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GA-ASI Final Report and Program Wrap-up for NASA System Integration and Operationalization (SIO)

General Atomics Aeronautical Systems, Inc. (GA-ASI)
Poway, California

May 2021

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EXECUTIVE SUMMARY

The NASA SIO demonstration flight of April 3, 2020 represents a successful culmination of 18 months of coordinated effort between GA-ASI, NASA, the FAA, Collins Aerospace, and Honeywell Aerospace to operate a Medium Altitude, Long Endurance (MALE) Unmanned Aircraft System (UAS) safely in the National Airspace System (NAS) using industry leading prototype technologies. The GA-ASI team consisted of technical experts, program managers, engineers, mechanics, flight technicians, flight crews, and numerous other subject matter experts. This final report describes the most significant and potentially impactful aspects of the planning, integration, test, and flight aspects of this effort.

GA-ASI successfully integrated the key technologies needed for UAS to fly in the NAS onto our prototype SkyGuardian UAS, which was designed to meet the most stringent airworthiness standards applicable to an aircraft of its size category. A proven Detect and Avoid (DAA) system, developed by GA-ASI and utilizing Honeywell Aerospace technology was integrated onto SkyGuardian for the first time, along with datalink radios from Collins Aerospace that meet the new civil standard for Control and Non-Payload Communication (CNPC) links. GA-ASI also obtained approvals from the FAA and FCC to operate the reconfigured UAS.

The SIO demonstration flight represented a commercial aerial surveying operation conducted at medium altitude (>10,000ft above mean sea level). The aircraft's onboard sensors were used to capture photographic, infrared and radar imagery of public and commercial infrastructure and land, and to subsequently produce the types of data products that would provide business value to potential customers. These survey services would supplement or replace services currently provided by manned airplanes and helicopters, small drones or satellites. A "virtual" mission was also planned, to show what additional survey data could have been captured during the flight if additional sensors had been installed on the aircraft's external hardpoints.

This revision of the final report focuses on information of value to the wider UAS community, and avoids propriety data to facilitate broad dissemination. It also includes a description of GA-ASI's engagement with the FAA following the SIO flight, which led to the award of an updated Special Airworthiness Certificate in the Experimental Category (SAC-EC) and a Certificate of Waiver or Authorization (COA) allowing operation of the SkyGuardian UAS using its DAA system to satisfy right-of-way rules, instead of a chase plane. The associated operational limitations are described to illustrate the further steps that would be needed to remove those limitations for unhindered commercial operations.

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1. INTRODUCTION

General Atomics Aeronautical Systems, Inc. (GA-ASI) successfully conducted their demonstration flight, the culminating event of their participation in the NASA SIO program, on Friday, April 3, 2020. GA-ASI leveraged its existing Certificate of Waiver or Authorization (COA), issued from the FAA, which contains an approved route of flight to and from its airport located at Gray Butte, CA and the military restricted airspace associated with Yuma Proving Grounds (YPG) in southwestern Arizona. Both before and after transiting to YPG, the SkyGuardian flight crew spent over two hours in the local Gray Butte area observing infrastructure points of interest while operating in Class E airspace with the use of a chase plane. The transit to YPG in Class A airspace and operations while inside the restricted airspace were conducted without a chase plane. Surveys of infrastructure points of interest were conducted both during the transit to and from Yuma as well as while operating in YPG. SkyGuardian flew a total of 9.5 hours for the demonstration flight.

As part of the program, the following subsystems were integrated on GA-ASI's SkyGuardian prototype aircraft, N190TC:

1. Collins Aerospace Command and Non-Payload Communication (CNPC) prototype (CNPC-5000E) datalink radio
2. Class 2 DAA system, including GA-ASI's Air-to-Air Radar, Honeywell Aerospace's modified TCAS II unit (TPA-100B) with built-in DAA tracker and hybrid surveillance from ADS-B In
3. Raytheon DAS-4 multi-spectral camera turret
4. GA-ASI Lynx® multi-mode radar

GA-ASI utilized its existing Gray Butte to YPG transit COA to complete the demonstration. This COA authorized no-chase flight only when established in Class A airspace or when inside the military restricted airspace of YPG.

The CNPC datalink used a ground terminal at Gray Butte airfield, and was used to control the aircraft while in the Gray Butte vicinity, before and after the transit to YPG. It remained powered on until reaching 100 miles range (the limit permitted by the FCC license), and was switched on again at the same distance upon return, to collect range performance data. Due to its experimental nature, CNPC was only enabled for command and control once the aircraft was safely airborne; it was not used for take-off and landing. Legacy Line-of-Sight and SATCOM datalinks remained installed on the aircraft. The CNPC radio provided a reliable line of sight (LOS) datalink connection when enabled.

The Detect and Avoid system was active during the entire flight and provided the aircrew with situational awareness for traffic in the vicinity of the aircraft.

Survey imagery collections for numerous infrastructure points of interest were planned along the COA route, and briefed to NASA during an operational readiness review the day prior to the demonstration flight (4/2/2020). Most were successfully surveyed and imaged with the payloads aboard SkyGuardian during the flight.

This report provides a brief description of the accomplishments of the SIO demonstration flight, technical findings and regulatory engagement needed for operational approvals.

1.1 NASA SIO OBJECTIVES

The objectives of the SIO Program, as well as an indicator of success for each, are summarized in Table 1. These are based on the cooperative agreement between NASA and GA-ASI, the terms of which were finalized in January 2019:

No.	Objectives	Status
1	Conduct a shared resource project that will lead to progress toward commercial UAS operations in the National Airspace System	ACHIEVED
2	Integrate UAS technologies required for a commercial mission	ACHIEVED
3	Generate a mission concept of operations (CONOPS) with high commercialization potential	ACHIEVED
4	Generate safety and airworthiness data	ACHIEVED
5	Identify operational requirements and restrictions	ACHIEVED
6	Obtain approval to operate in the national airspace	PARTIALLY ACHIEVED[1]
7	Facilitate progress toward generating artifacts for type certification and operational approval required for routine commercial UAS operations	ACHIEVED
8	Safely conduct a UAS flight demonstration in the National Airspace System with specified technologies (detect and avoid and command and control systems) integrated	ACHIEVED
9	Generate publicly available documentation of lessons learned from the type certification efforts to benefit the UAS community	ACHIEVED

Table 1: Achievement of NASA SIO Objectives

2. POST-MISSION SUBSYSTEM PERFORMANCE EVALUATION

2.1 DETECT AND AVOID SYSTEM

A Detect and Avoid (DAA) system is composed of two general functional groups:

1) Traffic surveillance sensing and tracking
2) Alerting, guidance and display

[1] As noted in Section 4.2.6, page 30, the final COA negotiated with the FAA (though not exercised during the SIO effort) did allow some flight in Class E national airspace without a chase aircraft

For the GA-ASI prototype DAA system, the functions of airborne traffic detection and tracking are performed by components integrated on the aircraft, while alerting, guidance and display is hosted on the ground (Figure 1). The airborne traffic surveillance sensing equipment includes:

- Honeywell TCAS II with ADS-B IN
- GA-ASI Air-to-Air Radar (ATAR)

TCAS II and ADS-B IN are the cooperative sensors that rely on transponder equipment onboard other aircraft. The ATAR system is used for detecting non-cooperative aircraft (aircraft that are not equipped with operating transponders for traffic identification).

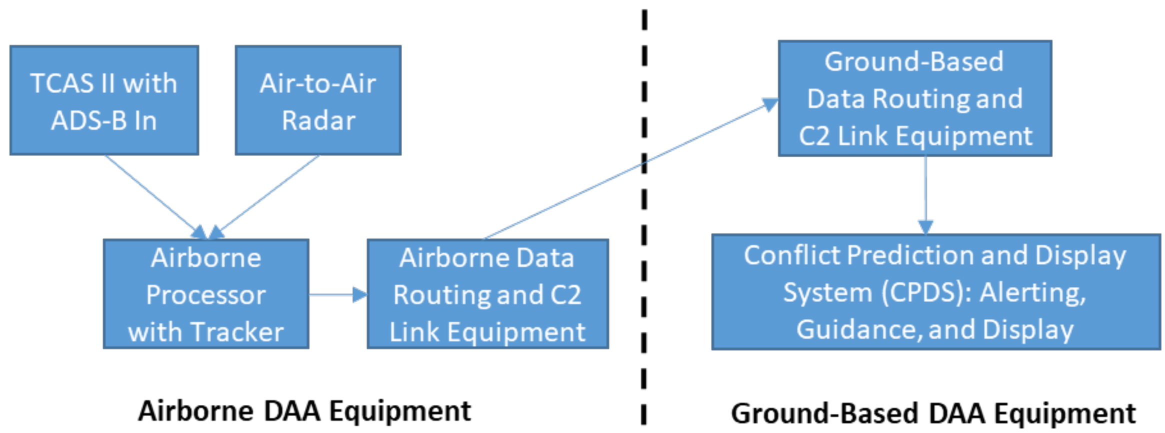

Figure 1: GA-ASI Prototype DAA System

This DAA system was previously installed and operated successfully on NASA's Ikhana UAS (variant of GA-ASI Predator B) during the NASA No-Chase COA demonstration program in June 2018[2]. The SIO program is the first time the DAA system has been installed on a GA-ASI SkyGuardian type aircraft. Overall, the GA-ASI DAA system performed well, and as necessary for the NASA SIO demonstration flight. The DAA system was active during the duration of the SIO demonstration flight and provided situational awareness to the flight crew located in the ground control station. All DAA air traffic surveillance sensors, including TCAS II, ADS-B IN, and the Air-to-Air Radar (ATAR), performed as expected and provided the necessary traffic data to remain well clear of both cooperative and non-cooperative air traffic. Because the aircraft spent much of the flight in restricted or controlled airspace, few unplanned encounters were expected to occur during the flights that would require maneuvering not already initiated by Air Traffic Control (ATC) or the chase plane. Nevertheless, during the flight, the alerting and guidance algorithms functioned as designed, and were used to monitor surrounding traffic throughout the flight.

