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AiRanger™ UAS NASA SIO Program Final Report

American Aerospace Technologies, Inc. (AATI)
Sterling, Virginia

May 2022

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A	Initial Release	4/26/2021
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Executive Summary

National Aeronautics and Space Administration (NASA) awarded a Cooperative Agreement to American Aerospace, and two other companies, under the Unmanned Aircraft Systems Integration and Operationalization (SIO) demonstration with the goal of accelerating routine unmanned aircraft systems (UAS) operations in the national airspace (NAS). Our goal was to pioneer the development, integration, and testing of our AiRanger™ UAS, with the intent to make progress towards type certification. The program culminated in flight demonstrations representing future commercial operations by each partner.

The team lead by American Aerospace Technologies Inc (AATI) demonstrated its UAS AiRanger™ successfully on February 25 as part of NASA's SIO program. The objective of the AiRanger demonstration was to tackle key challenges to enable routine commercial UAS operations in the National Air System (NAS) today, including development, integration, and certification of UAS and the technologies required for safe operation with other manned and unmanned aircraft traffic in the NAS in support of critical customer missions including beyond visual line-of-sight (BVLOS) flights over customer selected non-urban environments with multiple sensors in uncontrolled (Class G) and controlled (Class B) airspaces. AiRanger gained approval to fly 1000-5000ft above ground level as it tested its sensors in working toward commercial UAS operations in the NAS.

On display was the AATI-developed Airborne Detect and Avoid (DAA) and Command and Control (C2) system that enables AiRanger to fly safely in civil airspace alongside manned aircraft. The DAA system consists of a dual Echodyne Echoflight RADAR with tail and wing cameras mounted on the UAS. The system's DAA radar provides an essential safety feature for integrating unmanned aircraft into civil airspace. Compliant vehicle DAA was achieved via integration of the Sagetech MXS ADS-B In/Out Transponder. The AiRanger platform, equipped with state-of-the-art in cooperative and non-cooperative DAA sensing technologies, has the ability to provide a technological leap in safe operation of unmanned aircraft in Class E and G airspace in the NAS. Through collaboration with modeling and simulation experts at MIT Lincoln Laboratory and Johns Hopkins Applied Physics Laboratory, we are scientifically and methodically quantifying and mitigating collision risks.

As part of the demonstration, American Aerospace Technology Inc's AiRanger exhibited its ability to provide a wide variety of commercial and public services using onboard sensors. Commercial services planned include inspections of thousands of miles of linear rail, energy pipeline, powerline, and canal infrastructure, upstream oil & gas fields, wind farm inspections, agriculture monitoring and topological surveys, as well as wildfire and flood monitoring, and maritime surveillance.

For the demo, the AiRanger departed from AATIs Buttonwillow Airfield facility in Bakersfield, CA, and flew a pre-determined route over the pipeline. Data collected during the flight will be used to evaluate DAA and C2 technologies in support of future standards development and FAA certification guidelines. AATI's partners for certification include End State Solutions.

The AiRanger is a conventional takeoff and belly-landing design powered by a GS190 engine. The aircraft has a range of 75 nautical miles, top speed of 100 knots and can carry payloads of up to 75 pounds, including fuel and sensors. The AiRanger UAS is a mature system that is at Technology Readiness Level (TRL) 8. The actual system in this configuration has been proven through ground and flight testing in its final form under expected conditions at various locations in CONUS.

The AAISR AiRanger UAS is composed of a fixed-wing unmanned aircraft and associated ground systems to support unmanned flight operations. The AiRanger UAS has met Technology Readiness Level (TRL) 8 through successful developmental test and evaluation (DT&E) of its proposed configuration. This robust UAS carries up to 75 pounds of payload, depending on takeoff weight, including up to 54 pounds of fuel. In the NASA SIO configuration, with an ability to launch and recover at the mission profile required density altitude of 6,000 feet, the AiRanger is capable of an endurance of over 17 hours, depending on the payload configuration and fuel load at launch. The AiRanger accommodates the InstiMaps payload and has the capability to simultaneously carry additional payloads, including DAA technologies. It is powered by an 8.2-horsepower four-stroke engine offering smooth, quiet, and efficient power.

