreamCaster radio set. Manual RPIC inputs could be provided through both datalinks as a backup means of controlling the aircraft. Data was simultaneously transmitted on both links and a set of airborne and ground based arbitrators utilized the highest quality link between the aircraft and GCS.

Persistent Systems MPU5 radio datalink spectra used was C-band at 5.200 GHz and the Silvus StreamCaster radios datalink spectra used was S-band at 2215.475 MHz. FCC approval was received for use of the RF bands during the SIO demonstration. The tracker antenna had a gain of 32 dBi at C-band and 23 dBi at S-band, resulting in Effective Radiated Power (ERP) of 2427.5 W and 385 W, respectively.

A Troll Systems MT-300 auto tracker antenna was used with the GCS. It featured a dual-band left-hand and right-hand circular polarization high gain antenna feed with a vertical polarized omni antenna for each radio RF stream totaling five omni antennas for short range operations.

The MT-300 tracker antenna featured two radio enclosures mounted on the side of the tracker for the Silvus and Persistent Systems radios. The tracker antenna could be configured to manually or automatically switch between the high gain directional antenna for long range operations and omni-directional antenna for short range operations. The SIO demonstration utilized the manual switching mode.

The tracker antenna provided autonomous tracking in azimuth and elevation with continuous rotation. It had the ability to follow the aircraft's position using the aircraft's GPS and/or RF tracking of an onboard beacon or radio signal. The GPS tracking feature was used for the SIO demonstration. The tracker featured a built-in dual GPS with high-precision INS for auto-calibration.

The Ubiquiti Edge Router arbitrator, on the APT and a corresponding one on the GCS, utilized the multiple links to increase communication reliability and decrease average latency. The arbitrators sent all flight critical data through both links synchronized and without duplication.

Radio Performance

The Persistent Systems MPU5 transmitted 6 W of power with a sensitivity of -94 dBm at the low modulation and coding rate and -72 dBm at the high modulation and coding rate. The Silvus transmitted 4 W of power with a sensitivity of -99 dBm (per the datasheet). The C2 datalink signal strength was monitored by the GCS operator during all flight operations.

The minimum C2 data rate for operating the APT 70 was 0.7 Mbps for flight critical control. Utilization of one of the onboard video systems increased the total data rate to 2.2 Mbps. Prior



to approval for launch, the link's data rate were verified to be large enough with safety margin to successfully accomplish the mission requirements.

The overall system one-way latency (all datalinks utilized) was expected to be less than 128ms, which would be consistent with the DO-362 C2 Datalink MOPS (Terrestrial) requirements. Signal latencies were expected to be similar in both directions.

The SIO C2 capacity/throughput was limited by each of the individual link's capacity/throughput. The additional links do not increase the throughput of the system as a general rule, however the effective throughput can be increased by means of unbalanced packet losses. Since the SIO C2 system has line-of-sight (LOS) links, the links operated nominally out to at least 3.2 miles, which encompassed the planned flight path. The aircraft C2 data was recombined on the ground into a singular, synchronized data stream, automatically based on data packet sequence numbering. The data was automatically handed-over between links as links changed based latency or packet losses; so, there were no explicit hand-overs.

The RPIC had a constant display of C2 link quality for each link. During the SIO demonstration flight, no signs were observed of a multiple link degradation that would have initiated a return to base maneuver to improve link quality. A sample screen shot of the GCS display is shown below in Figure 3.

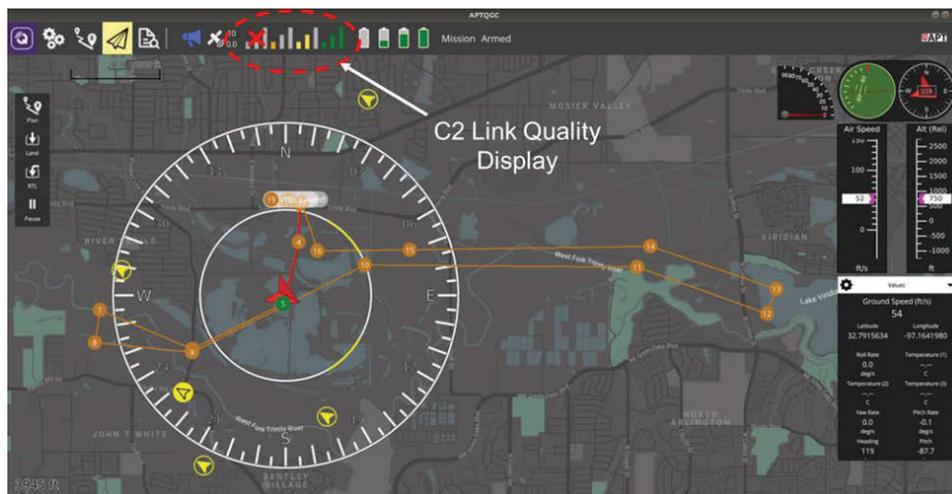


Figure 3. Sample GCS Display with C2 Link Highlighted.

C2 Testing Results

Prior to installation on the APT 70, the C2 system underwent lab and risk reduction testing. The C2 system testing included testing of the radio frequency (RF) and long-term evolution (LTE) links as well as the arbitration equipment. Lab and flight testing using a Bell Flight Research Center (FRC) helicopter were accomplished to characterize the system throughput performance, datalink integrity, datalink range, and C2 system performance along the planned NASA SIO demonstration flight path. The system accumulated over 40 hours in the lab and over 8 hours of flight test prior to integration on the APT 70.



The significant configuration selections and observations after analyzing the results of the FRC C2 testing were:

- Omni to Omni link selected only for close range operations.
- The use of the High Gain to Omni link satisfied the needs of the SIO operation.
- The Silvus 5 MHz and MPU5 10 MHz bandwidths are the recommended options based on SNR and throughput performance.
- No interference was observed between the Silvus & MPU5 when they were both powered ON.
- The signal path from the GCS to both extreme ends of the flight path had a clear Line of Sight (LOS) and was free from any obstruction within the first 3 Fresnel Zones.

A summary of select measured signal to noise ratios (SNR) and throughput data for both radios are presented in Table 2. The table shows values for omni to omni and high gain to omni modes at extreme ends of the planned flight path.

Table 2. C2 Test SNR & Throughput Summary.

	Omni to Omni at 0.3 miles		High Gain to Omni at 3.2 miles	
	SNR (dB)	Throughput (Mbps)	SNR (dB)	Throughput (Mbps)
MPU5 (10 MHz.)	43	13	32	9
Silvus (5 MHz.)	24	17	16	8

The results of the FRC C2 flight testing verified that the current C2 SIO configuration satisfied the estimated requirement of 3.7 Mbps for operating the onboard video and far exceeded the minimum requirement of 0.7 Mbps.

APT 70 C2 Flight Testing

APT 70 flight testing occurred in both rural and urban areas. The two locations had different tracking antenna setups that impacted the overall performance of the links.

- For the rural area test setup, the tracking antenna was mounted on a five foot tripod set on the ground. In this condition, the Fresnel zones 1-3 were partially blocked.
- For the urban area, the tracking antenna was mounted on a five foot tripod set on top of a 50 foot platform. For this setup, the Fresnel zones 1-3 were clear.

Flights less than 0.4 nmi from the tracking antenna utilized the ground omni antenna and flights further than 0.4 nmi from the tracking antenna utilized the directional antenna. Data was collected



out to 2.2 nmi distance from the tracking antenna. Both the air and ground radios showed a SNR improvement in the rural area over the urban area when using the omni antennas. The reason was attributed to the RF noise floor being lower in the rural area than the urban area, which was to be expected.

For flights utilizing the directional antenna, the partial blockage of the Fresnel zone in the rural flight area negated the benefits of the low noise floor. As a result, the SNR for the ground radios were about the same while the airborne radios seemed to benefit from the rural area.

The individual radios also performed differently with respect to each other. On the ground side, both radios' SNR stayed above 23 dB with the average being well over 30 dB.

The individual radios also performed differently with respect to each other. On the ground side, both radios' SNR stayed above 23 dB with the average being well over 30 dB. The airborne radios exhibited different results. Having two antennas on the aircraft, the Silvus had a minimum SNR of 11 dB in the urban area and 24 dB in the rural area. The airborne Silvus radio had an average SNRs of 22 dB and 33 dB in the urban and rural areas, respectively. With three antennas on the aircraft, the airborne MPU5 had minimum SNR of 24 dB for both flight areas and average SNRs of 36 dB and 33 dB in the urban and rural areas, respectively.

