Systems Integration and Operationalization: Supporting Unmanned Aircraft Systems Integration into the National Airspace System

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ABSTRACT

The NASA Systems Integration and Operationalization activity was a collaboration with three industry partners to integrate prototype detect-and-avoid and command-and-control systems into their unmanned aircraft systems, make initial progress toward type certification, and conduct flight demonstrations that were representative of publicly beneficial commercial missions. The goal of the Systems Integration and Operationalization activity was to progress toward routine unmanned aircraft systems operations, learn about barriers to routine operations, and identify best practices. All three industry partners successfully completed flight demonstrations in the United States National Airspace System with a range of operational mitigations that must be resolved before routine commercial operations can occur. The barriers and best practices identified throughout the Systems Integration and Operationalization activity are focused on design and safety assurance, detect-and-avoid, and command-and-control system integration, and operations.

1.0 INTRODUCTION

Today, unmanned aircraft operate in the National Airspace System (NAS) at prescribed altitudes, largely below conventional aviation, providing commercial services that are suitable at these altitudes. The operation of unmanned aircraft at higher altitudes, however, is currently limited. When unmanned aircraft are fully integrated into the NAS, they have the potential to offer a variety of new commercial services that are expected to revolutionize the aviation industry. Examples of these services include infrastructure inspection, cargo transportation, search and rescue, transportation of life-saving medical supplies, and communication relay. Such services can extend to disaster relief and transporting aid and supplies into regions that may be unsafe for conventionally piloted aircraft. In order to attain the benefits of these types of operations, unmanned aircraft systems (UAS) must be safely integrated into the NAS. The National Aeronautics and Space Administration (NASA), the Federal Aviation Administration (FAA), industry, and other organizations have been working diligently for several years to address technical, procedural, and regulatory barriers that prevent robust and scalable commercial unmanned aircraft operations in the NAS.

The NASA Unmanned Aircraft Systems Integration into the National Airspace System (UAS-NAS) project was established with the goal of providing research to address barriers that currently prevent full integration of UAS (Ref. 1). Throughout its lifespan, the UAS-NAS project (2011 to 2020) was primarily focused on leading research to support the development of standards for two key technologies that are necessary for NAS integration: detect and avoid (DAA); and command and control (C2). Detect-and-avoid systems use sensors, alerts, and guidance to detect surrounding air traffic and ensure that the unmanned aircraft remains well clear. Command and control is the data link used to transmit information between the unmanned aircraft and the control station that is used to control the unmanned aircraft and manage the flight. Together, the DAA and C2 research completed under the UAS-NAS project helped advance these technologies and facilitated significant progress toward UAS integration into the NAS; however, additional work is required before routine commercial UAS operations can occur (Ref. 2). To influence progress in this area the UAS-NAS project established the Systems Integration and Operationalization (SIO) activity.

The SIO partners were required to make initial progress toward type certification, to the extent that such was possible within the available compressed timeframe. This progress included creating foundational documents such as concepts of operations, operational risk assessments, and draft project specific certification plans. The SIO partners were also expected to integrate prototype DAA and C2 systems into their unmanned aircraft and conduct a flight demonstration that emulated commercial missions. In order to conduct the demonstrations, the SIO partners were required to obtain approvals from the FAA such as experimental airworthiness certificates, Certificates of Waiver or Authorization (COA), exemptions, and in one case a 14 Code of Federal Regulations (CFR) 91.113 waiver for beyond visual line-of-sight (BVLOS) operations. Various best practices were identified by observing interactions between the FAA and the SIO partners.

The NASA selected three industry partners with which to collaborate. The three companies chosen as SIO partners proposed vehicles that varied in size, powerplant, and configuration according to their commercial missions. These missions ranged from long-endurance high-altitude surveys to short-hop urban deliveries, using vehicles that ranged from under 300 lb to over 12,500 lb with powerplants that ranged from turboprop to piston to electric-powered. All vehicles weighed more than 55 lb and were expected to conduct operations at altitudes greater than 400 ft above ground level (AGL), which required integration into the conventional air traffic management system.

This paper provides an overview of the SIO partner missions, unmanned aircraft, DAA and C2 systems, and the SIO flight demonstration. Additionally, best practices and key challenges identified throughout SIO are described.