The AiRanger UAS includes an Air Vehicle Launcher (AVL) system, aircraft fitted with all communications equipment, ground control station (GCS), a GCS tracking antenna, mobile operations center (MOC), and all ground support equipment for payload data collection and real-time operations. The AiRanger has a modular design that uses an open architecture.

The AiRanger UAV in the NASA SIO Configuration is shown in Figure 1-1**.**

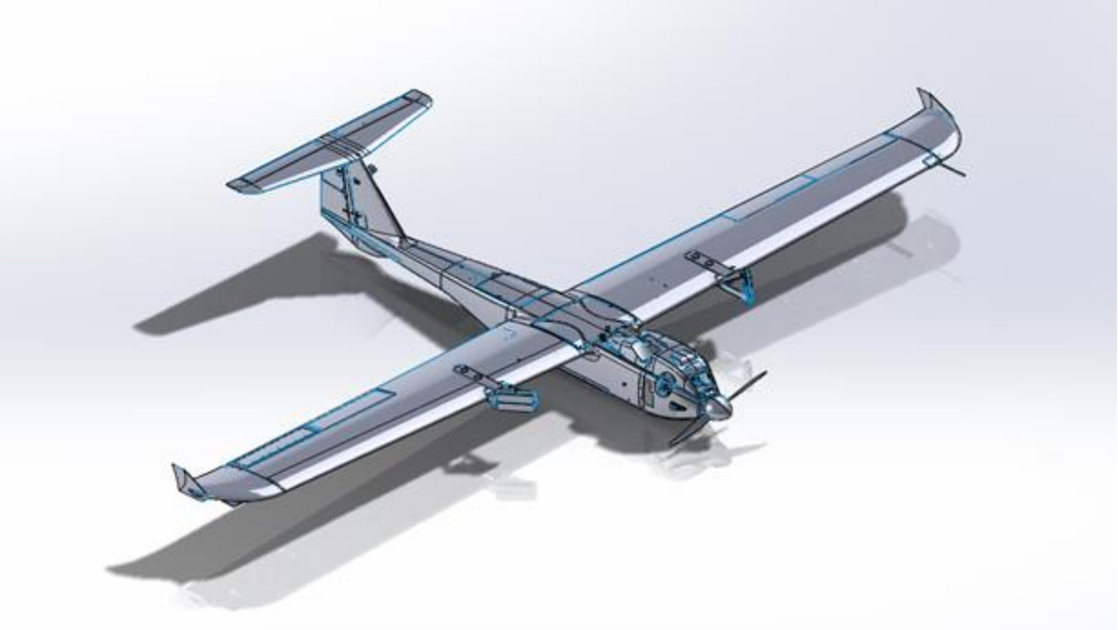


Figure 1-1. AiRanger NASA SIO Configuration

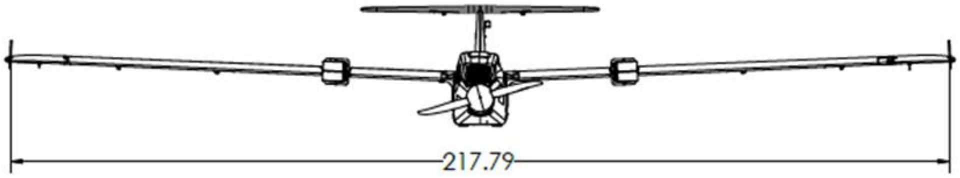


Figure 1-2. AiRanger NASA SIO Configuration Front View

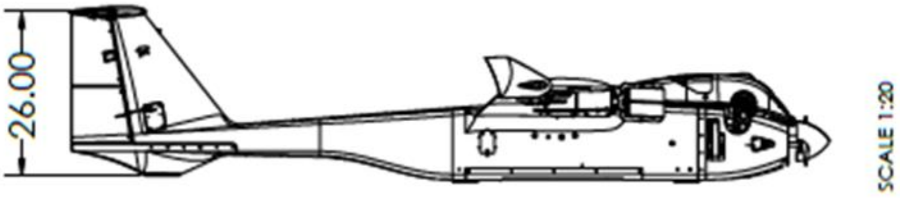


Figure 1-3. AiRanger NASA SIO Configuration Side View

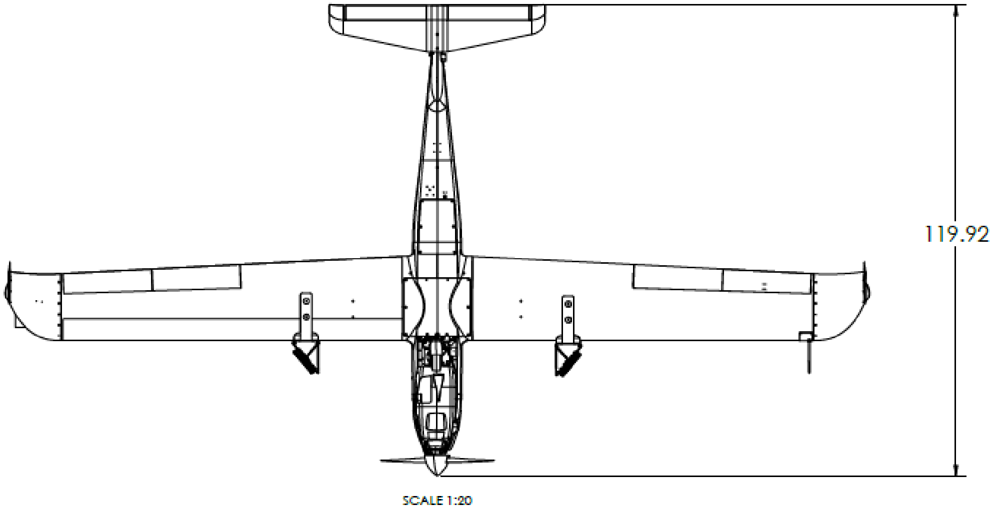


Figure 1-4. AiRanger NASA SIO Configuration Top View

1 System ConOps and Intended Mission of the UAS

The AiRanger UAS gathers airborne data to develop products that inform economic decisions for commercial and civil customers. The AiRanger is part of a commercial system that includes the air vehicle with multiple / interchangeable payloads, and a ground control station (GCS).

AATI 's mission objectives are focused on mapping, data collection and monitoring for commercial and civil business. This includes a broad category of large linear structures and area surveillance including infrastructure such as energy pipelines, water pipelines, railroads, roads, fence lines, power lines, and emergency/disaster area mapping and surveillance. For the purposes of an end-state CONOPS discussion, the focus is primarily on energy pipeline commercial business development.