The differences in the airborne Silvus radio and the MPU5 can be attributed to the Silvus antenna orientation being sub optimal, where the full null of the antenna's radiation pattern possibly pointed to the tracker antenna on the ground. One possible performance improvement is to switch the Silvus airborne antennas to half null blade antennas. Additionally, the MPU5 operated on a ground directional antenna with an inherently higher gain in C-band.

Radio data rate stayed between 7 and 18 Mbps throughout the test flights, which exceeded the SIO requirements.

Scalability

The spectrum usage for the SIO demonstration was not in accordance with DO-362 due to hardware availability. Frequencies used were 2215.475, 2271.225 and 5200 MHz in accordance with the FCC license. The C2 system could support any frequencies within the S-band (2200-2500 MHz) and Upper C-band (5100-6000 MHz). As command and non-payload control (CNPC) radios become available, the CNPC specific frequencies can be utilized in lieu of the current frequencies. There are concerns about the available bandwidth that will need to be addressed with CNPC frequencies. Future Bell commercial operations will use a downward facing camera for the RPIC to verify that a remote landing zone is clear of people and obstructions. Bell considers this a safety of flight issue and will need sufficient C2 bandwidth to accomplish this task.

The APT 70 C2 system design is manufacturer and hardware agnostic but does impose the requirement that the radio must be IP based. The system has also been shown to work with cellular based radios and direct LOS radios. The Troll auto tracker system is also radio agnostic. However, the SIO tracking antenna was optimized for Silvus and Persistent Systems radios.



Safety and Cybersecurity

The Silvus radios use the encryption standard: DES Standard, AES/GCM 128/256 Optional (FIPS 140-2), Suite B. The Persistent Systems MPU5 encryption standard is: CTR-AES-256 Encryption, HMAC-SHA-256 Authentication & Integrity, utilizing Suite-B Algorithms.

Due to the system constraints and the novelty of the system, this C2 system was secured taking formal security standards into consideration but not directly meeting one particular standard. The C2 system was designed to be secured from the external channels and each internal subsystem was designed to be locked down only allowing through expected communications.

C2 Technology Gaps

Remote Landing C2

The commercial CONOPS for the APT 70 includes the need to successfully maintain a C2 link while performing remote, BVLOS landings. Direct line-of-sight RF links will lose link as an aircraft descends to its remote landing location unless some additional technology is implemented. This could take the form of a remote radio link to the GCS, satellite communications, LTE technology or something else. Additional research is needed for low-SWaP technology to accomplish this task.

CNPC Radio Bandwidth

Initial investigations in the proposed CNPC frequency allocation showed possible bandwidth limitations for future Bell commercial APT 70 operations. Since the proposed operations include remote BVLOS landings, those landings will require confirmation that the landing zone is clear of people or objects; Bell considers having a live video feed of the landing zone for RPIC evaluation a flight safety item. Depending on the nature and quality of such imagery, the bandwidth for CNPC radios may not be adequate for these operations. Additional research will need to take place to establish required image quality and frequency of image refresh rates for safe landing zone determination. Additionally, research is required to find alternate methods for verification of remote landing zones while using limited CNPC bandwidth radios.



Detect and Avoid

The second technology area explored to achieve routine BVLOS flight operations was that of detect and avoid (DAA) systems. This technology area strives to substitute the trained eyes of a pilot in the cockpit with a combination of sensing, algorithms and situational data. This can be a combination of ground-based sensing and/or air-based sensing, and situational data shared between the ground and air platforms.

For the SIO demonstration, the Bell team integrated an airborne, multi-sensing DAA system on the APT 70. The air-based sensing comprised of low SWaP radars, a visual system, and ADS-B information. The data was processed on-board the aircraft and was designed to send tracks, alerts and maneuver recommendations to the GCS through the C2 datalink.

Airborne Detect and Avoid System

The airborne detect and avoid (ABDAA) system was designed and developed by Xwing and integrated by Bell. The ABDAA system consisted of two Echodyne EchoFlight radars, three FLIR HD ethernet cameras and an uAvionix ADS-B receiver. Figure 4 shows an overview of the ABDAA System architecture. Developed by Xwing, the system was integrated as an independent system on the APT 70 for support of the NASA SIO demonstration. The ABDAA system was operational during the demonstration but was not the primary means of traffic avoidance. The downlink and display on the GCS were tested during prior flights.

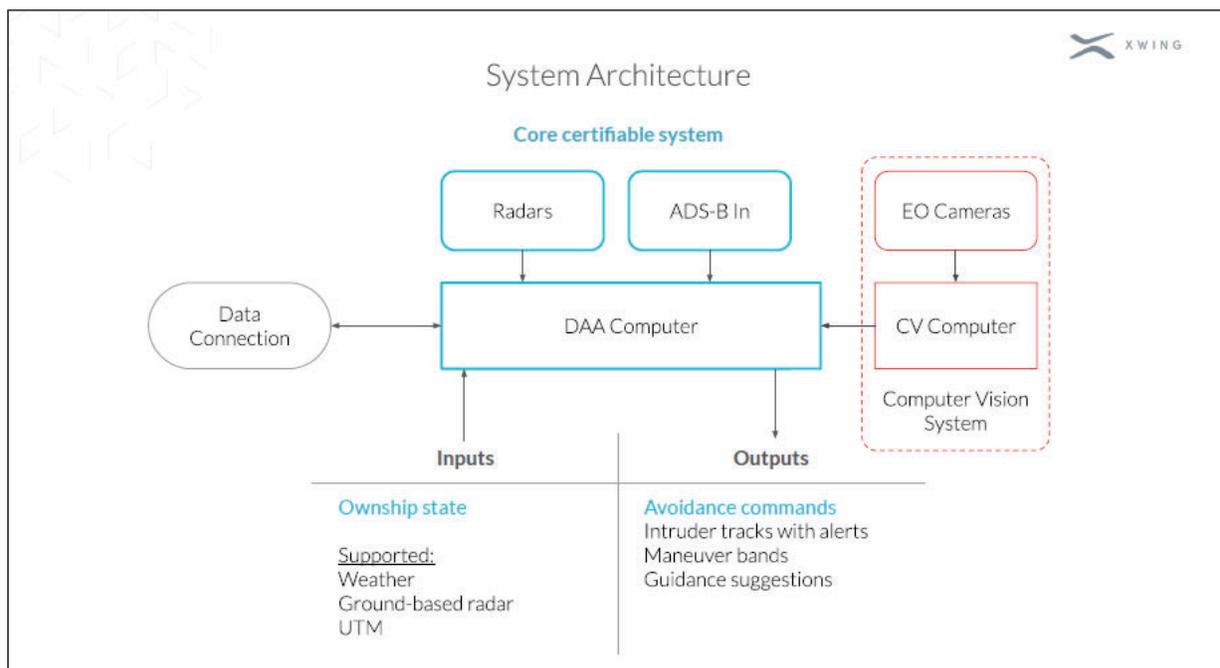


Figure 4. ABDAA System Architecture.



Radars

Two Echodyne EchoFlight radars were used for the radar sensors in the ABDAA system. The radars were configured to provide a forward horizontal field of view of 220° and a vertical field of view of 60° as shown in Figure 5 and Figure 6. The detection ranges for small general aviation aircraft after the inclusion of ground filtering during testing was approximately 4,500 – 6,500 ft depending on encounter geometry and relative speeds. The radar updated radar tracks at 10 Hz per track and had a volume scan of 1 to 2 Hz varying with the number of tracked objects.

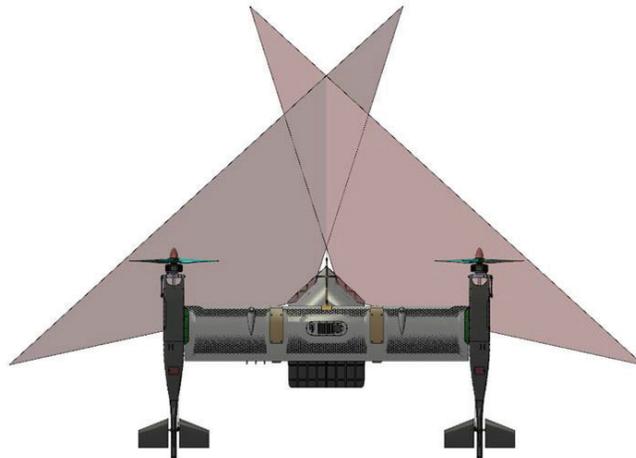


Figure 5. DAA Radar Horizontal View of Field of Regard.