During the 9.5 hour flight, there were a few instances where the DAA traffic display experienced a brief (30-40 second) loss of data, then returned to normal operation. During these drops, TCAS alerts on the pilot's Head-up Display, including resolution advisories (RAs), remained

[2] https://www.ga-asi.com/ga-asi-daa-system-aids-faa-approved-flight-of-nasa-unmanned-aircraft

operational. GA-ASI's investigation into the root cause concluded that these events were related to a brief data bandwidth conflict on the SATCOM downlink between the DAS-4 camera system and the DAA system, which has since been corrected by updating payload configuration settings to ensure DAA system messages remain prioritized during any unexpected data conflict situations. Section 2.1.4 below provides an overview of these observations and the results of the investigation.

There are several topics with lessons learned from the demonstration flight that are noteworthy and would be valuable for providing insight to the UAS community regarding common issues that may occur with similar DAA systems. These topics include:

- Air-to-air radar (ATAR) track altitude filtering
- Nuisance alerts
- Benefit of ATAR system above 10,000'
- DAA integration considerations
- 14 CFR §91.113 waiver and operational approval challenges

2.1.1 ATAR Track Altitude Filtering

Among the challenges for proper function of an air-to-air radar at low altitudes is differentiating between ground tracks and airborne tracks. The radar is designed to search for objects moving relative to itself (with the aircraft typically referred to as "ownship"). The ground has relative movement to ownship, but it is predictable based on ownship airspeed, so static objects on the ground (e.g., buildings, parked vehicles, etc.) can be filtered out. The ATAR needs to differentiate Ground Moving Targets (GMT) from low altitude airborne targets. To remove ground moving targets, the ATAR utilizes multiple parameters, including the ground altitude above Mean Sea Level (MSL). For a maritime environment, the parameter would be set slightly above 0 feet MSL. For a high desert environment, a parameter closer to the local elevation would be more appropriate. As successfully demonstrated on previous flights flown in the high desert, the ground altitude filter should have been set at 3,500 feet. However, for this flight, the ground altitude value was inadvertently not updated resulting in the ATAR reporting GMTs. In the future, this potential human error will be prevented by updating the preflight check list to verify a valid ground altitude value. Also, GA-ASI is investigating options to update the ground altitude value as the aircraft proceeds along its route.

For the demonstration flight, despite taking off from an airfield at approximately 3,000 feet elevation, the ATAR's internal altitude parameter was pre-set for a maritime environment. As discussed above, this resulted in the ATAR tracking and reporting ground vehicles within its field of regard.

Conflict Prediction and Display System (CPDS) is the software that GA-ASI uses for alerting, guidance, and display for the DAA system. One of its many functions allows filtering of traffic detected above or below a certain threshold altitude (e.g., 5,000 feet below ownship and 9,000 feet above ownship). Altitude filtering with CPDS was the interim solution chosen to filter out the ground tracks during the demonstration flight. The lower altitude-filtering threshold is a manual setting that requires adjustment as the aircraft altitude and terrain height changes. For the SIO demonstration flight, this function properly filtered ground tracks for the majority of the flight. In lower altitudes, however, ground tracks were unnecessarily displayed. To achieve optimal traffic filtering, this threshold would automatically adjust based on GPS-defined aircraft position, and may be an available future feature as GA-ASI continues development of its DAA system.

2.1.2 Nuisance Alerts

A nuisance alert can be described as an alert that provides little or no safety value to the pilot. They typically occur when sensitivity levels for the alerting criteria are not adjusted properly for the environment. To minimize nuisance alerts, it is important to tailor system/alert sensitivities based on the active flight environment.

Traffic alerts in the enroute environment are designed for typical enroute aircraft spacing. When the same alerting criteria is used in higher density/proximity airport environments, it can result in elevated nuisance alerts. CPDS alleviates this by the use of a conflict probe, which provides a graphical representation of the predicted conflict volume; this is a helpful, real-time tool for additional airborne traffic situational awareness.

During the NASA SIO demonstration flight, as mentioned in the previous section, a CPDS filter was used to eliminate ground tracks from being shown on the traffic display. However, CPDS conflict probe algorithms still consider filtered-out tracks when determining potential conflict volumes. During the demo flight, there were instances when conflict volumes appeared on the display that were caused by non-threatening ground traffic. This was likely due to high uncertainty values for vertical rate of the ground tracks. This is an area for improvement, as the situational awareness tool produced excessive nuisance alerts. This highlights the importance of conducting human factors evaluations on the complete DAA system to ensure that it displays only what the pilot will require to remain well clear of other air traffic during stressing cases. Future DAA systems should be well tested against all forms of nuisance alerts that could be presented to the pilot to ensure pilot workload is not adversely increased during routine operations.

2.1.3 Benefit of ATAR above 10,000 feet

While in the Yuma restricted airspace flying at 15,000 feet, SkyGuardian twice detected a non-cooperative aircraft operating at 1,000 feet above ownship with the use of ATAR. The DAA system provided the appropriate alerts and preventative guidance for both encounters. Although most aircraft operating above 10,000 feet MSL are required to have an active transponder/ADS-B Out, not all aircraft are equipped (e.g., any aircraft which was not originally certificated with an engine-driven electrical system). Although a DAA system was not required for operation in this restricted area, this encounter clearly shows the utility of an active ATAR while operating above 10,000 feet.

As noted in Section 2.1, during the 9.5 hour SIO demonstration flight there were a few, brief instances when the CPDS displayed a red “X” for 30-45 seconds, indicating temporary loss of traffic data. These events were not related to any loss of command and control of the aircraft or loss of TCAS function. Study of this anomaly revealed that this issue was associated with the aircrew applying configuration changes to a non-safety critical system, which temporarily impacted the flow of DAA data to CPDS. During these events, the DAA processor and CPDS continued operating, and responded as designed. When the traffic data from the airborne DAA processor was interrupted, the CPDS display showed that it did not have a valid data source. When traffic data returned, the CPDS returned to normal operation.

During each occasion, TCAS alerts and Resolution Advisories (RA) were not impacted, because they use a different data path in the Command and Control (C2) link, included with other flight-critical data. RAs would still have displayed on the Heads-Up Display (HUD) as normal, but the CPDS traffic display, including conflict volumes for non- cooperative aircraft, was unavailable during these brief outages.

A review of the logger and network setting identified that the cause was a misconfigured network priority setting on the airborne router. This error arose in part because the DAA system was integrated into the legacy C2 links on N190TC as an add-on, along with other payload subsystems, in an experimental configuration. It has been corrected for all future DAA operations with N190TC.

2.1.4 Waiver to 14 CFR §91.113 (b)

Regulations contained in 14 CFR §91.113 (b) provide a framework for see-and-avoid requirements. Because GA-ASI's DAA system has not yet been certified as a means of compliance with all such see-and-avoid requirements for UAS, GA-ASI sought a waiver to §91.113 (b) from the FAA, using the DAA system as the means to remain well clear of other air traffic. The FAA's process required concurrence from many different disciplines and departments, and ultimately, the necessary coordination was not completed in time for the SIO demo flight.

After completion of the SIO demo flight, the FAA re-booted the waiver application for N190TC, working closely with GA-ASI and with tighter internal coordination, to achieve a successful outcome. This second iteration of the §91.113 (b) waiver process led to the issuance of a revised Special Airworthiness Certificate in the Experimental Category (SAC-EC) for N190TC on September 23, 2020. The SAC-EC included operating limitations to allow use of the baseline DAA system as a means of complying with see- and-avoid requirements, without the need for a chase plane. The FAA issued a corresponding COA on September 25, 2020 with a specific route from Gray Butte eastwards to the Grand Canyon and back again. Further details of how this was accomplished are provided in Section 4.2.

2.2 COMMAND AND NON-PAYLOAD COMMUNICATION (CNPC) – INTEGRATION, PERFORMANCE, LIMITATIONS

2.2.1 Background

Use of the CNPC datalink standard is largely accepted across industry as being part of the certifiable path forward for UAS integration into the National Airspace System. It creates a Radio Line-of-Sight (RLOS) datalink with time division duplex (TDD) uplink and downlink in a protected portion of C-band spectrum (5030-5091 MHz). The technology and efficacy of the Collins CNPC-5000E radios had been analyzed on previous NASA projects. The NASA SIO program represented the first time a CNPC radio was used for command and control of a large UAS.

The bandwidth of Data Class 4 over a CNPC datalink, the widest available for routine C2 functions, is limited to 120 kHz per RTCA DO-362. This supports 138 kbps (with one bit per symbol), of which only about 35.5 kbps is available for data content – the remainder being used for routing and encryption headers, data validation and error correction. The functions intended for this Data Class include command messages to the UA, telemetry from the UA, voice audio relay to and from the UA's VHF radios, DAA system tracks and weather radar data from the UA. To fit all of these functions into the available data rate requires extremely efficient data structures and data compression. The scope of engineering development and integration for this SIO project did not allow for significant changes to the data structures used by existing GA-ASI datalinks. This limitation resulted in only UAS Command & Control (C2) and telemetry data being sent across the CNPC link for the SIO demonstration flight. The SATCOM C2 link carried all other data, including nose camera video, voice audio, DAA tracks, and payload imagery. The SATCOM C2 link also served as an active backup for CNPC link testing.