2.0 THE SYSTEMS INTEGRATION AND OPERATIONALIZATION ACTIVITY PARTNERS

The three industry partners selected by NASA to participate in SIO were American Aerospace Technologies, Inc. (AATI) (Bridgeport, Pennsylvania, U.S.A.), Bell Textron, Inc. (Fort Worth, Texas, U.S.A); and General Atomics Aeronautical Systems, Inc. (GA-ASI) (San Diego, California, U.S.A.). One of the objectives of the selection process was to create a portfolio of partners representative of the breadth of suitable commercial operations, using UAS of different sizes and weights. The operations and weights correspond to the risk-based process that the FAA plans to use for UAS certification, which considers both the kinetic energy of the unmanned aircraft and the risk associated with the operating environment (Figure 2-1). Together, the three partners formed a portfolio of different commercial use cases, risk, and vehicle capabilities.

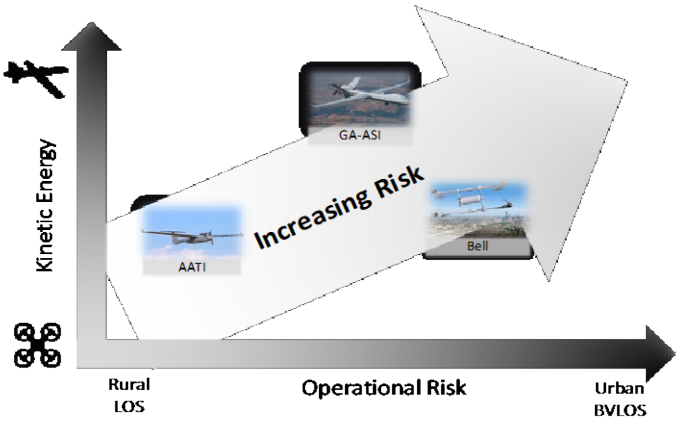

Figure 2-1: The Systems Integration and Operationalization partners were selected to create a portfolio of different risk unmanned aircraft systems and operations.

2.1 American Aerospace Technologies, Inc.

American Aerospace Technologies, Inc. (AATI) used their AiRanger™ unmanned aircraft, shown in Figure 2.1-1, to conduct an infrastructure inspection mission (Ref. 3). The AATI concept of operations is focused on pipeline inspection in rural areas using a proprietary pipeline threat detection system, which can help detect threats to pipelines, including leaks, to prevent environmental disasters. The AiRanger™ provides greater range, endurance, and payload capacity than a small UAS (sUAS) under 55 lb, thus enabling the unmanned aircraft to cover more miles of pipeline for a given number of operators. Typical pipeline inspection flights are between 1,000 and 5,000 ft AGL. The AATI objective is to conduct flight operations independent of an instrument flight rules (IFR) flight plan, Air Traffic Control (ATC) separation services, or routine ATC interactions.

Figure 2.1-1: The American Aerospace Technologies, Inc. (Bridgeport, Pennsylvania, U.S.A.) AiRanger™ unmanned aircraft.

2.1.1 The AATI AiRanger™ Unmanned Aircraft

The AiRanger™ is a fixed-wing unmanned aircraft that weighs approximately 200 lb. The aircraft is launched from a pneumatic launching system and lands on its belly using skid plates. As such, operations may be launched from non-traditional NAS access points and require only a relatively short flat surface for landing. Because of its relatively small size and weight, it is important for all required onboard systems to be low size, weight and power (SWaP) in order to maximize the range and payload capacity of the aircraft.

2.1.2 The Detect-and-Avoid System of the AATI AiRanger™ Unmanned Aircraft

The DAA system used two low-SWaP radars for detection of non-cooperative intruders (aircraft not transmitting ownship state information), Automatic Dependent Surveillance-Broadcast (ADS-B) -In for detection of cooperative intruders, and a prototype version of airborne collision avoidance system for small UAS (ACAS-sXu) for generating alerting and guidance. Flight being assumed to occur absent an IFR flight plan, also assumed was that prior ATC coordination would not be required to perform DAA maneuvers.