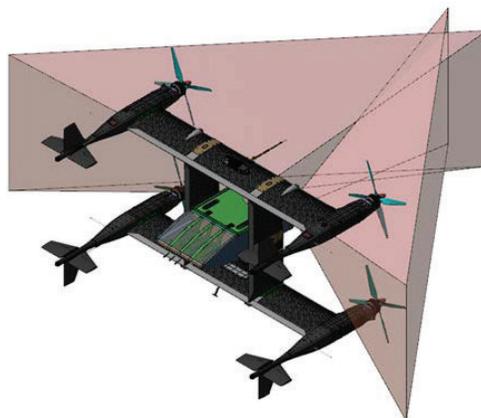


Figure 6. DAA Radar Isometric View of Field of Regard.

Electro-Optical (EO) Cameras

The Bell demonstration aircraft utilized a computer vision system consisting of three FLIR high definition cameras and a vision computer to verify aircraft detections. The FLIR camera specifications are shown in Figure 7. The cameras were arranged to provide over 220° horizontal field of view and over 60° vertical field of view as shown in Figure 8. Detection ranges and target



size capabilities for the camera vision system demonstrated the ability to identify a helicopter track over 9,000 ft away. The cameras had an update rate of 10 Hz spread across all existing tracks.



Field of View:	80° x 60°
Interface:	Serial
Size:	1.14" x 1.14" x 1.18"
Weight:	.079 lb
Power:	< 3 W (12V)
Environmental:	0 to 50 C operating temperature < 80% humidity non-condensing

Figure 7. FLIR Camera Specifications.

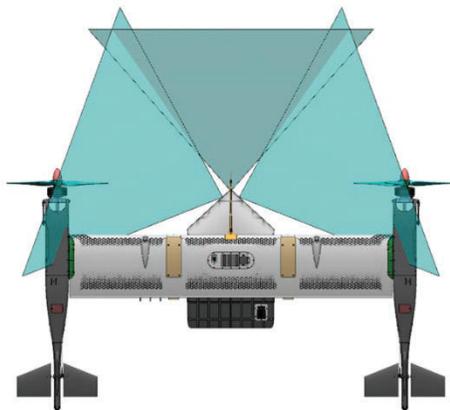


Figure 8. DAA Camera System Horizontal View of Field of Regard.

ADS-B Receiver

A uAvionix EchoUAT ADS-B receiver was installed to collect air traffic information on the 978 MHz Universal Access Transceiver (UAT) and 1090 MHz Extended Squitter (ES) frequencies. The EchoUAT is a non-TSO'd receiver and its specifications are shown in Figure 9. ADS-B data is updated at 1 Hz per track. The ADS-B data was used for airborne track generation and was also fused with the radar and camera data for improving the location of cooperative traffic.



Model:	uAvionix EchoUAT
Interface:	Serial
Size:	2.17" x 2.56" x .75"
Weight:	.132 lb
Input Voltage:	11-33 V DC
Environmental:	-45 to 70°C operating temperature 18,000 feet altitude

Figure 9. uAvionix EchoUAT Receiver.

DAA Supporting Hardware

In addition to the sensors, the DAA system included onboard processing and routing/connection hardware. The prototype system utilized two commercial off-the-shelf (COTS) computers. The DAA computer handled the fusion of the sensors and the processing of the DAA algorithms. The Vision computer processed the digital camera data for inclusion within the DAA algorithms. Both computers had the capacity to store collected data. Table 3 provides more detailed specifications on the major supporting components.

Table 3. DAA Supporting Hardware.

Function	Component	Size	Weight	Power	Temp
DAA Computer	AAEON GENE-SKU6	5.75" x 4"	1.16 lb	21 W (12V)	0 to +60°C
Vision Computer	Zotac QK7P3000	8.94" x 7.97" 2.46"	7.48 lb	180 W (19.5 V)	-20 to +40°C
Networking Switch	Startech IES51000	1.1" x 4.4" 3.5"	0.725 lb	3.63 W (12-58 V)	-40 to +75°C

DAA Installation for SIO

The cargo pod housed the DAA equipment and was rigidly mounted between the aircraft's pylons, parallel with the wings. The pod itself is a combination of aluminum, carbon fiber and nylon parts. The cameras and radars are installed in the nose of the pod. The design chosen was a modular one to allow for ease of maintenance. The nose-fairing ports allowed an unobstructed field of view for the cameras or the radars. The rest of the DAA equipment was installed inside the main body of the pod. These components were accessible through the hinged, double doors on the top surface of the pod. The pod doors were designed to open even while the pod was installed on the aircraft for servicing and maintenance.



The electrical components are cooled by passive airflow through the pod. Figure 10 and Figure 11 show the APT 70 pod during final assembly. Future designs will optimize the installation, weight and power requirements for production implementation.

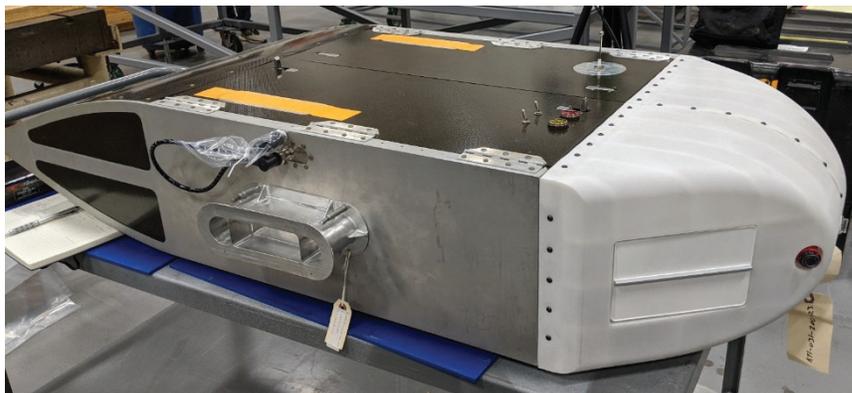


Figure 10. DAA Pod Assembly (before paint).

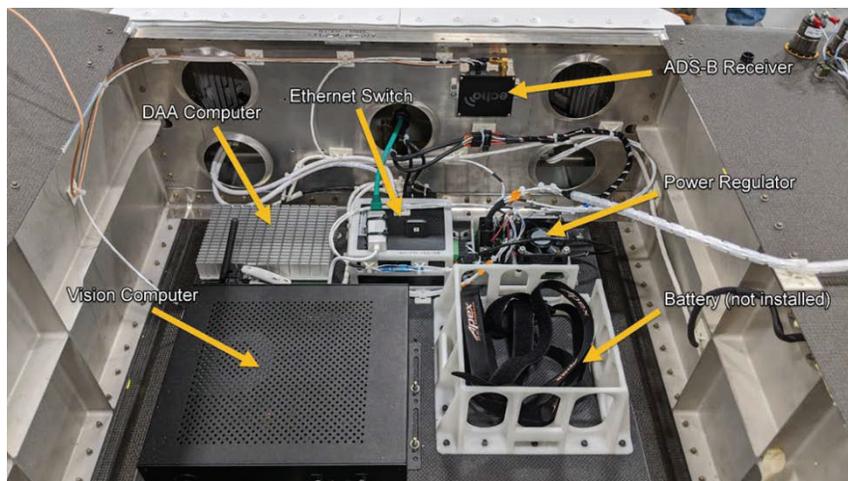


Figure 11. DAA Components Installed in Pod.

DAA Software and Performance

The DAA software onboard the DAA computer fused the sensor data to form tracks and added own-ship state information into the DAIDALUS v1.0.2 algorithm for computing maneuver guidance. DAIDALUS produced heading, vertical speed bands, and a heading guidance that was processed by the ABDAA system. The DAA target information along with any maneuver guidance was transmitted to the GCS via the C2 link for RPIC situational awareness and evasive maneuvering.