2.2.2 Overview

The CNPC link performed better than expected during the demonstration flight. GA-ASI flight crew exercised positive C2 of the UAS using the CNPC link for up to 100 nautical miles from the ground radio terminal located at Gray Butte airfield. Link hits (drops) occurred in expected situations, but did not adversely affect C2 functions as the UAS reverted to the SATCOM C2 link in these situations. CNPC did not experience any thermal issues within the demonstrations flight envelope, nor were there were any signal interference issues. From the perspective of the SIO flight crew, there was no perceivable difference or degradation when controlling the aircraft via the CNPC link as compared to controlling it using GA-ASI's legacy C-band RLOS C2 link, including no increase in latency.

2.2.3 Demonstration Summary

The Federal Communications Commission (FCC) license, which authorized airborne transmissions of the CNPC radio, limited its use to within 100 nautical miles (nm) of Gray Butte airfield. As a result, CNPC was the active datalink during the outbound portion (Figure 2) and the inbound portion (Figure 3) of the flight, within 100 nm of Gray Butte. In total, CNPC was tested for more than five hours during the demonstration flight, with almost four hours as the active datalink. Because the CNPC link is still a prototype and was not configured to support all CNPC link functions, to minimize risk it was not used during taxi, take-off or landing phases of flight; instead, GA-ASI's legacy C-band RLOS C2 link was used.

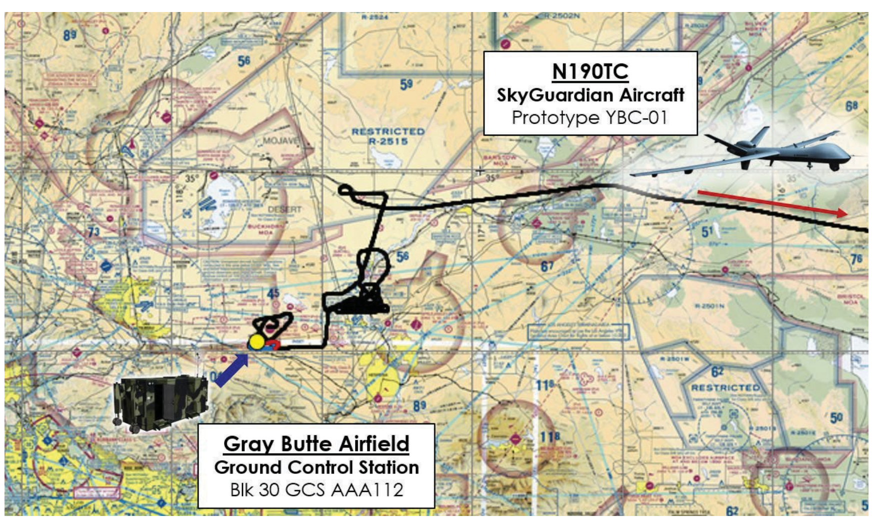

Figure 2: Outbound flight path

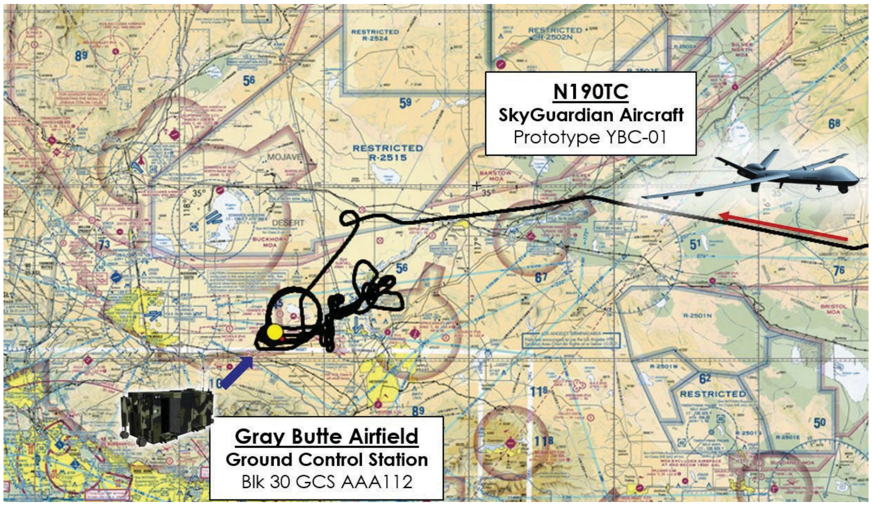

Figure 3: Inbound flight path

2.2.4 CNPC Link Configuration

The aircraft's lower C-band omnidirectional and directional antennas were paired with the legacy RLOS C2 link. These antennas have the most reliable all-round coverage and least airframe blockage. The upper directional antenna was allocated for the CNPC link (see Figure 4). This configuration ensured that the legacy C-band C2 link would be available within range of Gray Butte with the aircraft at any direction and in any typical orientation relative to the ground terminal, because this was the only link suitable for completing a piloted landing.

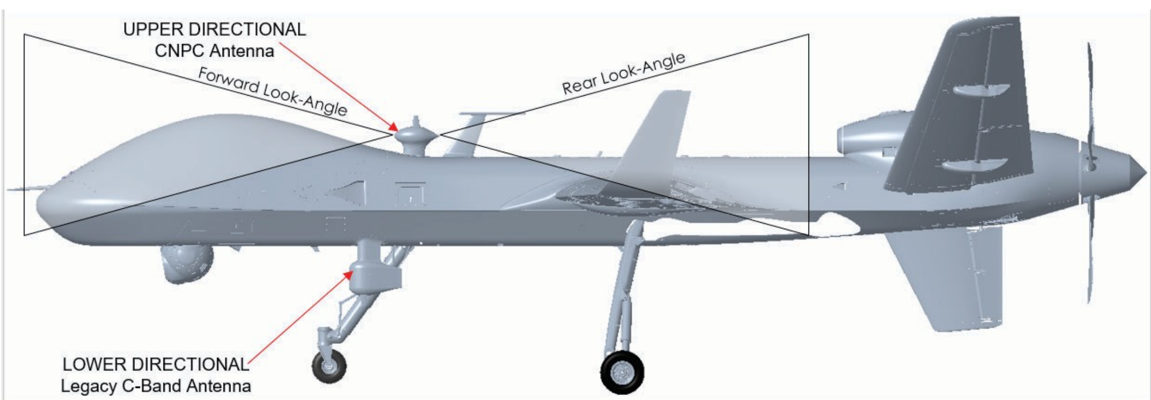

Figure 4: Antenna Location

The ground radio station of the CNPC link was connected to an omnidirectional antenna to avoid the need for antenna steering control, simplify the ground installation, and to allow for the possibility of a single ground antenna supporting multiple UAS. The air and ground radios were each connected to a 10W amplifier. The azimuth-steered, directional antenna on the aircraft provided approximately 14dB of gain.

2.2.5 CNPC Link Performance

With this antenna configuration, the CNPC link maintained full health 95% of the time while within 50 nm of Gray Butte. The link experienced significant health degradation beyond 50 nm, as shown in Figure 5. Health is measured as the percentage of time the CNPC link data was available, versus reversion to SATCOM backup link data. The SATCOM C2 link was active throughout CNPC link testing, and relaying the same C2 data. The UAS was programmed to accept the C2 data from the CNPC link in preference to the SATCOM link data, but to revert to the SATCOM data whenever CNPC link data was unavailable or garbled. Thus, positive control of the aircraft was maintained through lapses in CNPC connectivity.

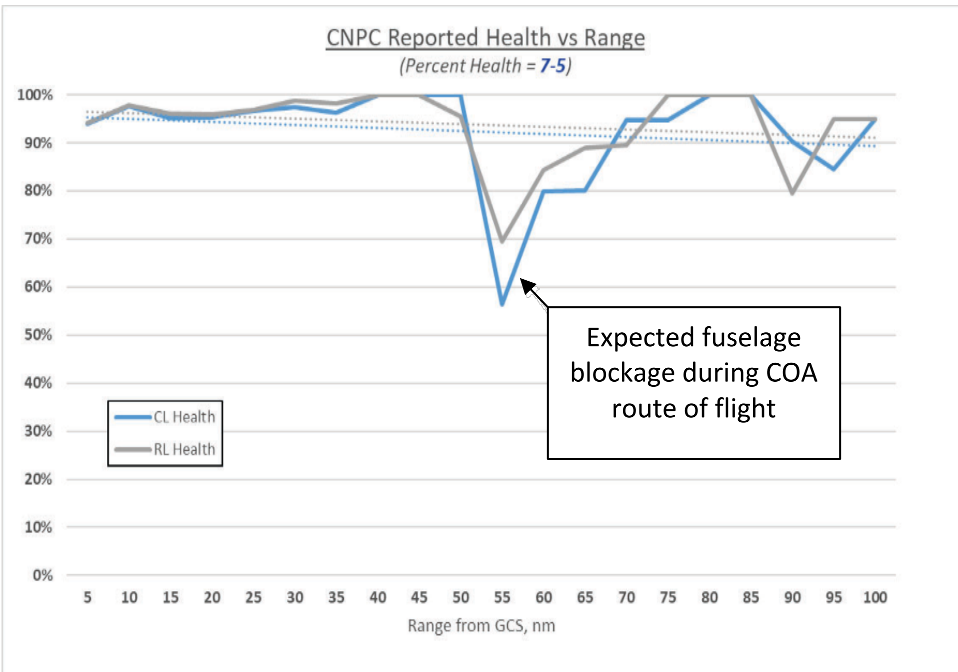

Figure 5: CNPC Health vs. Range

The large performance dip shown in the above figure is an expected consequence of using the upper directional antenna for the CNPC link for this test integration, and the airframe blockage that occurs at certain orientations relative to the ground terminal. At 0º and 180º relative to the aircraft's heading, the fuselage will cause blockage of the upper directional antenna. At 55 nm range, the aircraft's heading associated with the transit route happened to align the fuselage to block the antenna RLOS (flying directly away from/towards Gray Butte). Further away, where the heading was not causing airframe blockage, strong link performance was observed out to 85 nm range.