Commercial flight operations are initially focused on energy pipeline inspection and survey. Other inspection and survey operations include power lines, roadways, waterways, water pipelines, border infrastructure and area surveillance. Missions will be launched from convenient locations on airport or off-airport remote sites in proximity to start of mission profiles.

A typical commercial flight profile includes launch from the takeoff location, transit to infrastructure, climb to mission altitude and conduct as many as 12 hours of mission flight over infrastructure. This may include transit from one infrastructure project to a second project during same flight and may include landing and take-off from other launch sites.

Commercial flight operations are generally flown at 2,000 to 3,000 ft AGL over or near the intended infrastructure and are flown at a cruise airspeed between 65 to 75 KIAS.

The commercial flight operation is to gather visual spectrum photographic, hyperspectral images and gas spectrograph data products, which are scanned by AI/ML algorithms to efficiently identify threats to inform customer decisions on regulatory, economic and safety requirements on infrastructure. These products include right-of-way infringement, weather and natural disaster impacts, infrastructure damage and leaks and other aerial survey products required by the customer.

A typical flight operation profile is depicted in Figure 1-5 which illustrates a typical survey and inspection profile for the end-state commercial operations. All landings would be at an established remote site or airport with GCS and minimum crew. The AiRanger can accomplish multiple revenue operations with single system configuration and operating flexibility.