The ABDAA system latencies were partially measured during initial testing. The following portions of the total system latency were unable to be determined due to schedule constraints with APT 70



DAA flight testing and are therefore not available: downlink, alerting/guidance processing, uplink of conflict resolution maneuver and execution of the conflict resolution maneuver. The system detection time was defined as the time between the intruder entering the sensors' field of view and the system producing a track. Various sensor parameters and flight conditions (weather, intruder's size, relative speed, etc.) have a significant impact on detection times. Additional evaluation is required to validate detection times; however, the observed intruder detection times during the DAA flight test are listed below:

- Intruder Detection
 - Target with ADS-B: up to 1 sec once within 10 km
 - Target without ADS-B, head on encounter within 2 km: 10 sec
 - Target without ADS-B, crossing encounter within 2 km: 4 sec
- Track Processing
 - EchoFlight forms track to radar driver processes: 0.2 sec

Due to some sensor limitations, the DAA system was able to track up to 36 simultaneous targets with an update rate of 10 Hz.

Tracks were automatically dropped when no sensor inputs have been received for a specified period of time. If intruders exceed the tracking limit, the intruders were prioritized by range from the ownship. Radar intruder measurements were filtered using a minimum-allowed distance above the ground. The setting of the radar altitude filter during the demonstration flight was set at 410 ft AGL. Other filters included radar cross section, target motion, ground detections due to transmitted beam width and sidelobe detection reduction.

The intruder declaration range changed depending on if the intruder was broadcasting an ADS-B signal or not. Based on test results, intruders with ADS-B were declared at 5 nmi while intruders without ADS-B were declared at of 0.8-1.1 nmi.

Final definition of hazard zones, alerting thresholds, and/or maneuver guidance outputs were not evaluated in flight test due to schedule constraints. It was determined that the primary avoidance maneuver for APT 70 will be a horizontal maneuver. This type of maneuver provided the quickest response due to the design of the aircraft.

DAA Targets Observed during Demonstration Flight

Several aircraft were detected by the DAA system during the D/FW flight demonstration on September 28th, 2020. The DAA data was collected on-board the aircraft and post processed using Xwing's Xviz engineering display. The Xviz engineering display had many features for displaying flight data, intruder detections, and encounters with other aircraft. The three camera feeds are stitched together to provide a single, composite image. The image could be panned horizontally and vertically to see the full field of view of the three camera system. Overlaid onto the camera image, Xviz displayed tracked data with various colors and symbols to differentiate



between the sensor sources and different symbol sizes to indicate the range. In addition, a heads-up-display (HUD) provided vehicle state data and an overhead view was shown at the bottom center of the display.

Figure 12 is a close-up of the target information shown in Xviz that provided the target tail number on top, detection method (for example ADS-B) in the middle and “slant” range in feet to the target at the bottom. In this example, the target was a Bell Training Academy M429 helicopter, N429NA, being tracked with ADS-B at a range of 19,029 ft.

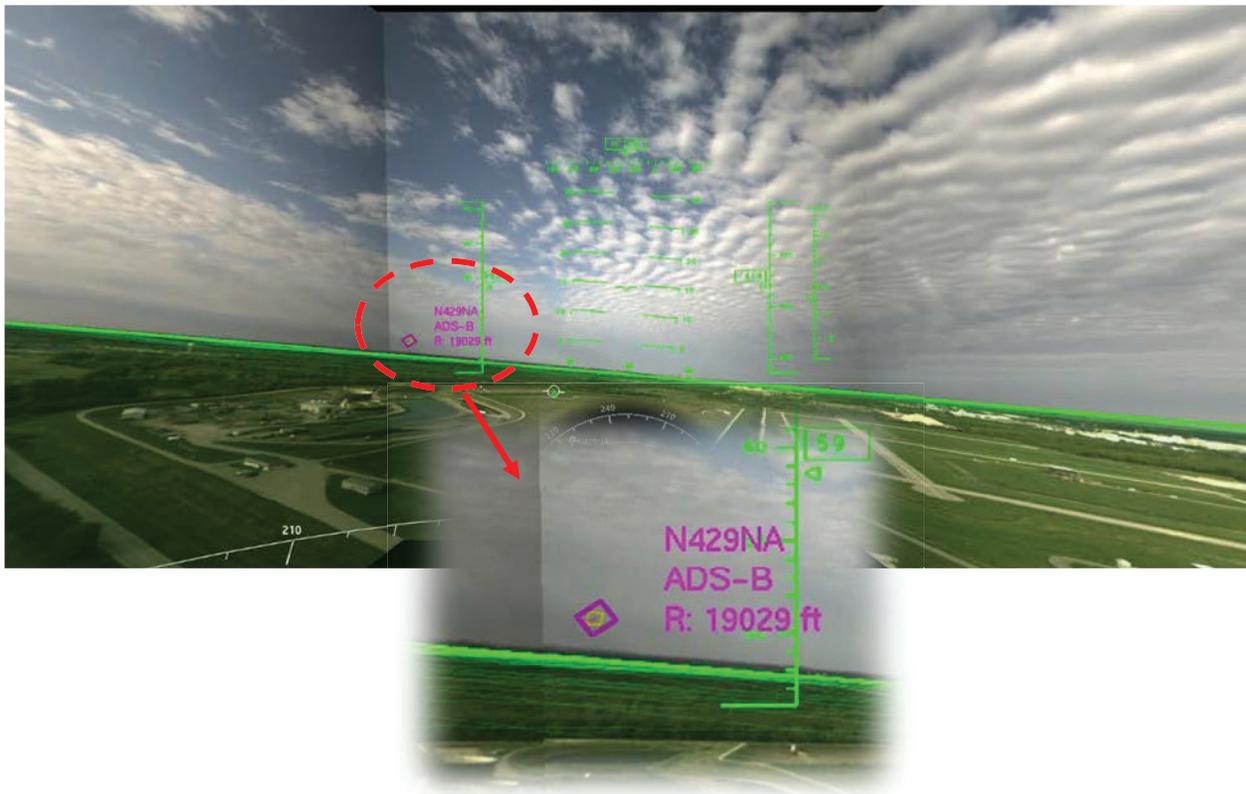


Figure 12. DAA Target Information.

Figure 13 is a screen shot of the Xviz tool showing ADS-B tracks of aircraft on final approach to DFW international airport. While the overhead map identifies four targets, only three are visible in the forward view of the cameras. The fourth target is to the right of the vehicle out of view.

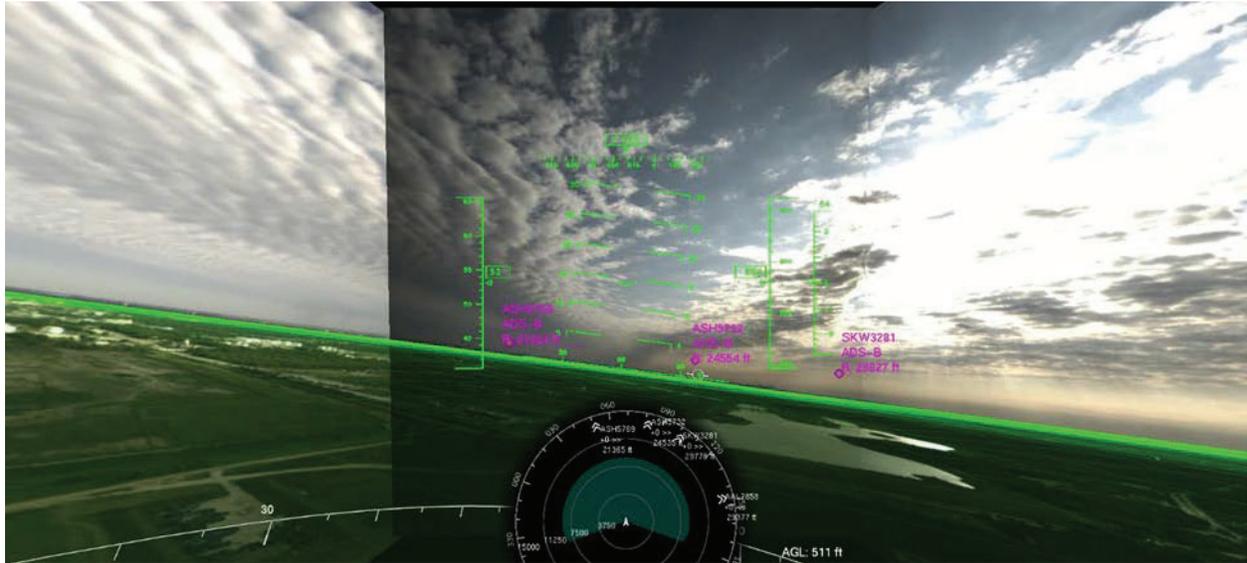


Figure 13. DAA ADS-B Targets on DFW International Final Approach.