Analysis of the measured signal strength showed that the dip in link health at 55 nm corresponded to a 10 dB reduction in received signal strength relative to the predicted, unobstructed received signal strength. A similar 10 dB reduction relative to predicted signal strength was measured when the range was <5 nm from the ground antenna. This reduction is attributed to the gain pattern of the directional antenna with increased elevation angle, and the unfavorable angle to the ground antenna when the aircraft is high and close. This reduction is noticeable in the link health at short range, but is less pronounced than the 55-mile dip because the baseline signal strength is much higher at short range.

Use of a lower directional and/or omnidirectional antenna, would dramatically decrease or even eliminate a loss of CNPC connectivity due to airframe blockage or antenna pattern. However, overall range performance would be reduced if only the lower omnidirectional antenna had been used. With a combination of directional and omnidirectional antennas suitably located on the aircraft, and a single ground omnidirectional antenna, these findings indicate that the CNPC link could be relied upon out to 85 nm range.

3. PROGRESS TOWARDS TYPE CERTIFICATION

3.1 INTEGRATING UAS INTO THE NATIONAL AIRSPACE SYSTEM (NAS)

GA-ASI is committed to work towards certification from a technology, regulatory, and NAS integration framework perspective. The efforts will extend well past the conclusion of the SIO program and will ultimately lead to routine, efficient UAS operations in the NAS and globally.

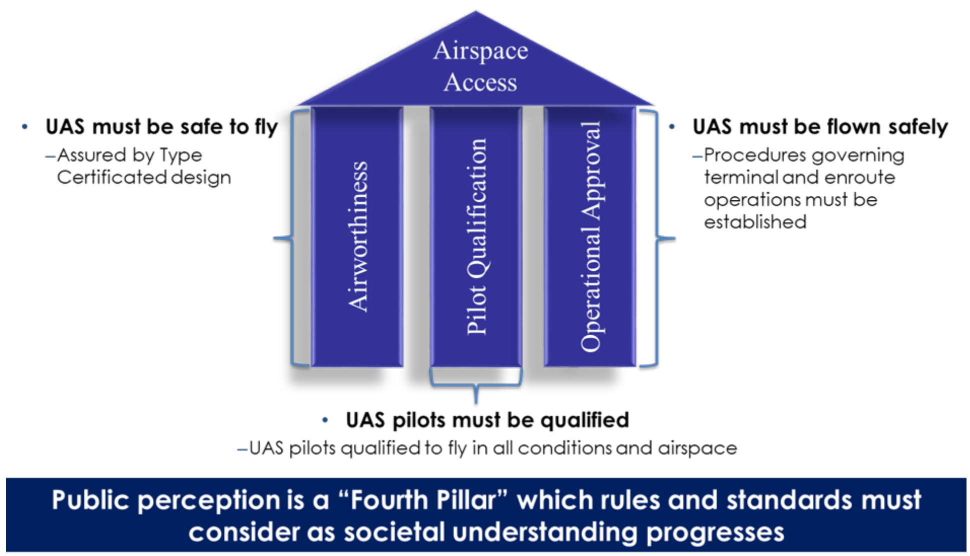

Figure 6: Pillars of Airspace Access

The access of any aircraft to the NAS is predicated on three "pillars," as shown in Figure 6, Airworthiness, Pilot Qualification, and Operational Approval. Underpinning these three pillars is public perception. Unless the public recognizes the benefits of commercial aviation and accepts the attendant or perceived risks, it would not matter how strong the pillars are. This is even more pronounced for the case with UAS. Full integration of UAS into the NAS will be in doubt unless public perception is favorable.

While prior-generation UAS lacked capabilities inherent in manned aircraft to safely integrate into controlled airspace, great strides have been made in technology development, regulatory establishment, and operational use case definition to move the industry towards full NAS integration. UAS cannot comply with some sections of 14 CFR Part 91 and, therefore, require an alternate means of compliance. Most notably, the lack of an onboard pilot necessitates an alternate means of compliance with the following paragraphs of 14 CFR Part 91:

- §91.111, Operating near other aircraft
- §91.113, Right-of-way rules

Furthermore, UAS introduce new architectural features that are so different from manned aircraft, such as a C2 link connecting the pilot with the aircraft, that new approaches to certification and approval are required.

3.2 SKYGUARDIAN CERTIFICATION ARTIFACTS DEVELOPMENT

The SkyGuardian UAS is on a path to type certification in accordance with FAA Order 8110.4C and 14 CFR §21.17(b), for special classes of aircraft, to prove the airworthiness of the UAS. As part of the NASA SIO program, the following certification artifacts required by the FAA were created for the SkyGuardian UAS, to facilitate further progress towards certification:

- Concept of Operations (CONOPS)
- Operational Risk Assessment
- Project Specific Certification Plan (PSCP)

Regular coordination with the FAA's local Aircraft Certification Office will continue to be required to confirm that the basis of type certification and associated methods and processes are firmly in place in order to achieve full type certification of the SkyGuardian UAS. Through the §21.17(b) process, the FAA will publish the basis of certification to the public registry; therefore, substantial details on the project will become public. The proposed basis of certification for the SkyGuardian UAS was reviewed by NASA as part of the PSCP document. In the interim, GA-ASI is committed to continued progress towards certification from a technology, regulatory, and NAS integration framework perspective. The efforts will extend well past the conclusion of the SIO program, with the ultimate goal of routine, efficient UAS operations in the NAS and globally.

3.2.1 CONOPS

The Concept of Operations (CONOPS) for GA-ASI's SkyGuardian UAS portrays how it will operate within the NAS under a future operational scenario, where the UAS seamlessly integrates with other aircraft, including the ability to aviate, navigate and communicate similar to manned aircraft. Since the CONOPS is meant to support derivation of design standards for full, unfettered airspace access, it describes a representative mission that involves flight operations across multiple classes of airspace and places the most stringent certification requirements upon the UAS.

Specifically, the CONOPS document describes the following:

- A notional UAS mission, set in the future to represent a realistic scenario and the foreseeable interactions in the NAS with ATC services, other airspace users and the environment.
- Operational concepts, capabilities, procedures and equipage that will permit the safe integration of SkyGuardian UAS into the NAS within this notional mission.
- General areas of flight within this notional mission, including routes, loiter areas and

altitudes, and characteristics of those areas, including population and air traffic densities.

- Conditions required for desired operations, including applicable flight rules and meteorological conditions.

3.2.2 Operational Risk Assessment

The Operational Risk Assessment (ORA) developed as part of the SIO program was a certification artifact deliverable to both NASA and the FAA. It was developed as a compilation of reliability and safety analyses for each system identified as part of the SkyGuardian UAS configuration. The SkyGuardian aircraft is a modified version of the Predator B Block 5 UAS that also incorporates components from multiple, previous Predator B versions.

The purpose of the in-depth risk study included in the ORA was to assess safety-critical functions and potential failure modes by identifying and analyzing functional failure.

Means of risk mitigation have been suggested in order to eliminate such failures on the SkyGuardian UAS or reduce their effect. Functional failures at the subsystem level and below are identified and analyzed, with both single and multiple software and hardware failure conditions considered. These failure conditions are ranked according to the following safety hazard severity levels: Catastrophic/I, Hazardous/II, Major/III, and Minor/IV. The ORA for the FAA includes prior analyses conducted for subsystems of the entire UAS. However, the NASA ORA deliverable focused specifically on those subsystems (CNCP and DAA) specific to the NASA SIO program.

3.2.3 Project Specific Certification Plan

The purpose of the Project Specific Certification Plan (PSCP) is to define and document the requirements, tasks, and responsibilities necessary for GA-ASI to obtain a new Type Certificate (TC) from the FAA for the SkyGuardian UAS. The plan is managed and maintained by GA-ASI as part of the SkyGuardian TC Project. Information on systems, structures, and capabilities of the entire aircraft are described in the PSCP to allow for understanding of the product, as well as definition of certification requirements. This PSCP will be coordinated with the Los Angeles Aircraft Certification Office (LA ACO) Program Manager as part of the overall SkyGuardian TC effort. It will continue in effect throughout all phases of the SkyGuardian UAS certification program, as a living document, being revised to reflect changes agreed upon with the FAA.

3.2.4 Airworthiness Basis of Certification

The SkyGuardian UAS would be certified by the FAA primarily in accordance with applicable 14 CFR Part 23 airworthiness requirements. The UAS was originally designed for a Military TC, using NATO Standardization Agreement (STANAG) 4671 Edition 2, and UK Defense Standard (Def Stan) 00-970 and other agreed upon requirements.

The Type Certification Basis for the SkyGuardian program is summarized in the PSCP, which includes the applicable requirements from 14 CFR part 23, STANAG 4671 and Def Stan 00-970, and how they are related. STANAG 4671 was originally developed from a Part 23 standard, and is closely comparable to 14 CFR Part 23 Amendment 63 – the latest FAA version of the standard in that form. However, Amendment 64 significantly changed the structure and compliance approach for Part 23. In order to show how the SkyGuardian design and Military TC artifacts relate to the latest FAA standard, a traceability table for requirement decomposition between 14 CFR 23 Amendment 64, 14 CFR 23 Amendment 63, and NATO STANAG 4671 is included.