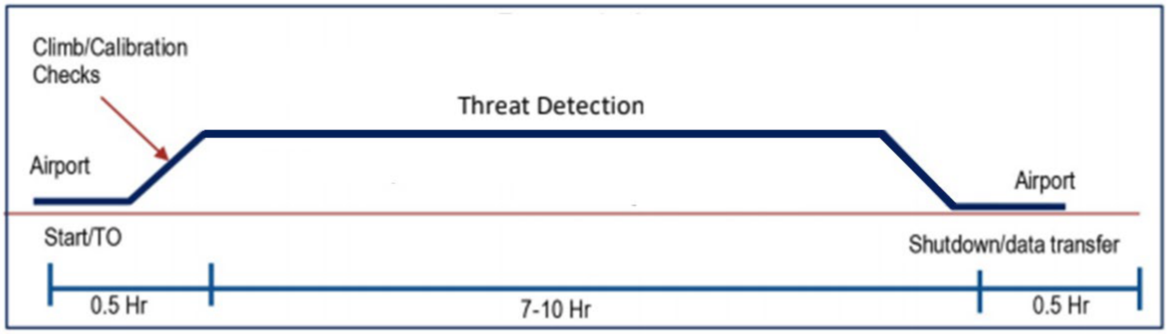


Figure 1-5. Notional AiRanger Survey/Inspection Flight Timeline

2 AiRanger UAS Platform Design and Architecture

2.1 AiRanger NASA SIO Configuration and Features

The AiRanger (Figure 2-1) is a fixed-wing commercial unmanned aircraft launched from the AVL. The propulsion configuration is a tractor type and the motor and propeller are intended to be certified as part of the AiRanger configuration. The AiRanger UAS wing is a conventional cantilevered semi-monocoque structure. The skins, spars and majority of the wing internal structure is made from carbon fiber composites; however, aluminum and titanium are also used at hardpoints and the wing-to-fuselage interface. The completed wing structure is an inseparable assembly. By complying with the operational approvals and limitations derived through the certification and airworthiness process, AATI expects that the FAA certified UAS system will be capable and permitted to operate throughout the United States with the appropriate route approval.

Figure 2-1. Pictures of AiRanger at SJV for NASA SIO

Characteristic	**Configuration**
Wing Span	18.4 ft (5.6 m)
Length	9.5 ft (2.9 m)
Maximum Equivalent Diameter	1.29 ft
Gross Weight (Maximum Takeoff Weight)	220 lbs. (99.8 kg)
Empty Weight	162 lbs. (66.2 kg)
Payload	AATI InstiMaps Sensor or TASE400 EO/IR Sensor
Maximum Payload/Fuel Weight	58 lbs. (33.6 kg) (including up to 54 lbs. (24.5 kg) of fuel)
Payload Bays	Fuselage and underwing hard points. Payload areas are reconfigurable
Aircraft Type	Fixed Wing
Launch/Recovery	Lightweight catapult / belly skid landing
Power Plant	GS190 Engine: Single cylinder, single piston, fuel-injected, four-stroke, 190 cc displacement, rated to 8-HP engine. Manufacturer: American Aerospace ISR (AAISR)
Propeller	Dual blade 30” X 19° pitch propeller. The propeller is directly driven from the engine.
Minimum / Maximum Operating Altitude	Ground Level/17,000’ MSL Standard Day (rated to 4,572 m)
Fuel	Avgas 100 Octane Low Lead

Table 2.1 Air Vehicle key components for the NASA SIO Configuration.

2.2 Ground Control Station

A ground control station (GCS) is located proximal to the MOC. AAISR uses a high-gain parabolic antenna, the Troll MT 300 Antenna (Figure 2-2). The configuration minimizes the length of cable for all RF cables and serial cables, as proximities of RF equipment are intended to be close. Two of the port servers in the architecture function as serial extenders to convert long serial data run to Ethernet traffic and back again. Two side saddles allow external radios to be readily integrated into the tracking antenna. The Collins CNPC-5000 radio was integrated in the C-band side saddle, while the MMT radio was integrated in the L/S-band side saddle. The tracker has both omnidirectional and tracking (high gain) modes. The antenna control software at the GCS allows the operator to select use of the omni-directional or directional antenna and to toggle between them during the mission. The ground tracking antenna follows the UAV based on GPS position relayed by telemetry from the aircraft.