2.1.3 The Command-and-Control System of the AATI AiRanger™ Unmanned Aircraft

The C2 system consisted of a Collins (Collins Aerospace, Charlotte, North Carolina, U.S.A.) Control and Non-Payload Communications (CNPC) 5000 prototype radio for CNPC communications; and L- and S-band links for transmission of non-safety-critical data and payload data, and to serve as a backup in case the primary C2 link was lost. The Collins CNPC 5000 prototype radio is aligned with an RTCA minimum operational performance standard (MOPS) (Ref. 4) and an FAA Technical Standard Order (TSO) (Ref. 5), thus allowing temporary use of the C-band spectrum allocated for safety-critical UAS CNPC communications.

2.1.4 The Flight Demonstration of the AATI AiRanger™ Unmanned Aircraft

The flight demonstration took place in the San Joaquin Valley of California. The AiRanger™ unmanned aircraft transited to a pipeline over the desert and farm fields and inspected approximately 40 mi of pipeline using the AATI-developed pipeline threat-detection payload (Figure 2.1.3-1). This route had a maximum distance from the control station of approximately 16 nmi. The DAA system was a prototype system, so visual observers in a chase aircraft were used to augment the DAA system.

Figure 2.1.3-1: The flight demonstration path of the AATI AiRanger™ unmanned aircraft.

2.2 Bell Textron, Inc.

Bell Textron, Inc. (Bell) has been developing an electric-powered vertical takeoff and landing (VTOL) unmanned aircraft called the Autonomous Pod Transport (APT) (Ref. 6). This aircraft comes in different versions related to different payload capacities. For SIO, Bell used the aircraft with an approximately 70-lb payload capability called the APT70. While there are several potential use cases for the aircraft, the one that motivated the SIO demonstration was the transportation of emergency medical supplies over urban areas. The APT70 is larger and more capable than sUAS that weigh less than 55 lb, enabling greater range and payload capacity. The desired flight altitude range for the APT70 is between 500 and 1,000 ft AGL to remain above obstructions and hobbyist-grade UAS and below most conventional aircraft flights. The objective being to conduct operations above an urban area, the Bell use case requires transit through the Mode-C veil and Class B terminal airspace that is often located above urban areas.

2.2.2 The Bell Textron APT70 Unmanned Aircraft

The Bell Textron APT70 unmanned aircraft, shown in Figure 2.2.2-1, weighs approximately 300 lb. When the aircraft is on the ground it sits on its tails, takes off and lands vertically, and then transitions to horizontal flight during cruise. The VTOL capability of the APT70 enables it to operate from helipads and small aerodromes, independent of airport infrastructure. The APT70 is controlled by a control station utilizing a human-in-the-loop paradigm wherein which the remote pilot provides a flight path, and the aircraft automatically flies the programmed flight path. The APT70 is also capable of autonomously executing selected contingency procedures in the event of lost link or other failures. Because of its relatively small size and weight, it is important for the systems and subsystems to be low-SWaP to maximize the range and payload capacity of the aircraft.

Figure 2.2.2-1: The Bell Textron (Fort Worth, Texas, U.S.A.) APT70 unmanned aircraft.

2.2.2 The Detect-and-Avoid System of the Bell Textron APT70 Unmanned Aircraft

The DAA system uses two low-SWaP radars, three high-definition cameras, and an ADS-B transceiver. A remote pilot controls the DAA maneuvers using control station displays based on the RTCA MOPS DO-365 (Ref. 7), which provides alerting and guidance to the remote pilot. On a separate display, the pilot has access to a weather application with data sources from local weather radars and weather sources such as Meteorological Aerodrome Reports (METARs).

2.2.3 The Command and Control System of the Bell Textron APT70 Unmanned Aircraft

The C2 system consists of four different redundant links and a mechanism to merge the received data into a single stream to minimize the probability of lost link. The four links are two terrestrial radio systems operating on different frequencies and two long-term evolution (LTE) links utilizing different providers. The two terrestrial radio links did not use the C-band spectrum allocated for safety-critical CNPC communications due to the lack of commercial off-the-shelf radios that comply with standards that must be met to access the allocated CNPC spectrum (Refs. 4 and 5). Instead, temporary spectrum licenses were obtained with the knowledge that the radios would need to be substituted for a compliant system for any future certification activities and commercial operations.