A tailored Certification Basis for the SkyGuardian UAS based on 14 CFR 23 Amendment 64 is presented in Appendix C of the PSCP. Also included in Appendix G of the PSCP are special conditions, deviations, and Equivalent Level of Safety statements. As noted in section 3.2, through the §21.17(b) process, the FAA will publish the basis of certification to the public registry during the type certification process.

3.2.5 Additional Certification Items

In addition to the previously discussed areas where progress towards type certification has been made, GA-ASI has been leading an ongoing ASTM F38 standardization effort with the goal of creating a design and construction standard for large, fixed wing UAS. This effort aims to create a tailored certification basis specific to large UAS with identified means and methods for showing compliance to the regulations. The standardization efforts bridge the gap between general airworthiness requirements for manned aviation and requirements that are applicable to the unique considerations of constructing and operating a large unmanned platform. This standardization effort will be leveraged to assist in creating a certification basis for the SkyGuardian and will serve as a baseline reference moving forward for FAA Order 8110.4C and UAS certification programs following §21.17(b).

4. OPERATING APPROVALS

4.1 FEDERAL COMMUNICATIONS COMMISSION (FCC)

General Atomics began the process of seeking approval for electromagnetic spectrum use of the various emitters needed for the SIO demonstration flight in September 2019. The process for obtaining such approvals is managed by the FCC's Office of Engineering and Technology (OET) and the approval comes in the form of a grant (or license). Per Table 2, experimental license requests were submitted for CNPC datalink radios, TCAS and ADS-B transponders, and the DAA ATAR at the OET's Experimental Licensing System portal in the fall of 2019. Following an additional review of GA-ASI's current spectrum use licenses, an additional request for the use of the Lynx radar was submitted in January 2020.

Table 2: FCC Approvals

Payload	Call Sign	FCC Submission Date	Status/ Date Granted	Expiration Date
CNPC	WK2XUS	9/12/2019	3/25/2020	4/1/2022
ADS-B	WK2XWH	10/2/2019	4/7/2020	9/1/2020
TCAS	WK2XWG	10/2/2019	4/18/2020	9/30/2020
ATAR	WK2XOK	10/8/2019	1/27/2020	2/1/2021
LNXD22000-003	WK2XUX	1/30/2020	5/14/2020	5/1/2022
Lynx, CNPC, TCAS, ADS-B	WQ9XFT	2/18/2020	3/6/2020	9/1/2020
Lynx, TCAS, ADS-B	WQ9XFT	3/13/2020	3/24/2020	9/22/2020

The first FCC grant was issued in late January for the ATAR. Shortly thereafter, the OET directed GA-ASI to combine requests for all remaining emitters (CNPC, TCAS, ADS-B, and Lynx) in the form of a Special Temporary Authorization (STA) request, due to an OET backlog of experimental license requests. STAs, which are for a limited duration (typically up to six months) and intended for more-limited uses, involve less administrative processing by the OET and therefore are approved more quickly. The resulting STA, which was granted on March 6, authorized use of CNPC, Lynx, TCAS, and ADS-B. A revised STA was issued approximately two weeks later to increase the authorized area of operation of the latter three emitters and was the final approval from the FCC needed for a successful demonstration flight. In order to prevent interference with several licensed commercial uses of the spectrum, GA-ASI was limited to using only a portion of possible Lynx radar bandwidth, limiting its use to lower resolution modes, as discussed in Section 5.

Of the five experimental license requests originally submitted for individual emitters, only those for ATAR and CNPC were granted in time for use during the demonstration flight on April 3. The three remaining licenses were approved later, highlighting the lead- time required to obtain experimental license grants from the FCC. GA-ASI subject matter experts coordinated with FCC representatives frequently throughout this approval process and learned that the extended timeline was due to OET understaffing and a six-month backlog of similar requests across the United States.

As a result, for planning purposes, GA-ASI recommends submitting long-term (one year or beyond) experimental license requests seven to eight months in advance of the date that emitter use is required. It was fortunate for the SIO program that the quicker STA grant process delivered spectrum approvals just in time for the first test flight of SkyGuardian in the SIO configuration on March 27. GA-ASI has since shifted to regularly applying for STAs, instead of experimental licenses, for all internal testing of limited scope and duration, in order to ensure timely issue of the grant.

4.2 FEDERAL AVIATION ADMINISTRATION (FAA)

4.2.1 Initial Application for no-chase COA

The process of requesting a no-chase COA from the FAA to fly the route in the baseline mission CONOPS document began in September 2019, following the application for a waiver to 14 CFR §91.113(b) submitted in late August 2019. In November 2019, the FAA's §91.113 Waiver Working Group indicated that a new Safety Risk Management Panel (SRMP) would not be required, due to the similarities with the NASA Ikhana No-chase flight of 2018. The previous COA used for NASA's groundbreaking Ikhana DAA/no- chase flight was a public use COA where NASA certified the airworthiness of the UAS and the FAA granted the COA based on NASA's airworthiness certificate, the results from a FAA SRMP, and FAA approval of the flight route. The goal of the SIO demonstration was to be the first FAA approved civil COA for operation of a large UAS using DAA. Per the request from the FAA Flight Standards District Office (FSDO) located in Scottsdale, AZ, an updated mission CONOPS document was provided in January 2020. The approval from all required lines of business within the FAA was not obtained in time for the planned demo flight.

Significant factors contributing to the delay of approval included the novelty of this UAS-specific internal process for the FAA, the number of different FAA lines of business involved, and the perceived degree of risk associated with the proposed route of flight. The FAA has since indicated that this experience prompted them to evaluate their internal coordination process, and to improve assistance to applicants in obtaining appropriate approvals for novel UAS operations.

The following technical and policy issues became significant hurdles during the original approvals process:

- Use of a non-certified DAA system as operational mitigation for the see-and- avoid requirements in Class E airspace.
- Operational use of the DAA ATAR with an Experimental FCC license.

Because the aircraft certification stakeholders could not agree to rely on the experimental DAA system for see-and-avoid, they determined that flight following by ATC would be needed as a safety backup throughout the route of flight. However, with limited primary radar coverage in Class E airspace throughout the region, and staffing limitations, the FAA's Air Traffic Organization (ATO) could not commit to provide sufficient air traffic de-confliction services for any viable route within the mission CONOPS. Furthermore, the ATO determined late in the process that an additional application for exemption from 14 CFR §91.319(c) would be needed to fly an aircraft with an Experimental Certificate over densely populated areas and/or in congested airways. GA-ASI was notified on April 1, 2020 that the AJV-115 office could not issue a new COA for the SIO demo flight.

4.2.2 No-chase COA Approval Revision

The delay to conclude a no-chase COA approval prior to GA-ASI's SIO demo flight was disappointing to the project, and the FAA agreed to revise the approvals process for the original §91.113(b) waiver and COA for N190TC to make it possible for GA to repeat elements of the SIO demo flight as originally planned, at a later date. The FAA appointed a Director from the UAS Integration Office and a Senior Adviser for Air Traffic Policy to coordinate the FAA response. A kickoff meeting with FAA and GA- ASI stakeholders was held on June 30, 2020. There followed several Technical Interchange Meetings (TIMs) between the FAA and GA-ASI subject matter experts, along with NASA representatives. The FAA's target for completion of the process was less than 75 days from the first TIM in July 2020, and an amended SAC-EC and revised COA were issued in late September. The timeline of events was as follows:

- June 30, Kickoff Meeting
- July 22, TIM 1:
  - FAA presented revised process and timeline
  - Specific technical questions for GA-ASI on DAA and C2 link
- August 3, TIM 2: GA-ASI presentation of data for Safety Evaluation
- August 11, FAA presented responses to TIM 2 information POI
- August 20, TIM 3:
  - FAA's proposed operational limitations for use of DAA/No-chase
  - COA route negotiation kickoff
- August 26, COA route discussion with FAA Western Service Center
- September 17, Inspection of N190TC by Van Nuys FSDO

- September 22, Amended SAC-EC issued for N190TC with DAA ops limitations
- September 25, No-chase COA issued

The kickoff meeting was an open discussion to reset expectations on both sides. The FAA explained that there had been internal reviews and correspondence after their SIO experience to determine how to improve the §91.113(b) waiver process. GA-ASI explained its aim to revisit as much of the original SIO flight plan as possible, and when N190TC would be available to fly the route. The FAA explained some of the difficulties with the original COA request, and agreed to work closely and iteratively with GA-ASI to make adjustments to the flight plan as needed for success. GA-ASI confirmed that it would not seek to fly over densely populated areas or in congested airways to avoid the need for an exemption to §91.319(c), which would have substantially extended the approval timeline. The FAA reiterated concerns about FCC Experimental versus Operational licenses and the adequacy of the DAA system to provide protection from non-cooperative traffic, but agreed to complete the FAA process independently of the FCC licenses needed to legally operate within the COA. Through the process, however, the FAA determined that Experimental FCC licenses would be sufficient for experimental operation of an experimental aircraft. Also, N190TC's DAA system could be used as the primary means of ensuring separation from non-cooperative traffic, where the likelihood of an encounter with such is low. These determinations removed the two fundamental hurdles encountered during the first approval attempt.