Figure 14 is a screen shot of the Xviz tool showing the ADS-B track (in purple) of a M429 Bell Training Academy helicopter near the APT 70 landing zone at Floyd Carlson Field. The helicopter target is also visible on the overhead map located at the bottom center area of the figure.

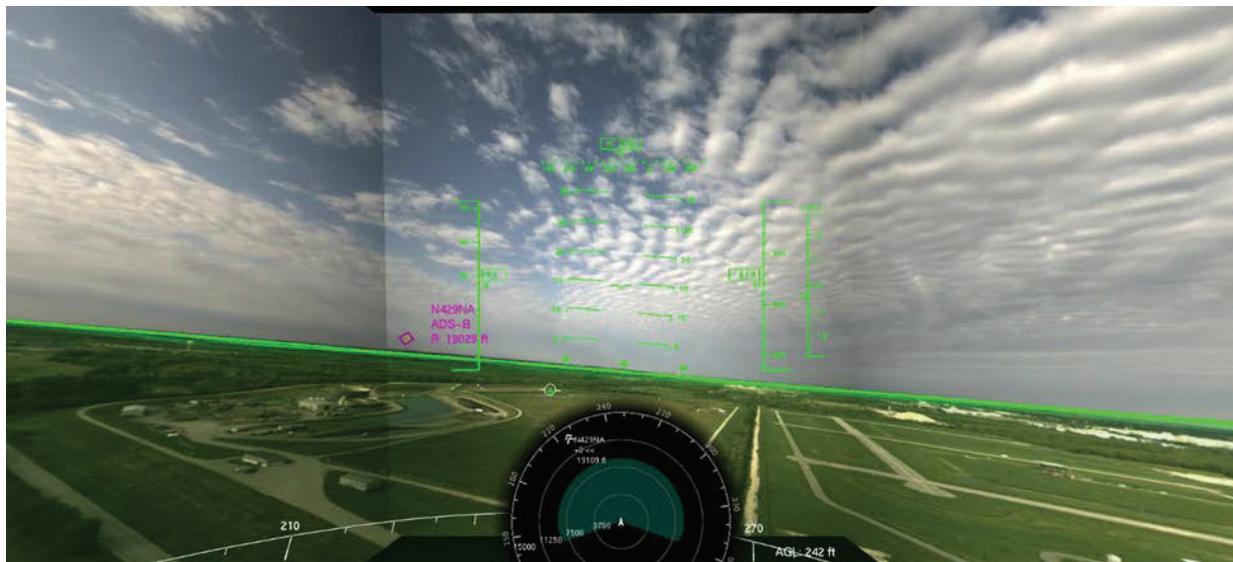


Figure 14. DAA ADS-B Target at Floyd Carlson Field.

Figure 15 is a typical image of radar ground clutter during the demonstration flight as viewed through Xviz. The APT 70 was flying at approximately 500 ft AGL in this image. The target on the right was a legitimate ADS-B target while the target on the left was a “ghost” radar track. A second ghost track was identified near APT 70 but is out of view of the camera system on the APT 70.



Note the DAA guidance information processed from the two ghost images shown in the overhead view located at the bottom center of the image.



Figure 15. Ghost Radar Track.

Figure 16 shows an extreme example of radar ground clutter during the flight demonstration. The APT 70 was flying at approximately 200 ft AGL in this image. The ground clutter depicted in the image grew in number as the aircraft descended in altitude. In flight testing prior to the demonstration flight, ground clutter was observed to increase near buildings due to their high radar reflectivity. The DAA guidance for the multiple ghost images is shown in the overhead map. Ghost images to the right of the APT 70 are out of view of this Figure 16 image.

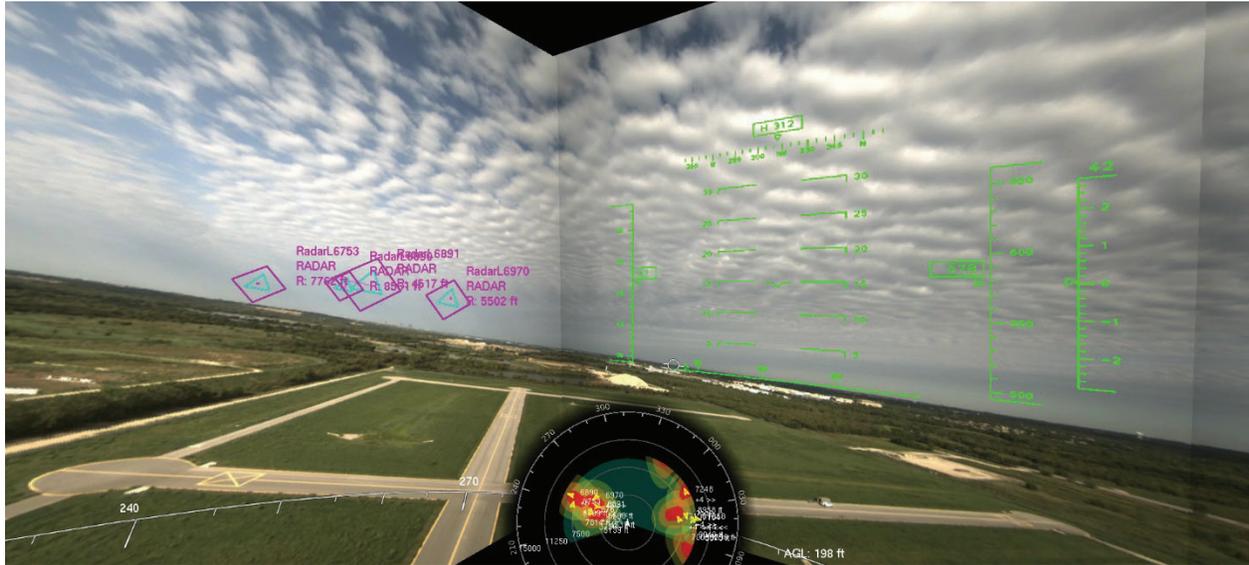


Figure 16. Multiple Ghost Radar Tracks.

DAA Display

The APT 70 GCS consists of a Linux-based computer running a Bell modified version of QGroundControl, an open source software configured for use with the APT 70 platform. The GCS displayed the APT 70 UA flight position, velocity, attitude, heading, altitude, ascent/descent rate, charge status, GCS link status, GPS position, DAA information and other information. The GCS could be operated from the environmentally controlled Bell APT Flight Test Trailer or from a portable GCS, shown in Figure 17. The GCS had plug-in ports for connections with external equipment including C2 radios, mouse, keyboard, etc. All GCS flight control inputs were made through the mouse/keyboard interface with the GCS software.



Figure 17. APT Portable GCS.



Central to the GCS is a real-time display with integrated DAA information as highlighted in Figure 18. The DAA display symbology originated from guidance found in DO-365 and NASA Ames documentation and was implemented on the APT 70 display that provided situational awareness to the RPIC.



Figure 18. GCS Display with DAA Specific Information Highlighted.

Demonstration DAA Information

In Figure 19, the GCS depicts two aircraft in the vicinity of APT 70. The number below the aircraft icon multiplied by 100 represents the altitude separation in feet. The horizontal guidance band is green.

The contact behind the ownship was N62774 which was the chase aircraft for the flight demonstration, a Bell 407. The DAA system was programmed to ignore N62774 as a DAA target for the demonstration. The other contact to the right of the ownship was AAL2447, an American Airlines flight descending to position itself for a northbound approach into DFW airport. The number (+57) below the icon for AAL2447 shows that the aircraft was 5,700 ft above APT 70.



Figure 19. Demonstration Aircraft Tracks on GCS.

DAA Technology Gaps

Several DAA technology gaps became apparent during the execution of the Bell SIO flight activities.

Radars Ground Clutter

Urban low altitude operations below approximately 1,500 ft AGL show a susceptibility of radar beam width and side lobes. These sensitivities caused spurious reflections and false detections. Additional testing for optimizing the filtering and/or the inclusion of additional technologies to aid in the removal of the ground clutter is needed for this radar system to provide adequate reliable detections while flying at low altitudes.

Detection Range of Low SWaP Radar

The added filtering employed to reduce the low-altitude, ground clutter negatively impacted the detection range of the radars. As tested, the effective range was a little over a mile. This performance is less than the required detection range to avoid non-cooperative air traffic with a pilot in the loop.