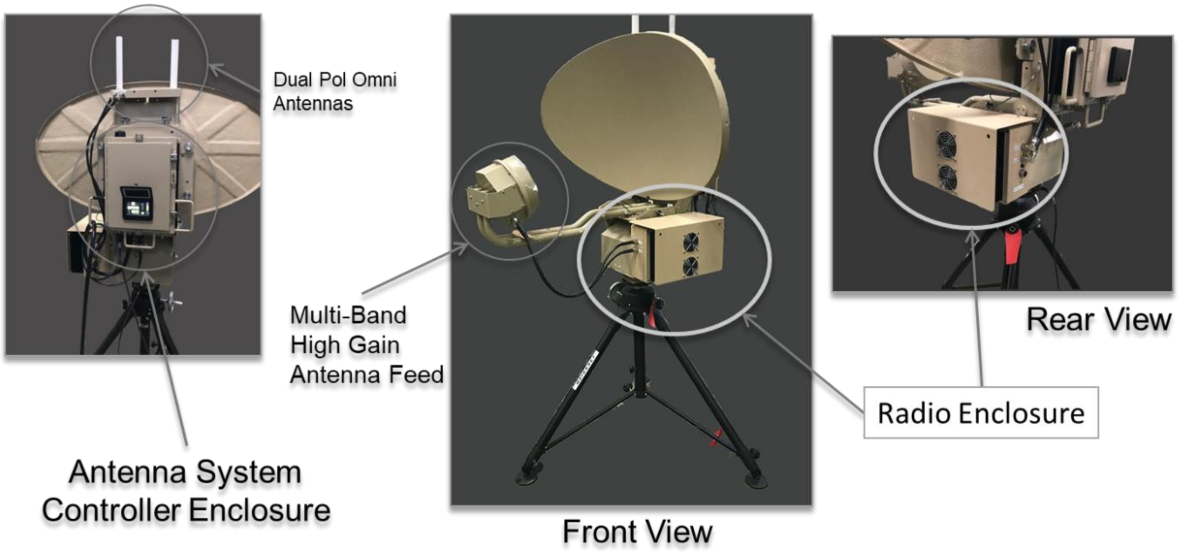


Figure 2-2. Troll MT300 Ground Tracking Antenna

2.3 C2: Command and Non-Payload Control (CNPC) Radio

The datalink segments on the AiRanger supports bidirectional UAV to GCS operations. The AiRanger UAS utilized the Collins CNPC-5000 and Cubic Defense Systems MMT radios for non-payload and payload communications, respectively. The data link architecture used L and S-Band links for payload data, and the C-Band link for C2 within the TSO compliant 5030-5090MHz range. The data link also carried the C2 data, to enable redundancy in the event of a failure. Waveforms and bandwidths with both data links selectable. All data can be encrypted using FIPS-197- compliant Advanced Encryption Standard (AES). The AES can be enabled or disabled from the GCS while the UAV is in flight.

The Collins Aerospace CNPC-5000 radio is TSO compliant for use in the World Radio Conference 2012 – 5035-5090 MHz frequency band for use by UAS C2. The uplink and downlink rates are 285 kbits/s. The CNPC-5000 is connected directly to the Piccolo autopilot only, preventing payload data from cross-talk between the radios that could otherwise overwhelm the system. The Cubic Multiband Miniature Transceiver (MMT) radio on the AiRanger is configured for L/S-band communications. The MMT provides reliable, secure communication links over hundreds of miles at data rates up to 44.73 Mbps. The MMT carries the payload and DAA data, while providing priority back-up for the C2 data link to the Piccolo autopilot. Antennas are in the following locations on the aircraft:

- C-band (fuselage)
- Transponder (fuselage)
- L-band (Left Wing)
- S-band (Right Wing)

2.4 Autopilot

The AiRanger UAS utilizes the Piccolo II flight management system, which includes the following key components:

- Onboard autopilot module (Piccolo II)
- C2 radio link (900 MHz)
- Compatible ground control station to relay instructions to the UAV in flight. The onboard Piccolo II receives electrical power from the PMU by way of the Interface Box.
- Back-up battery to support autopilot in case of alternator/engine failure

The Piccolo II processor accepts inputs for the pitot and static ports to establish airspeed of the UAV. The GPS receiver, rate gyro and clinometer determine flight attitude, pitch, rate of climb and other necessary data to determine flight path and conditions. The Piccolo II autopilot/PCC combination provides the operator with positive C2 of the AiRanger UAV and payload continuously, as well as relaying data on system health, airspeed, altitude, location, fuel level, and other information. A C2 link streams telemetry back to the GCS to provide situational awareness to the operator. The Piccolo II autopilot and GCS interface, PCC, and the payload interface software is located in the GCS. The Piccolo II has an uplink and downlink rate of 1.2 Mbps.

2.5 Launch/Landing System

AATI designed the AiRanger and the AVL to operate from small areas in difficult terrain. The AVL operates on compressed air that is generated onsite by an air compressor. The AVL has proven to be reliable and easy to assemble and operate during thousands of hours of flight operations. It is based on a proven rod-in-tube method. The AVL will work on almost any surface, whether improved or austere, even sloping terrain up to 5 degrees. Two flight crew members can assemble the AVL in 10 minutes, and the pack-up process is just as quick. Subsequent launches can be executed in 5-minute intervals, providing a dramatic surge capability. There is a small amount of equipment, as well as an operator, positioned within and out to a distance of 15 feet beside the tank. It is 28 feet long and when fully deployed and 24 feet wide when it has an aircraft prepared for launch.

During or after setup, the AVL is oriented for a direct launch into the prevailing wind, and the landing is set up into wind as well. The AiRanger has the capacity to take off and recover with 30-knot headwinds, 25 knot crosswinds, and gusty wind conditions of 15 knots or more. The AVL hardware is dependable for thousands of launches. Launch operations can be performed in adverse weather conditions, including extreme temperatures that might ground other AVs.

Figure 2-3. AiRanger on AVL

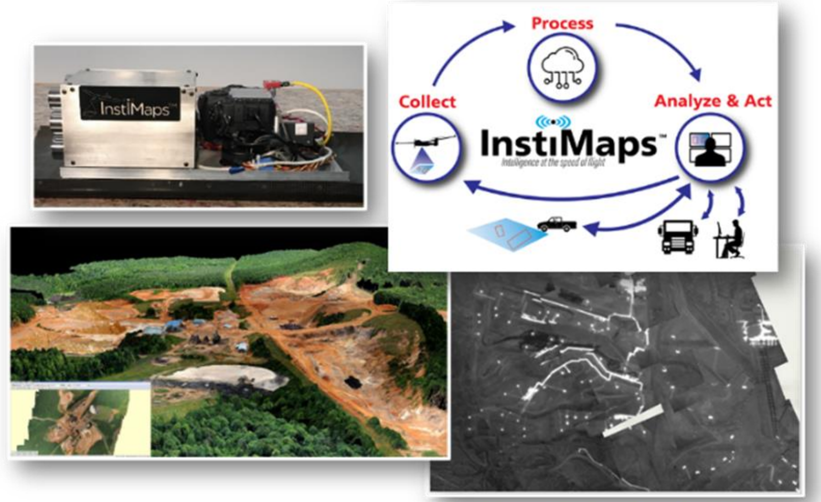
2.6 Payloads

One of the key advantages of the AiRanger UAS is its large payload carrying capacity, its flexibility with respect to mounting locations (and thus package volume) and significant onboard power available for payloads. The platform can carry a maximum payload of up to 75 pounds, including up to 54 pounds of fuel, and has up to 1,150W of power available for payloads. The AiRanger power distribution scheme integrates the radios and antennas by using standard and available electrical and data interfaces.

AAISR standardizes electrical, mechanical, and data platform/sensor interfaces on the AiRanger so that sensor exchange can be accomplished in 30 minutes or less. The AiRanger flies InstiMaps as its primary payload, and an EO and/or IR imagery sensor can also be used interchangeably for specific detection missions.