4.2.3 Revised Process and FAA Internal Coordination

At TIM 1, the FAA laid out that the §91.113(b) waiver process would now be tied to the FAA Order 8130.34D process for obtaining airworthiness certification of the UAS, in addition to the COA approval process. This change allowed for clear separation between the evaluation of system safety and the airspace coordination aspects. The airworthiness process would determine general operating limitations for the system, which would then be documented in the SAC-EC. The Air Traffic Organization (ATO) could then evaluate the requested COA against the operating limitations and other route and traffic considerations. FAA lines of business responsible for each step were clearly identified, as shown in Figure 7.

To try to meet a short window of opportunity in September 2020 to perform the flight, the FAA set a tight timeline for completion of the approvals process. From TIM 1, the allotted times for each step were as follows:

Immediate: GA-ASI to resubmit updated application documentation for Airworthiness Certificate and Waiver to §91.113(b)

- <2 weeks: GA-ASI to prepare technical data for Safety Evaluation
- +15 days: FAA to draft DAA operating limitations for SAC-EC
- +15 days: FAA to determine approved route for COA
- +30 days: FAA to brief/train Air Traffic Controllers, complete COA/91.113 Waiver/SAC-EC processing

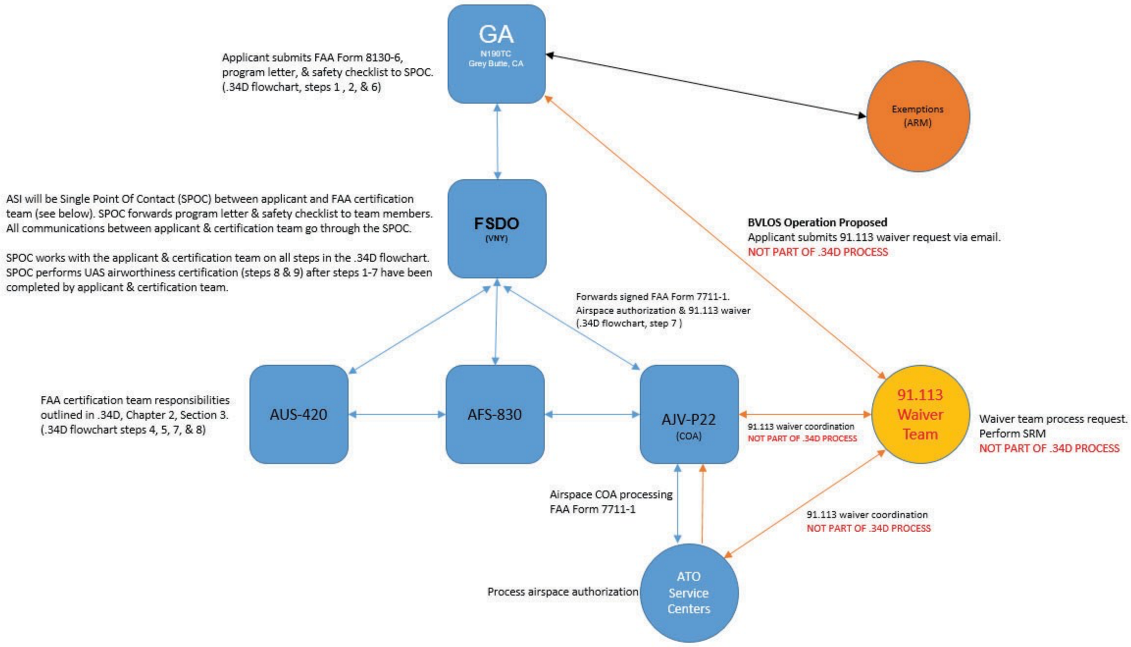

Figure 7: FAA Approval Process and Organizations for GA-ASI SIO §91.113 Waiver

4.2.4 Safety Evaluation

The FAA already had a head start on their safety evaluation, having previously received and reviewed the following documents during the initial SIO COA/91.113 Waiver application:

- System Description Document for N190TC SIO configuration
- SIO Demo CONOPS
- Risk-Based Safety Assessment for SIO Demo
- Program Letter
- N190TC Safety Checklist

The Aircraft Certification Service (AIR) requested technical information to address the following specific issues they highlighted at TIM 1:

- DAA/ATAR performance on non-cooperative targets
- Failure chain for non-cooperative targets
- ATAR performance under interference
- C2 link-related DAA system interruptions observed during the April 3 SIO flight
- SATCOM C2 link safety evaluation, relative to Major category hazards

GA-ASI's Class 2 DAA system incorporates TCAS II, which has a proven capability to detect transponder equipped (cooperative) aircraft and even to initiate automatic maneuvers to avoid collisions. The FAA's focus, therefore, was on the novel elements of the DAA system, primarily the ATAR, which is needed to detect non-cooperative aircraft. The C2 link with the Control Station is also important in non-cooperative encounters, because the system requires the remote pilot to respond to displayed conflicts and maneuver the aircraft to remain well clear and avoid collisions. The FAA presumed that the probability of encountering non-cooperative traffic was low in airspace where cooperative surveillance is required (i.e., ADS-B Rule airspace).

The Van Nuys FSDO also requested information on the following operations and maintenance questions related to the DAA system and C2 link:

- What is the lost link functionality in all phases of flight?
- What safety protocols are in place for loss of C2 link and/or DAA function?
- What are the automatic/pilot controlled responses to TCAS and non-cooperative traffic surveillance?
- How are GA-ASI crews trained to use the DAA system?
- What are the maintenance, inspection and testing program and procedures for the DAA system?

GA-ASI prepared a comprehensive brief to address all of these issues and questions at TIM 2, including the following information:

- DAA system architecture and functionality overview
- DAA/ATAR MOPS compliance/gap analysis and mitigations
- ATAR testing history and measured performance against non-cooperative targets
- ATAR techniques and testing for interference detection and rejection
- SATCOM C2 link safety, reliability and availability analyses
- DAA system integration ground and flight testing on N190TC
- DAA system functional check procedures and health monitoring
- DAA operating procedures and training material references
- General contingency procedures for loss of C2 link, loss of DAA
- Route-specific contingency plans for loss of C2 link, loss of DAA

After TIM 2, AIR determined that they would provide operating limitations for the SAC- EC for use of the DAA system, supporting the grant of a §91.113 waiver. They stipulated that the Van Nuys FSDO would need to review certain additional documentary evidence prior to issuing the revised SAC-EC, including DAA operating, maintenance and inspection procedures and DAA training material. They also wanted to see evidence of configuration control of the hardware and software of the DAA system, and datalink priority settings to avoid a repeat of the DAA display interruptions experienced during the April 3 flight. To address the concern of the FAA's Spectrum Office about interference in the frequency band used by the ATAR, the setting for channel deletion time after detecting interference had to be increased.

4.2.5 Operating Limitations

At the reboot kickoff meeting, AIR explained that at best they could authorize use of the DAA system only within the verified operating scope of the DAA/ATAR Technical Standard Orders, TSO-C211 and TSO-C212. These TSOs permit use of a certified system only for climb and descent through non-ADS-B Rule airspace (e.g., below 10,000 ft. MSL in Class E airspace), and for transit within ADS-B Rule Class E airspace (10,000 ft. MSL to 18,000 ft. MSL) and to Class A airspace. Reliance on a DAA system is not yet verified for “Extended Operations,” which includes the area survey loiter and raster flight patterns planned for the SIO demo. These surveying patterns would therefore have to be flown in Class A airspace, if without a chase plane.

Given those constraints, the operating limitations granted for use of N190TC’s experimental DAA system were as follows:

1. DAA operations without visual observer or chase plane are to be conducted for Research and Development purposes only.
2. The Pilot-In-Command (PIC) must hold the appropriate certificates and ratings for the operation and have successfully completed DAA training.
3. Beyond Visual Line of Sight (BVLOS) operations utilizing the onboard DAA system requires a §91.113 waiver on FAA Form 7711-1, COA.
4. All flight operations and routing utilizing the onboard DAA system must remain within the lateral and vertical boundaries of the designated flight areas as provided in the FAA Form 7711-1. The following provisions apply when operating under a COA:
    a. The DAA system must be used at all times during flight.
    b. The §91.113 waiver is valid for altitudes above 3,000 ft. above ground level (AGL).
        i. A visual observer must be used during departure and arrival phases of flight at or below 3,000 ft. AGL.
    c. The experimental DAA system is only authorized to support operations without a chase plane or visual observer in “cooperative surveillance required” (ADS-B Out/transponder) airspace, at and above 10,000 ft. Mean Sea Level (MSL) and transitions from 3,000 ft. AGL to 10,000 ft. MSL after takeoff, and from 10,000 ft. MSL to 3,000 ft. AGL for landing.
        i. Climb as expeditiously as practicable to 10,000 ft. after takeoff
        ii. Descend as expeditiously as practicable from 10,000 ft. to landing
        iii. Sustained level flight below 10,000 ft. MSL is not authorized.
    d. Flight in Class E airspace at and above 10,000 ft. MSL shall be point-to- point only, in accordance with the flight plan route.
        i. Loitering in Class E airspace is not authorized.
    e. Flight in Class A airspace at FL180 and above shall be point-to-point in accordance with the flight plan route.
        i. Loitering in Class A airspace is authorized as cleared by ATC.
5. The DAA system must be installed and configured in accordance with an FAA-accepted revision of the System Description document. GA-ASI shall provide the FAA a list of part numbers, serial numbers, and loaded software of the DAA system configuration prior to operation.
6. GA-ASI must notify the Van Nuys FSDO of any hardware and/or software changes to the DAA system and provide updated documents. GA-ASI must receive written

concurrence from the FSDO before resuming operations with their DAA system.