2.2.4 The Flight Demonstration of the Bell Textron APT70 Unmanned Aircraft

The flight demonstration of the Bell APT70 unmanned aircraft took place in the Dallas-Fort Worth (DFW) area and included flight at altitudes between 500 and 1,000 ft AGL in alignment with the Bell expected future commercial concept of operations. For the flight demonstration, the APT70 flew an approximately 8.2-nmi round-trip route (see Figure 2.2.4-1) that included segments in Class G and Class B airspace at a location that was deconflicted from instrument departure and arrival procedures used by commercial airliners arriving and departing from DFW airport. There were several safety risk mitigations implemented for the SIO demonstration due to the level of maturity of the UAS and its DAA, C2, and other key subsystems. Risk mitigations included visual observers to augment the DAA system and reducing risk to people on the ground by flying above unpopulated riverbeds and maintaining a one-to-one ratio between the altitude of the aircraft and any populated areas, in keeping with recommendations provided by Joint Authorities for Rule Making on Unmanned Systems (JARUS) Specific Operations Risk Assessment (Ref. 8). The flight was coordinated with DFW air traffic controllers. In the event of C2 lost link or other emergencies, there were several emergency landing sites specified along the path that were monitored by visual observers to ensure that they were free of people. If the aircraft lost its C2 link it would automatically land at one of those contingency landing areas before any air traffic could become a threat, since the prototype DAA system required a remote pilot to initiate avoidance maneuvers. There were other failsafe conditions, such as loss of global positioning system (GPS), that would trigger a similar, but not necessarily identical, automated response.

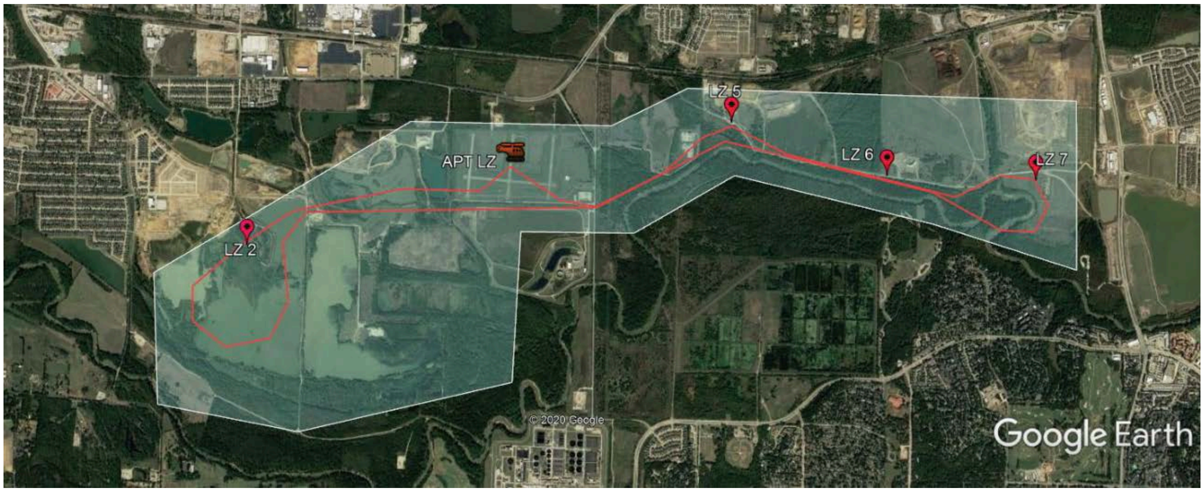

Figure 2.2.4-1: The flight demonstration path of the Bell Textron (Fort Worth, Texas, U.S.A) APT70 unmanned aircraft.

2.3 General Atomics Aeronautical Systems, Inc.

General Atomics Aeronautical Systems, Inc. (GA-ASI) used their SkyGuardian UAS to conduct a long-endurance multi-modal infrastructure survey and inspection flight demonstration (Ref. 9). The concept of operations was to fly a long-endurance mission above 10,000 ft to survey multiple pieces of infrastructure in a single flight. In the future, data products from these types of flights may be sold to a variety of organizations to provide services such as public safety support, pipeline leak detection, powerline inspection, railroad inspection, precise mapping of terrain, and crop survey, among other services.