This range could possibly be adequate if operating with an automated avoidance maneuvering system. Latency improvements using an automated avoidance algorithm would need to be assessed in order to determine if this is a possibility.



Limits of Camera Detection Capabilities

The cameras used on the Bell SIO flights were used to verify track detections, not to detect tracks independently. Additional testing of the EO camera system is necessary to evaluate them as an independent technology for detecting non-cooperative aircraft. This evaluation should include intruders above and below the horizon, day/night operations and for various cloud conditions. All of these variables should be tested at multiple intruder aspect angles.



CASA Weather Avoidance System

The SIO demonstration flight crew received weather data from Engineering Research Center for Collaborative Adaptive Sensing of the Atmosphere (CASA) at University of Massachusetts-Amherst. The software that provided the data was the CASA CityWarn™ Hazard Notification software suite. The Software suite provided situational awareness regarding weather hazards that could affect flight of unmanned aerial vehicles (UAV), such as the APT 70, and future air taxi operations. CASA designed an intuitive, integrated display, Flight Weather Display and Alerting Console (FlightDAC), that provided pilots with enhanced weather risk awareness. Gridded wind forecast arrows were shown alongside observed wind measurements from Automated Surface Observing System (ASOS) stations in an interactive environment that users could query for more information as needed. Flight plans were shown with live updates for aircraft locations, and airspace classifications were depicted in light shades for reference.

CASA aggregated weather data from its weather radar network in Dallas Fort Worth, National Weather Service NexRad radar and model data, and aviation weather reports (e.g. METARs). The CASA X-band radar network that supported the SIO demonstration consisted of 7 radars in the Dallas Fort Worth area that have been operating since 2013 and made high resolution measurements of rainfall and precipitation type. The GCS received current weather data and weather alerts for surface and aloft winds, rain, precipitation type, visibility, ceilings, and National Weather Service warnings based on alert thresholds defined for the mission criteria and mission profile.

For the SIO demonstration, data was made available via a query interface to the GCS, supporting both mission planning and real time flight operations. During the demonstration, the primary use was to monitor the local area winds. The METAR wind data from five local stations was displayed along with the CASA X-Band radar data. This provided an operational view of the area to assess weather-based flight planning. Figure 20 shows an image of the display at the ground station.

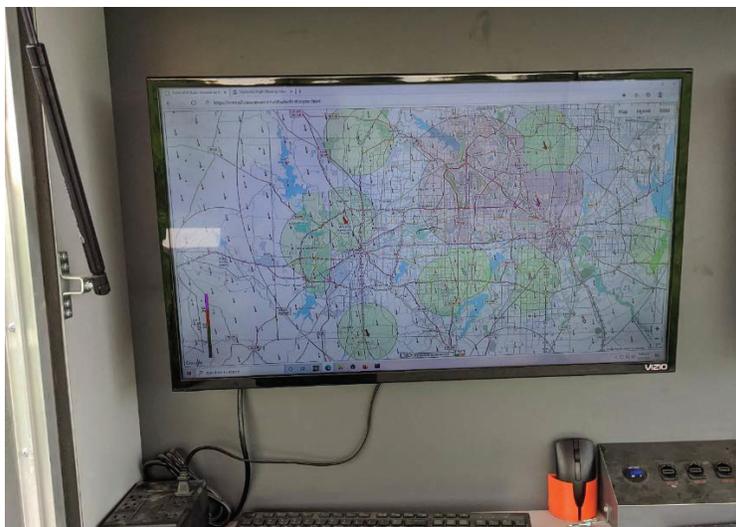


Figure 20. Weather Display Monitor at the Ground Station.



System Testing

Prior to utilization for the demonstration, an eight-week test was conducted from March 23, 2020 to May 15, 2020. During this period, the FlightDAC website was available to project participants, displaying real-time weather alerts for simulated flights over the NASA SIO flight path. System performance was monitored, and a usability study was conducted with the help of volunteer Bell and NASA pilots. The pilots were interviewed remotely via one hour Zoom meetings to assess usability and collect feedback.

While the FlightDAC website performed as expected, the usability study revealed some challenges faced by the interviewed pilots related to interpretation of the weather data and alerts, and usability of the website. The pilots also made several recommendations for new features that would add value to the FlightDAC. The CASA and Bell team discussed these challenges and opportunities and prioritized the important changes to be made in advance of the flight demonstration. Updates to the interface were made to improve readability and to better convey information.

Flight Weather Display and Alerting Console (FlightDAC)

The weather observation and avoidance system were displayed via an internet browser on a non-flight critical computer. The display was co-located with the GCS crew for the pre-flight weather forecast and for real-time monitoring during the flight for weather avoidance. Figure 21, Figure 22 and Figure 23 show sample displays of the weather avoidance tool and highlighted features.

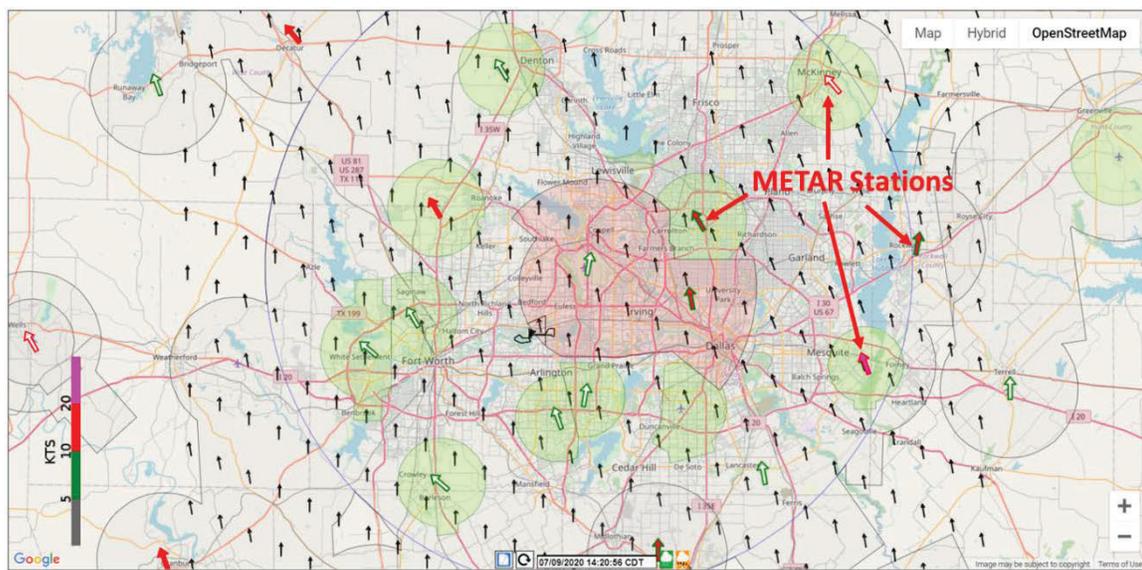


Figure 21. CASA D/FW UAS Weather Display.

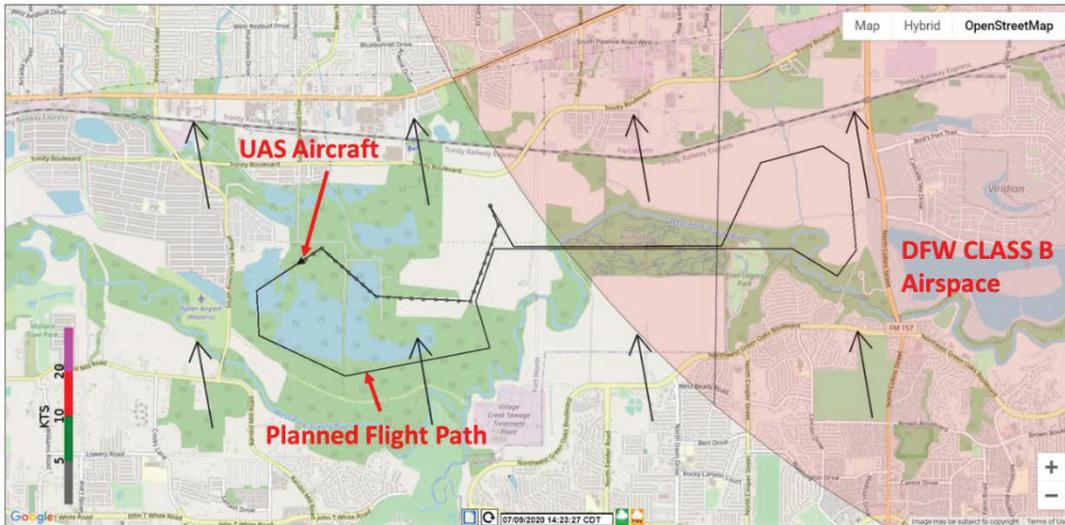


Figure 22. CASA UAS Weather Tool Closeup.