7. The DAA system must comply with the following:
    a. Must employ a Radio Frequency interference (RFI) detection system in the ATAR component of the DAA system, using a channel deletion time of 1 minute or greater to detect RFI in the ATAR and alert the remote pilot to the loss of ATAR DAA capability.
    b. In the event of any loss of DAA capability during flight (including RFI to ATAR) that cannot be promptly restored, the PIC must immediately inform ATC of the failure and request a clearance to climb to Class A airspace, or terminate the flight.
    c. Multiple DAA failures will constitute a hard equipment failure and require termination of the mission.
    d. Minimum operating altitude for ATAR is 3,000 ft. AGL.
    e. A satisfactory preflight operational check of the DAA system must be conducted prior to flight operations.
    f. Must have operating ADS-B Out per 14 CFR § 91.225/91.227.
8. Loss of DAA system and/or lost link procedures will be executed in accordance with FAA Form 7711-1 for outages above 5 seconds expiration time unless otherwise directed or authorized by ATC.
9. GA-ASI must notify the FAA of the loss of DAA system and/or lost link that occurred during flight operations and provide a follow up report prior to the next mission/operation.

These operational limitations were accompanied by the following explanation:

> "*The FAA has determined that the experimental ATAR system on this aircraft has sufficient demonstrated reliability to detect non-cooperative intruders (not emitting ADS-B or transponder signals) in airspace where the likelihood of encounters with non-cooperative intruders is low, but not to detect non-cooperative intruders in airspace where non-cooperative threat encounters may be more frequent.*"

These limitations have been designed to minimize the UAV's exposure to non- cooperative aircraft. In this regard, they are not much more restrictive than the TSOs currently allow for a certified system. The limitations also address in some detail the need for configuration control of this experimental system, and mandatory reporting of system failures, which would not be required of a certified system.

Under the extant version of the DAA/ATAR TSOs, a certified system would not be restricted to flying for research and development purposes only, but it would allow a little more operating flexibility in terms of flight paths and airspace access. To conduct commercial aerial surveying work in Class E airspace with a DAA-equipped UAS, which is the end goal of GA-ASI's SIO demo flight, the system would need to be certified, but also the scope of the TSO would need to be expanded by verifying the suitability of MOPS-compliant DAA systems for "Extended Operations." This is work to be done both by the standards development organization (RTCA) and by the FAA.

Nevertheless, with these operating limitations for the experimental DAA system, many of the originally-planned activities and routes for the SIO demo flight could be accomplished with a No-chase COA, if the area surveys are conducted in Class A airspace.

4.2.6 COA Negotiation

The FAA's revised process for §91.113 waiver approval uses the operational limitations determined by AIR as the starting point for the ATO's review of the proposed COA. Therefore, GA-ASI determined a new route of flight to propose for the COA, adapted for the operational limitations and concerns that the ATO had expressed about the original SIO demo route, while aiming to visit as many of the original survey locations as possible. The proposed route was modified as follows, for the reasons indicated:

- Routed around/over military restricted airspace, because the FAA does not have authority to grant access (though GA-ASI could have pre-coordinated with military authorities for the date of flight).
- All loitering-type flight patterns moved up to FL180 or above, to remain in Class A airspace.
- Routed around densely populated areas and congested airways, because of insufficient time to request a waiver to §91.319(c).

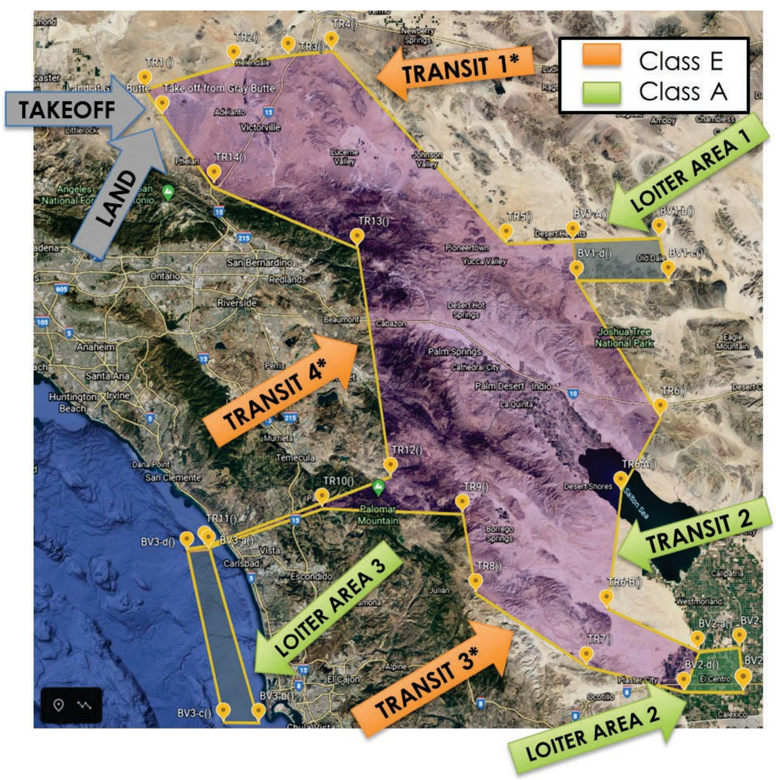

Figure 8: Revised Flight Route Proposed by GA-ASI for No-chase COA[3]

[3] Asterisks indicate legs where the DAA system was requested as the primary means of compliance to see and avoid requirements.

The proposed route (shown in Figure 8) was presented to the FAA at TIM 3, on August 20, along with detailed loss of C2 link / DAA contingency procedures for every leg of the route.

On August 26, the Western Service Center (WSC) representatives of the ATO presented to GA-ASI a "compromise" route from Gray Butte Airfield that would allow some aerial surveying while simplifying their airspace coordination challenges. Their proposed route, after taking off from Gray Butte and turning eastwards, continued East rather than turning South towards San Diego, with surveying areas near the Needles area on the California/Arizona border, and over the Grand Canyon, as shown in Figure 9. This route bore little resemblance to the one requested. Furthermore, this initial proposal incorporated the existing departure COA for Gray Butte, requiring a chase plane during the initial climb to 10,000 feet, then entering restricted airspace to climb above FL 180. After more negotiations, the WSC issued a COA on 9 September that removed the requirement of entering the restricted area except in the event of Loss of C2 Link, but still required a chase plane until 10,000 feet MSL. This still did not make use of the new operational limitations allowing use of the DAA system instead of a chase plane.

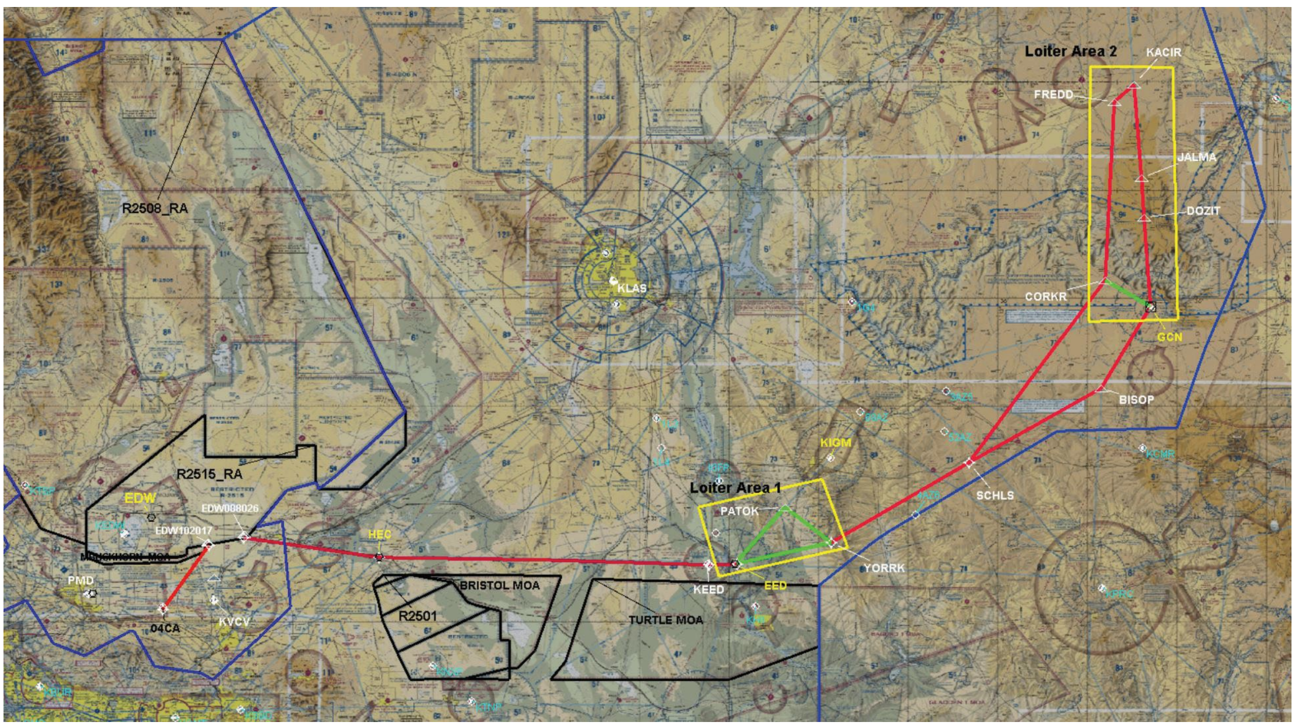

Figure 9: COA Route Proposed by Western Service Area

The reasons mentioned by the WSC for departing from our proposed route included the following:

- Arrivals and departures from the R-2508 restricted airspace complex
- ANJLL and HLYWD standard arrival procedure corridors for LAX, based on flight idle descent (ANJLL goes through proposed Joshua Tree loiter area)
- Military and airline traffic in the San Diego coastal area

The WSC staff were concerned that the Loss of DAA procedures involved climb to above FL180. They did not want to route our aircraft below any busy corridors, in case of a loss of DAA event.