2.3.1 The GA-ASI SkyGuardian Unmanned Aircraft

The GA-ASI SkyGuardian unmanned aircraft, shown in Figure 2.3.1-1, is a large, fixed-wing, unmanned aircraft that is a derivative of the military MQ-9 Reaper platform and designed for civil use and certification. The aircraft weighs approximately 12,500 lb when fully loaded, making it the largest unmanned aircraft that participated in SIO. The SkyGuardian resembles and operates like a traditional fixed-wing aircraft, and is expected to take off and land at traditional airports.

Figure 2.3.1-1: The General Atomics Aeronautical Systems, Inc. (San Diego, California, U.S.A.) SkyGuardian unmanned aircraft during the Systems Integration and Operationalization demonstration flight.

2.3.2 The Detect-and-Avoid System of the GA-ASI SkyGuardian Unmanned Aircraft

The GA-ASI DAA system was a close derivative of the system used in another joint NASA and GA-ASI activity to perform the first flight of a large unmanned aircraft in Class E airspace without a chase aircraft (Ref. 10), utilizing the DAA system as an alternate means of compliance to the detect-and-avoid requirements. This DAA system was directly aligned with the Phase 1 RTCA DAA MOPS (Refs. 7 and 11). The Class 2 DAA system used a suite of onboard sensors including an air-to-air radar, ADS-B transceiver, and Traffic Alert and Collision Avoidance System II (TCAS II) to detect both cooperative and non-cooperative aircraft. Detect-and-avoid alerting and guidance information was displayed on the control station using DAA traffic displays aligned with RTCA DO-365 standards, and the remote pilot controlled DAA maneuvers required to remain well clear of detected traffic. The DAA system on the SkyGuardian unmanned aircraft also implemented automatic maneuvering in response to TCAS Resolution Advisories, with the ability for the remote pilot to override the automatic maneuver. These automatic collision avoidance maneuvers helped compensate for C2 latency when the aircraft was controlled through a satellite communication (SATCOM) link.

2.3.3 The Command-and-Control System of the GA-ASI SkyGuardian Unmanned Aircraft

The C2 system used three different links: a legacy C-Band link, a Ku SATCOM link, and a CNPC link aligned with RTCA DO-362 [4] and TSO-C213 [5]. The legacy C-Band link is not intended for a future certified unmanned aircraft but was used for the SIO flight tests as a low latency line-of-sight link for takeoff, landing, and surface operations because the CNPC link integration did not support all required functions, and it was less risky to use a proven link during these critical phases of flight. The Ku SATCOM link was used for transmission of all ATC voice communications, DAA track data and payload imagery during en route operations. It was also used for transmission of C2 data to control the aircraft when out of range of the CNPC link, and as a safety backup during CNPC operation. The CNPC radio was a prototype Collins CNPC 5000 radio that was used only after take-off in the vicinity of the GA-ASI Gray Butte facility, just east of Palmdale, CA. The Collins CNPC 5000 radio was only partially integrated into the UAS. This radio did not follow the data classes specified in DO-362 due to the need to implement data compression techniques to transmit all the necessary information through the limited available bandwidth. When the unmanned aircraft was in range of the antenna located at Gray Butte, the CNPC link was used to transmit C2 data and control the aircraft. However, ATC voice and DAA information, which CNPC Data Class 4 is intended to also carry, were transmitted only over the SATCOM link. In order to fully comply with DO-362, additional work is needed to compress C2, voice and DAA data and conform with the specified data classes.

2.3.4 The Flight Demonstration of the GA-ASI SkyGuardian Unmanned Aircraft

The original flight demonstration was planned to occur on a route in the southern California area and included operations above densely populated Class B airspace, with portions of the flight in Class E airspace to be conducted without a chase aircraft. Initially, one of the risk mitigations explored by the FAA for the flight was supplemental ATC flight-following services, which were intended to help mitigate the risk associated with a non-certified DAA system. Air Traffic Control facilities, however, were not able to provide additional staffing to support the flight-following services due to COVID-19 virus restrictions. This condition resulted in a mitigated flight demonstration using an existing transit COA from the FAA.