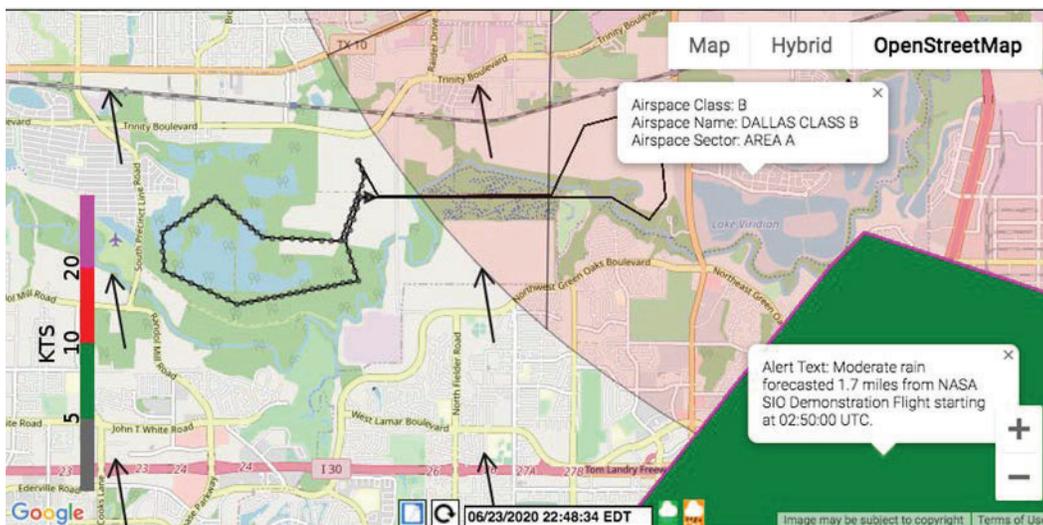


Figure 23. CASA Weather Tool with Local Precipitation.

An HTTP based REST interface is used for registering missions (“flight events”) and associated weather risk criteria (weather hazards and the distances and thresholds used to monitor those weather hazards). Registration takes the form of a query submitted through the GCS software. Registration parameters include flight event start and end times, mission profile or area coordinates, and weather risk parameters. Weather risk registration parameters include alertable weather hazards, alerting thresholds, distance from flight event and alert update rate. The system had the ability to monitor a variety of hazards including surface wind speeds, rain, hail, visibility, ceilings and severe storms.





CityWarn™ Hazard Notification System

CASA adapted its CityWarn™ Hazard Notification System for drone applications as part of this project. Previously developed under a National Science Foundation grant, CASA's CityWarn™ was designed to monitor various weather data feeds such as National Weather Service radar imagery and advisories, METAR data, CASA radar data, and to generate a 'universe' of representations of weather risk or "alerts". These alerts were geo-encoded representations of weather risks to the mission. The Alert Control System matched the alerts against user preferences specified in the flight event registration and returned CASA Alerts relevant to the flight event. The FlightDAC user could choose which CASA Alerts to display/monitor.



Safety and Certification

Airworthiness and safety are the cornerstone of the requirements to progress towards routine operations. The SIO demonstration enabled open discussions between industry and the FAA on requirements for low altitude, DAA and C2 operations for urban missions. Numerous discussions were arranged to evaluate and review mission concept of operations, detect and avoid capability and mitigations, spectrum, and command and control. These discussions were utilized in the preparation of documents for approvals for flight authorization to complete the SIO missions and will be built upon to make progress towards certification for the APT platforms.

Airworthiness Artifacts

Airworthiness artifacts were generated to support flight activities at remote test locations in Texas and Oklahoma, and urban flight operations in Fort Worth, Texas. These documents included: aircraft registration, exemptions, special airworthiness certificate – experimental category, and certificate of authorization/wavier (COA) for remote test sites and urban test sites. FCC licenses were also obtained as required.

The exemption process began early in the program as the rule exemption process includes an open public comment period prior to FAA review. Overall, the exemption process tends to require eight to twelve months to complete. To perform the developmental flight testing and the demonstration, Bell requested exemption from the following operational regulations:

- 14 CFR § 61.113(a),(b). This exemption was requested since the UAS pilot in command (PIC) may hold a private pilot certificate and be employed by Bell, thus flying for compensation. Further, the UAS flight is NOT incidental to that business or employment.
- 14 CFR § 91.121. This exemption was requested since Bell intended to operate the UAS in Class G airspace at a remote site and set the altimeter at the takeoff and landing location rather than at “the departure airport”. Bell recognized that an accurate altitude reading is a critical safety component of flight. Prior to each flight, a zero-altitude initiation point was to be established and confirmed for accuracy by the UAS PIC.
- 14 CFR § 91.151(a). This exemption was requested since the point of intended landing may be the same as the point of takeoff and hence the required fuel would not be based on distance but rather the duration of the UAS flight. Further, the UAS was to fly solely on electric powered propulsion, requiring no hydrocarbon fuel onboard.
- 14 CFR § 91.119(c). This exemption was requested since Bell intended to operate the aircraft at altitudes between ground level to 1,000 feet AGL over unpopulated areas (other than congested areas) where there are few permanent or significant structures.

The first document prepared for the demonstration was the exemption to cover flight operations for the APT 70S5 and APT 70S6. The APT 70 aircraft had an existing exemption for research flights at a remote test field in Texas. Additional exemptions were submitted to cover the required test areas. Following discussions with the FAA, these requests were rescinded and a revision to the existing exemption was issued. This revision extended the timeframe for two years, and amended the language of the exemption to eliminate UAS altitude, class of airspace, location of



operations and procedures such as visual-line-of-sight. These limitations were to be captured in either the Special Airworthiness Certificate-Experimental Category or the associated Certificate of Waiver or Authorization. Bell received the amended exemption supporting the SIO flight operations in March 2020.

Next in the airworthiness process was the development of required documentation for FAA UAS waivers and approvals for flights and developing the project specific certification plan. Waivers and approvals were required for integration test flights at Bell's remote test site and for the demonstration activity.

Airspace authorization was granted through the COA process. Bell applied for several COAs to support testing at the remote sites and at the Fort Worth site. These COAs allowed for flight beyond visual line of sight of the pilot in command through the use of visual observers at altitudes above 400 feet. Since the COAs required visual observers, a waiver for 91.113b was not required. Meetings were held with NASA and the FAA to improve the quality and clarity of the submittal packages. The FAA organizations engaged in the discussions were Aircraft Certification Service (AIR), Air Traffic Organization (ATO), Spectrum Engineering (AJW-1C3), Flight Standards (AFS), Fort Worth Manufacturing Inspection District Office (MIDO) and Fort Worth Flight Standards District Office (FSDO). The process of defining an acceptable mission profile was one example of cooperative discussions with NASA and the FAA. Bell, NASA and the FAA met over a span of 10 months to review and determine an acceptable flight area that addressed air safety and ground safety concerns.

Additional flight authorization activities included aircraft registration and the Airworthiness certificates. The two aircraft allocated for the SIO demonstration, APT 70S5 and APT 70S6, were registered as N314AN and N314AQ respectively. The registration was approved in June 2019.

The SIO demonstration and preceding flights were conducted as research and development flights under a special airworthiness certificate in the experimental category (SAC-EC) in accordance with 14 CFR § 21.191(a), which was issued per FAA National Policy described in Order 8130.34D. Documents required for the airworthiness certificate included a Program Letter and Safety Checklist, aircraft registration and Form 8130-6 completed on the FAA's Airworthiness Certification (AWC) portal. Special Airworthiness Certificates for research and development flights for Ship 05 and Ship 06 were awarded in August and September 2020, respectively.

Risk Based Safety Assessment

A risk-based safety assessment was conducted as a deliverable to the program. The analysis incorporated guidance from the Joint Authorities for Rulemaking of Unmanned Systems (JARUS) and the Federal Aviation Authority (FAA). The JARUS Specific Operations Risk Assessment (SORA) provided a method for assessing the risk of a specific operation, classifying and mitigating the risks, and making an informed decision regarding the safety of a planned operation.