Also, their proposed route kept the flight primarily within the Joshua Center area of responsibility, to minimize hand-overs and training needs for controllers.

The FAA staff agreed to changes to the departure and arrival procedure, allowing full use of the new DAA operational limitations. Also, the first loiter area was moved further West, to be within the original FCC grant area, in case GA-ASI could not obtain a change in time for the flight opportunity. These changes were included in the final COA route issued on September 25, plus maintaining the contingency routing into Edwards Range for the Loss of C2 Link contingency flight plan, as shown in Figure 10.

Figure 10: Final No-chase COA Route

5. LESSONS LEARNED

5.1 COMMERCIAL MISSION VIABILITY

The basic commercial mission concept was to use the aircraft's long endurance and multiple sensors (multi-mode radar and camera turret) to survey large areas of agricultural and public land, hundreds of miles of linear infrastructure and additional infrastructure points of interest along the route. The resulting mapping and imagery products would provide to multiple potential customers more-rapid coverage than is possible with ground vehicles, small UAS or manned aircraft, which have limited flight duration, and more timely data than is available from satellites. For example, this service would enable utilities companies to more quickly assess the condition and safety of power lines throughout their network after a high wind event, and more quickly restore power to their affected customers. Furthermore, the survey could be conducted safely and effectively at night, eliminating the wait for daylight to begin surveying.

Through the planning and execution of the NASA SIO demo flight, we proved our basic commercial mission concept for a MALE UAS, by successfully completing 39 different survey objectives within a 9-hour flight, spanning daylight and nighttime conditions.

These surveys included many miles of power lines, railway lines and canals, as well as power stations, solar power installations, pumping stations and telecommunications towers. Two agricultural areas and a nature preserve were also surveyed, mapping hundreds of square miles of land with radar and/or photographic/infrared imagery.

Although this first attempt to use the system for surveying land and infrastructure did not produce perfect imagery products, we now know what settings and techniques to use to get the desired results. We are also confident that providing substantial quantities of valuable survey data to a variety of customers from each flight could sustain viable commercial operations.

5.2 CNPC UAS INTEGRATION

The CNPC datalink radios worked well for the C2 and telemetry functions tested, and exceeded expectations for range performance. With a combination of omnidirectional and directional antennas, appropriately placed on the aircraft, operating ranges up to 85nm are possible. This finding has implications for the planning of ground radio station networks needed to support long-range UAS operations with CNPC links.

Integration of all CNPC functions on the link requires very efficient use of the available data capacity, and further studies are needed to determine how this can be done in practice. This data limitation makes the CNPC standard unsuitable for performing manually-controlled landings and taxi operations that rely on video streamed from the aircraft to the remote pilot. Therefore, a higher degree of vehicle automation is needed to be able to fully implement CNPC.

5.3 GROUND AND FLIGHT TEST

Ground testing of the SIO program configuration was completed on March 25, 2020. GA-ASI's test team in Gray Butte began flight test on March 27, 2020, and over the course of the next five workdays, completed five successful flight tests. Operational checks of safety of flight critical systems, software, autopilot, vertical speed indicator hold mode, DAA, ATAR, CNPC, and Lynx radar were thoroughly conducted to ensure a fully mission-capable UAS for the day of the flight demonstration.

The GA-ASI team leveraged the modularity of its ground control stations at Gray Butte to enable the ongoing support of various disciplines of engineers and technicians. This was accomplished by creating "shadow" ground control stations which enabled the minimal requisite technical know-how on site to ensure the proper level of needed support was maintained.

5.4 FAA/FCC ENGAGEMENT FOR UAS OPERATING APPROVALS

The FAA's §91.113 waiver process was largely untested when GA-ASI submitted the initial application. We should have expected some teething troubles and allowed even more time than six months before the need date for processing and approval. Any future, similar effort to conduct novel UAS operations needs to involve a liaison between the applicant and all applicable lines of business of the FAA, early and often in the flight planning process.

The FAA's internal review of the failure of the initial §91.113 waiver application process to reach a timely decision led to important changes in the process. By clearly separating the responsibilities and outputs of the AIR and ATO organizations within the process, each was able to reach a satisfactory decision. Also, with the re-boot, the FAA introduced close and planned coordination with the applicant and provided clear requests for information that was needed to reach a decision, rather than relying primarily on the documentation provided with the initial application. As a result of these changes, the goal of issuing an amended SAC-EC and COA within 75 days of the first TIM was accomplished.

Similarly, the process of obtaining the proper permissions from the FCC to radiate the payloads required to meet CONOPS objectives must begin early. GA-ASI filed requests to obtain such permissions in some cases six months in advance, which was not enough time for the FCC to complete the cross-organizational coordination that occurs amongst multiple government entities (NTIA and the FAA spectrum office, among others) that is required prior to a FCC license being granted. Coordination with the FAA spectrum office should begin immediately after completing the request for payload radiation via the FCC; otherwise, the program runs the risk of not being granted the proper permissions to radiate.

5.5 RECOMMENDATIONS

There are a number of recommendations for the next steps. The following recommendations facilitate further development of the commercial mission concept:

1. Develop additional COAs based on the new DAA operational limitations to allow "file and fly" access to more areas and destinations.
2. Re-run the commercial market survey flight in additional areas from the original mission plan, with the sensor data configuration fixes and lessons identified from the SIO demo.
3. Re-engage with our commercial mission partners when examples of survey data products for their assets are available, to understand their commercial value and conclude the business case assessment.
4. Investigate cooperative research opportunities with universities on the use of Synthetic Aperture Radar (SAR) for crop health monitoring.

We recommend conducting the following testing of UAS operations using CNPC links in expanded operating conditions:

1. Automatic takeoff and landing.
2. Switchovers between multiple, geographically spaced CNPC ground radios.

Additionally, data and evidence from the CNPC link integration and testing may provide useful feedback for the developers of the CNPC MOPS in RTCA Special Committee 228, specifically regarding the following topics:

1. Review the bandwidth allocations for each specified Data Class, to ensure all needed CNPC data types can be included in the CNPC link data allocations. This requires further internal (GA-ASI) study to determine how much existing data structures and protocols used for legacy datalinks can be compressed.
2. Review the need for the target 30 dB signal margin value, including which losses are accounted for within this value, to avoid underestimating the CNPC link's useable range.

5.6 CONCLUSIONS

GA-ASI is pleased to have participated in this program with NASA as we continue to move towards SkyGuardian type certification and further the effort of integrating commercial UAS into the NAS. We feel that the numerous lessons learned and discussion points herein will provide a solid foundation for both NASA and the UAS industry as a whole, to further the cause of UAS in the NAS. Government and industry partnerships proved invaluable for continuing advancement toward these goals. GA-ASI looks forward to continued partnerships with NASA, industry, and other government entities to further improve the public perception of the benefits of UAS and facilitate reaching the full potential of their use in many commercial, civil, and public applications.

6. LIST OF ACRONYMS

ADS-B	Automatic Dependent Surveillance-Broadcast AGL Above Ground Level
AIR	Aircraft Certification Service (FAA)
ATAR	Air-to-air Radar
ATC	Air Traffic Control
ATO	Air Traffic Organization
ASI	Aviation Safety Inspector
AV	Aircraft Vehicle
BVLOS	Beyond Visual Line of Sight
C2	Command and Control
CNPC	Control and Non-Payload Communication
COA	Certificate of Authorization/Waiver
CONOPS	Concept of Operations
CPDS	Conflict Prediction and Display System
DAA	Detect and Avoid
EM	Electromagnetic
FAA	Federal Aviation Administration
FCC	Federal Communications Commission
FSDO	Flight Standards District Office (FAA)
GA-ASI	General Atomics Aeronautical Systems, Inc.
GCS	Ground Control Station
HUD	Heads Up Display
IR	Infra-red
LAX	Los Angeles International Airport
LOS	Line of Sight
MALE	Medium Altitude Long Endurance
MOPS	Minimum Operational Performance Standards MSL Mean Sea Level
NAS	National Airspace System
NTIA	National Telecommunications and Information Administration
OET	Office of Engineering and Technology
ORA	Operational Risk Assessment
PIC	Pilot in Command
POI	Point of Interest

PSCP	Project Specific Certification Plan
RA	Resolution Advisory
RFI	Radio Frequency Interference
RLOS	Radio Line of Sight
SAC-EC	Special Airworthiness Certification – Experimental Category
SAR	Synthetic Aperture Radar
SIO	Systems Integration and Operationalization
SRMP	Safety Risk Management Panel
TC	Type Certificate
TCAS	Traffic Alerting and Collision Avoidance System
TDD	Time Division Duplex
TIM	Technical Interchange Meeting
TSO	Technical Standard Order
UAS	Unmanned Aircraft System
WSC	Western Service Center (FAA ATO)
YPG	Yuma Proving Ground

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14. ABSTRACT
The NASA SIO demonstration flight of April 3, 2020 represents a successful culmination of 18 months of coordinated effort between GA-ASI, NASA, the FAA, Collins Aerospace, and Honeywell Aerospace to operate a Medium Altitude, Long Endurance (MALE) Unmanned Aircraft System (UAS) safely in the National Airspace System (NAS). This final report describes the most significant and potentially impactful aspects of the planning, integration, test, and flight aspects of this effort.

15. SUBJECT TERMS
UAS, flight demonstration, DAA, NAS, GA-ASI

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