The mitigated flight demonstration used an existing transit COA between Gray Butte and the Yuma Proving Ground. Several pieces of infrastructure were identified along the route to emulate a multi-modal infrastructure inspection mission. The demonstration was a long-endurance mission that took place over an approximately nine-hour period. The COA did not authorize the use of the DAA system as the primary method of traffic avoidance, so a chase aircraft was used in Class E airspace, standard ATC separation services were provided in Class A airspace, and other portions of the flight took place in restricted airspace. The SkyGuardian unmanned aircraft took off from Gray Butte and conducted operations in the local Gray Butte area to test the CNPC C2 link and survey local Gray Butte infrastructure. Next, the aircraft climbed up to Class A airspace and transited along the cyan route shown in Figure 2.3.3.-1, surveying land along the route. After conducting surveying operations in restricted airspace at the Yuma Proving Ground for approximately two hours, the SkyGuardian transited back to Gray Butte, where additional CNPC radio testing and local infrastructure inspection were conducted.

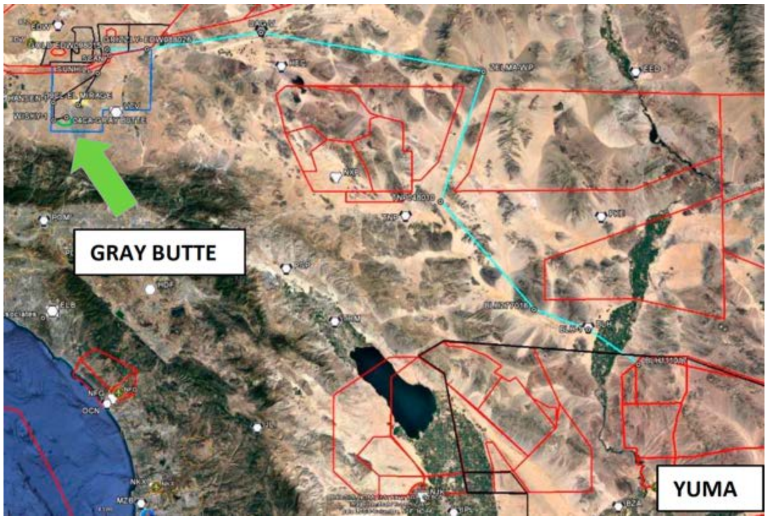

Figure 2.3.3-1: The General Atomics Aeronautical Systems, Inc. (San Diego, California, U.S.A.) flight demonstration route.

After the mitigated flight demonstration, efforts continued to obtain a COA for flight in Class E airspace without visual observers or a chase aircraft. The FAA Air Traffic Organization clarified that it does not intend to provide any special flight-following services to UAS as a mitigation for a non-certified DAA system. The lack of ATC flight-following services motivated the need for additional scrutiny of the DAA system by the FAA Aircraft Certification Service and the need for a new experimental airworthiness certificate that incorporated DAA system limitations based on the level of maturity of the DAA system. Later, GA-ASI received a new experimental airworthiness certificate and a COA that allowed BVLOS operations in Class E airspace without a chase aircraft. Operational mitigations required visual observers when below 3,000 ft AGL for takeoff and landing, and for operations that minimize time below 10,000 ft mean sea level (MSL) due to the possibility of VFR traffic without transponders that could only be detected with the uncertified air-to-air radar. Nevertheless, this approval represents significant progress towards the goal of unrestricted UAS flights within the NAS.

3.0 BEST PRACTICES AND CHALLENGES

The objective of SIO was to identify best practices that can be used to progress toward routine large UAS missions that benefit the public. Throughout SIO a series of best practices and challenges were identified (Ref. 12). This section focuses on observations associated with design assurance and certification, DAA, C2 and spectrum, and lost-link contingency planning.

3.1 Design Assurance and Certification

The SIO partners were required to make initial progress toward type certification, to the extent that such was possible within the available compressed timeframe. This progress included creating foundational documents such as concepts of operations, operational risk assessments, and draft project specific certification plans.

The move toward performance-based regulations is expected to increase the rate of innovation in aviation by enabling the use of different methods of compliance, such as different industry standards. An observation from SIO was that this philosophy has been successful. Most of the regulations in the latest version of 14 CFR Part 23 are applicable to the fixed-wing UAS demonstrated in SIO and were able to be used with only minor modifications. The switch to performance-based regulations, however, shifts the burden of compliance to industry standards and applicants, highlighting the importance of high-quality industry standards.