The FAA has been developing the Modernization of Special Airworthiness Certification (MOSAIC) for addressing certification requirements for unmanned aircraft. MOSAIC has been developed into a Draft Advisory Circular, AC 21.17- XX, documenting guidance for seeking certification of a UAS as a special class of aircraft under §21.17(b). The FAA has an established risk-based approach to system safety for manned aircraft with target objectives that have been extrapolated



to apply to UAS that may be below the size, weight, and performance capability levels of manned aircraft. Larger UAS will have a progressively higher level of safety resulting in a continuum of expectations for the safety of a UAS as shown in the following figure broken up into varying Risk Classes (RC).

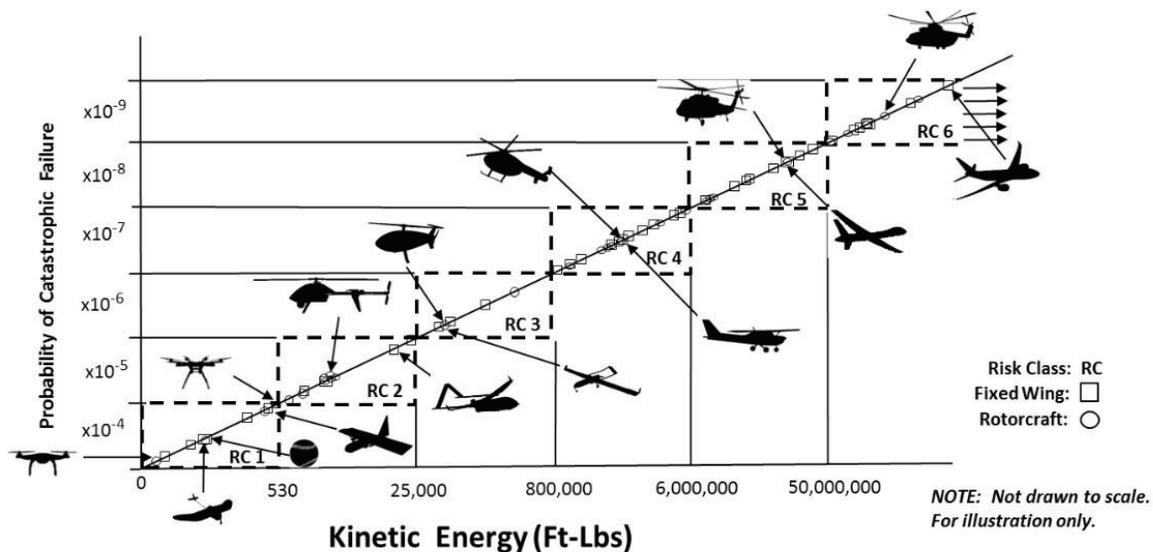


Figure 24. UAS Risk Classes (from FAA Draft AC 21.17-XX).

The certification basis utilizes an Operational Risk Assessment (ORA) process for identifying the functional hazards associated with a particular UAS and its particular CONOPS as well as the mitigations for each hazard. For a given hazard, the mitigations may include UAS airworthiness requirements, operational limitations, or a combination thereof to achieve an acceptable level of safety.

To support the ORA, a Systems Theoretic Process Analysis (STPA) based approach was used for identifying functional hazards associated with the planned UAS operations with a focus on the design and CONOPS for the SIO demonstration with APT 70 aircraft. STPA is a model-based approach to integrated system design and safety analysis that provides a holistic approach to system safety including the system interactions and system operations to account for how the system functions in its intended state. STPA is a relatively new hazard analysis technique gaining increased usage in the aviation industry with both Society of Automotive Engineering (SAE) and American Society for Testing and Materials (ASTM) standards in development to provide guidelines and standards for completing the analysis.

Following identification of functional hazards, mitigations involving UAS airworthiness requirements and operational limitations can be identified to address those hazards. The JARUS SORA process gives guidelines for assessing the robustness of mitigations and means to assess the effectiveness of a given mitigation.



The analysis summarized the application process of the presented methodology as well as the specific results for the SIO demonstration. Considerations for a future commercial system were identified. Some of these were not fulfilled by or applicable to the SIO demonstration.

Conclusions

Bell's team with its teammates, Xwing, and University of Massachusetts at Amherst's Collaborative Adapting Sensing of the Atmosphere (CASA), completed the SIO demonstration flight using a Bell APT 70 on September 28, 2020. Preparation for this flight included system and component testing, airworthiness and flight approvals, and flight testing at remote sites. Through the testing and airworthiness process, NASA and Bell gathered data and requirements for Command and Control and Detect and Avoid systems for larger than 55 lb UAS in urban operations. Gaps identified for C2 include remote landing C2 requirements and CNPC Radio Bandwidth and gaps identified for DAA include radar ground clutter, detection range of low SWaP Radar and limits of camera detection capabilities. It is recommended that these areas continue to be explored to improve UAS capabilities and safety in the National Airspace.

REPORT DOCUMENTATION PAGE

*Form Approved
OMB No. 0704-0188*

The public reporting burden for this collection of information is estimated to average 1 hour per response, including the time for reviewing instructions, searching existing data sources, gathering and maintaining the data needed, and completing and reviewing the collection of information. Send comments regarding this burden estimate or any other aspect of this collection of information, including suggestions for reducing the burden, to Department of Defense, Washington Headquarters Services, Directorate for Information Operations and Reports (0704-0188), 1215 Jefferson Davis Highway, Suite 1204, Arlington, VA 22202-4302. Respondents should be aware that notwithstanding any other provision of law, no person shall be subject to any penalty for failing to comply with a collection of information if it does not display a currently valid OMB control number.
PLEASE DO NOT RETURN YOUR FORM TO THE ABOVE ADDRESS.

1. REPORT DATE (DD-MM-YYYY) 01/03/2021		2. REPORT TYPE Contractor Report (CR)		3. DATES COVERED (From - To) 10/29/2018 - 10/31/2020	
4. TITLE AND SUBTITLE Bell Unmanned Aircraft Systems Integration and Operationalization (SIO) Demonstration: Final Report, Summary of Research				5a. CONTRACT NUMBER	
				5b. GRANT NUMBER 80AFRC19M0004	
				5c. PROGRAM ELEMENT NUMBER	
6. AUTHOR(S) Bell Textron Inc.				5d. PROJECT NUMBER	
				5e. TASK NUMBER	
				5f. WORK UNIT NUMBER	
7. PERFORMING ORGANIZATION NAME(S) AND ADDRESS(ES) Bell Textron Inc. 3255 BellFlight Blvd Fort Worth, Texas				8. PERFORMING ORGANIZATION REPORT NUMBER	
9. SPONSORING/MONITORING AGENCY NAME(S) AND ADDRESS(ES) National Aeronautics and Space Administration Washington, DC 20546-0001				10. SPONSOR/MONITOR'S ACRONYM(S) NASA	
				11. SPONSOR/MONITOR'S REPORT NUMBER(S) NASA/CR-20210009973	
12. DISTRIBUTION/AVAILABILITY STATEMENT Unclassified Subject Category Availability: NASA STI Program (757) 864-9658					
13. SUPPLEMENTARY NOTES Langley Technical Monitor: Kurt A. Swieringa					
14. ABSTRACT National Aeronautics and Space Administration (NASA) initiated the Unmanned Aircraft Systems Integration and Operationalization (SIO) demonstration as a partnership between NASA and Industry with the goal of accelerating routine unmanned aircraft systems (UAS) operations in the national airspace (NAS). In order to accomplish this goal, NASA partnered separately with Bell and two other industry teams each pioneering the development, integration, and testing of their UAS, with the intent to make progress towards type certification.					
15. SUBJECT TERMS Unmanned Aircraft Systems (UAS), Flight Demonstration, Systems Integration and Operationalization (SIO)					
16. SECURITY CLASSIFICATION OF:			17. LIMITATION OF ABSTRACT	18. NUMBER OF PAGES	19a. NAME OF RESPONSIBLE PERSON
a. REPORT	b. ABSTRACT	c. THIS PAGE			STI Help Desk (email: help@sti.nasa.gov)
				46	19b. TELEPHONE NUMBER (Include area code) (757) 864-9658