One of the challenges observed during SIO was that high quality industry standards did not exist for all the functions and systems needed for routine commercial operations. This condition made it challenging to identify methods of compliance and finalize the type-certification basis - particularly true for the smaller unmanned aircraft, such as the AiRanger™, that may be in a lower risk category than aircraft typically certified under 14 CFR Part 23.

An additional observation is that there is a trade-off between the specificity of industry standards and how easily they can be used. Standards that focus on high-level performance targets provide flexibility for an applicant to innovate and implement different technologies compared to a prescriptive standard; however, they often place the burden on the applicant to develop methods of compliance to the standards. The possibility of multiple technologies associated with a single standard can also make the approval process more challenging for the regulator.

3.2 Detect and Avoid

Deploying DAA systems in the SIO timeframe posed unique challenges. Commercial off-the-shelf DAA systems do not exist, and industry standards were in the process of being developed by RTCA Special Committee - 228 for large UAS and ASTM for low-altitude UAS operations. Standards were under development, so the SIO partners developed prototype systems that were at various levels of maturity.

Throughout SIO, the partners used a “crawl, walk, run” approach to implement safety mitigations that were commensurate with maturity of their DAA system. One of the SIO partners conducted a series of ground tests followed by tests onboard a conventional rotorcraft prior to integrating the DAA system into the unmanned aircraft. The tests onboard the conventional rotorcraft included functional tests followed by encounter tests with an intruder. Testing onboard a crewed rotorcraft allowed the partner to solve engineering problems, characterize the DAA system, and collect data without the need for visual observers or a 14 CFR 91.113 waiver. These tests were followed by tests with the DAA system integrated into the unmanned aircraft. Additionally, the SIO partners conducted surveys of the air traffic in the demonstration area to assess the unmitigated collision risk (that is, the collision risk without a DAA system). Databases enhanced by the Massachusetts Institute of Technology, Lincoln Laboratory (MIT-LL) (Lexington, Massachusetts, U.S.A.) as part of this activity, which have been open-sourced, may help future applicants conduct similar analyses (Ref 13). The SIO partner that ultimately received a BVLOS COA and 14 CFR 91.113 waiver developed a requirements matrix that showed all the requirements and tests for applicable standards, which requirements were met, and risk mitigations for any requirements that were not met.

One challenge encountered by SIO partners when testing their DAA systems was ground clutter from air-to-air radars when flying at low altitudes. Ground clutter can produce false alerts that reduce the effectiveness of the DAA system or cause unnecessary maneuvers if the DAA system is automated. While ground-based surveillance systems (GBSS) could help provide surveillance for low-altitude flights, they may not be an economically viable option for flights that traverse long distances. Additionally, GBSS may be more difficult to set up for certain missions, such as disaster relief, when ground-based infrastructure may be either unavailable or damaged.

3.3 Spectrum and Command and Control

There are currently no certified C2 radios commercially available, so the SIO partners either used prototype radios that were aligned with industry standards or commercial off-the-shelf radios using temporary authorizations on frequencies intended only for research and development and not viable for long-term commercial use. Nevertheless, substantial knowledge was gained.

The importance of using licensed spectrum that is legally protected against interference was emphasized throughout SIO. Spectrum requirements depended on the safety criticality of the functions that were supported and the risk mitigations in place, which may include operational mitigations or autonomous functions that ensure safety if the C2 link is degraded or lost.

The use of spectrum allocated for safety-critical UAS Control and Non-Payload Communications (CNPC) has been designed to be used for C2 and meet performance requirements. The use of commercial networks, such as cellular networks, were also discussed during SIO. Regulators asked questions about coverage, latency, reliability, and whether the UAS had priority if the network became overloaded. The development of industry standards, such as those being developed by RTCA, will be key to unlocking the use of commercial networks and identifying the functions they can support.

Some of the SIO partners used temporary authorizations for frequencies intended only for research and development for their primary C2 link, since there were no certified CNPC radios available at the time of the SIO demonstrations. The temporary authorizations allowed the use of existing radios that used licensed spectrum; however, it was often difficult to obtain the temporary approvals due to the possibility of interference in certain locations. The importance of early coordination of spectrum authorizations with the FAA spectrum office and the benefit of using spectrum and networks intended for the certified system as early as possible were highlighted throughout SIO.

3.4 Lost-link Contingency Planning

The UAS demonstrated as part of SIO were remotely piloted, and a C2 link was required to communicate DAA and other UAS subsystem data to the remote pilot and to allow the pilot to issue commands to the aircraft. Lost-link procedures were required to make sure that the UAS would not pose a hazard to other aircraft or people on the ground if the C2 link were lost. The lost-link procedures specified in the COAs obtained for the SIO demonstrations were specific to the routes of flight and UAS capabilities and are likely not scalable to future routine commercial operations.

As large UAS operations become routine, there will be a need for standardized lost-link procedures that are predictable to ATC and minimize impact on other NAS users (Refs. 14 and 15). The need for predictability resulted in one of the SIO partners inhibiting automatic traffic collision avoidance system (TCAS) maneuvers when the unmanned aircraft was in a lost-link state. In the future, it may be possible to develop bounds on DAA maneuvers and standardized return-to-course behaviour to enable automatic DAA maneuvers while providing sufficient predictability to ATC.

Lost-link procedures must also consider the loss of other functions that depend on the C2 link, such as voice communications with ATC, DAA functionality if maneuvers are not automated, or surveillance information from a GBSS. One question frequently encountered by the SIO partners was how the aircraft would avoid VFR traffic when in a lost-link state, since the DAA systems of all SIO partners required a pilot to initiate DAA maneuvers. This risk motivated solutions such as identifying emergency landing locations along the flight path or procedures to expediently climb to Class A airspace where all aircraft are IFR, enabling ATC to separate all traffic from the flight path of the unmanned aircraft.

Lastly, future standardized lost-link procedures must be compatible with actions such as vectors, speed changes, and altitude changes provided by ATC that could take the unmanned aircraft off its original IFR flight plan. Lost-link procedures must also be able to accommodate common actions such as reroutes around weather, diversions to an alternate airport, and the possibility of changes to the flow direction of an airport after the aircraft is in a lost-link state. During SIO, one of the partners observed that there were instances when ATC wanted to vector the unmanned aircraft or provide a shortcut, but the unmanned aircraft was unable to implement the vector because the action was not consistent with the prescriptive lost-link procedures specified in the COA. A possible solution is for a UAS to recompute lost-link routes throughout the flight and for the remote pilot to provide ATC with an up-to-date lost-link route after lost-link is declared.

4.0 FOLLOWING WORK

As we look toward the future, several companies have expressed interest in using large UAS at increasing levels of autonomy for missions such as regional cargo delivery. These increasing levels of autonomy include progressing from remotely-piloted operations to remotely-supervised operations in which a small number of pilots (m) supervise a greater number of aircraft (N) - often referred to as m:N operations. Progressing to increasing levels of autonomy is expected to reduce the cost of cargo transportation and may enable a shift from a hub-and-spoke distribution system to a more distributed cargo distribution system.

The NASA Air Traffic Management eXploration project (ATM-X) initiated the Pathfinding for Autonomous Vehicles (PAAV) research area to investigate paths toward using increasingly autonomous aircraft for cargo transportation between regional airports. One of the objectives of this research is to identify the roles, responsibilities, and allocation of functions needed to enable increasingly autonomous operations in airspace shared with conventional aircraft.

5.0 SUMMARY

Systems Integration and Operationalization (SIO) was a partnership between the National Aeronautics and Space Administration and three industry partners to: (1) integrate prototype detect-and-avoid and command and control systems into unmanned aircraft systems (UAS); (2) conduct flight demonstration in the National Airspace System; and (3) develop key documentation relevant to type certification. Three flight demonstrations were successfully completed in non-segregated airspace using operational mitigations commensurate with the maturity of the UAS. Various best practices and gaps were identified by observing interactions between the Federal Aviation Administration and the SIO partners as they worked through the initial stages of type certification and the process of obtaining approvals for the flight demonstrations, which can help inform efforts to make further progress toward routine commercial remotely-piloted and remotely-supervised operations.

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