AATI's Airborne Systems Group™ (ASG) is the OEM provider of InstiMaps near real-time mapping systems for pipeline patrol and emergency response. The system boasts high resolution EO and LWIR sensors, IMU, frame grabbing, frame stitching, and geo-referencing using RTK-DGPS. ASG also develops airborne wireless solutions for post-disaster communications. SkyScape Industries performs industrial inspection missions using EO/IR, LiDAR, and OSCAR, our in-house polarized EO/LWIR liquid petrochemical detection system. The AATI InstiMaps payload is shown in Figure 2-4 with sample imagery. InstiMaps is the sensor solution for autonomous detection of pipeline threats used in the AiRanger commercial mission. The payload is 18 x 5.75 x 5.5 inches (Volume: 569.25 cubic inches) and weighs 8.25 pounds. The ATDS approach uses a detect, process, distributed and archive architecture:

- **Detect** – Acquire & directly geo-reference multispectral imagery
- **Process** – Near real-time machine learning algorithms are used to identify threats
- **Distribute** – Communications and Cloud Publishing
- **Archive** – Threat detection: machinery, encroachment, fire, security, leaks, etc. Provides permanent record of conditions.



AATI InstiMaps provides Automated Machinery & Fire Threat detection to commercial customers through high-resolution geo-referenced imagery using custom EO/LWIR cameras and AI based algorithms

Figure 2-4. InstiMaps payload

2.7 Cooperative DAA: ADS-B In/Out Transponder

For the NASA SIO Demo, AATI integrated the Sagetech MXS ADS-B In/Out transponder to perform DAA with cooperative aircraft. The transponder is not yet integrated directly with the Piccolo Autopilot due to a missing plug-in that will be integrated later this year. The transponder is installed on board the aircraft and provides both notification to other cooperative aircraft of the AiRanger position and provides location and heading information from cooperative aircraft via the COMMS link down to the GCS. The Sagetech MXS Transponder interacts with air traffic control (ATC) by transmitting and receiving standard secondary surveillance radar pulses per ICAO requirements. The transponder replies to requests from ATC with a squawk code and altitude data. The Sagetech MXS Mode S Transponder with ADS-B In/Out contains all the functionality of the Sagetech XP Mode C Transponder. In addition, it provides Mode S replies (includes data such as ICAO1 address and call sign) and is capable of being selectively interrogated. This transponder adds Automatic Dependent Surveillance-Broadcast (ADS-B) In and Out capability. When configured with a GPS data source, the transponder can broadcast aircraft position and other relevant data to the ATC system and surrounding aircraft. The Sagetech transponder is controlled through a straightforward communication system via a serial interface (RS-232 port). The Cloud Cap Piccolo II supports the proprietary Sagetech XP and MXS Transponder protocol allowing plug-and-play integration with the Sagetech transponder. The Sagetech transponder utilizes a small monopole antenna, which is mounted to the outside of the UAV.

Figure 2-5. Sagetech ADS-B In/Out Mode S Transponder

2.8 Non-cooperative DAA

2.8.1 Echodyne RADAR

For its proposed Type Certification configuration, the AiRanger combines two Echoflight RADARs (Figure 2-6) mounted to the outer hard points and oriented facing outward at 50º to provide a total coverage angle of 220 º azimuth and 80 º elevation (Figure 2-7).

EchoFlight's MESA technology brings compact lightweight ESA radar performance to improve UAS mission safety and success, in an ultra-low SWaP package (20.3 cm x 16.3 cm x 4 cm) and with true beam-steering accuracy. High fidelity data is provided via multiple options for data output and integration into navigation platforms, from low bitrate fully processed Tracks to data-rich R/V maps. The technology is proven, reliable, and has been in use by private companies, Federal agencies, and UAS research centers. Echoflight provides the largest available field of view, with 120° azimuth x 80° elevation with angular resolution of ±1° azimuth x ±3° elevation. The RADAR operates in the K-band. 24.45 - 24.65 GHz (multichannel).

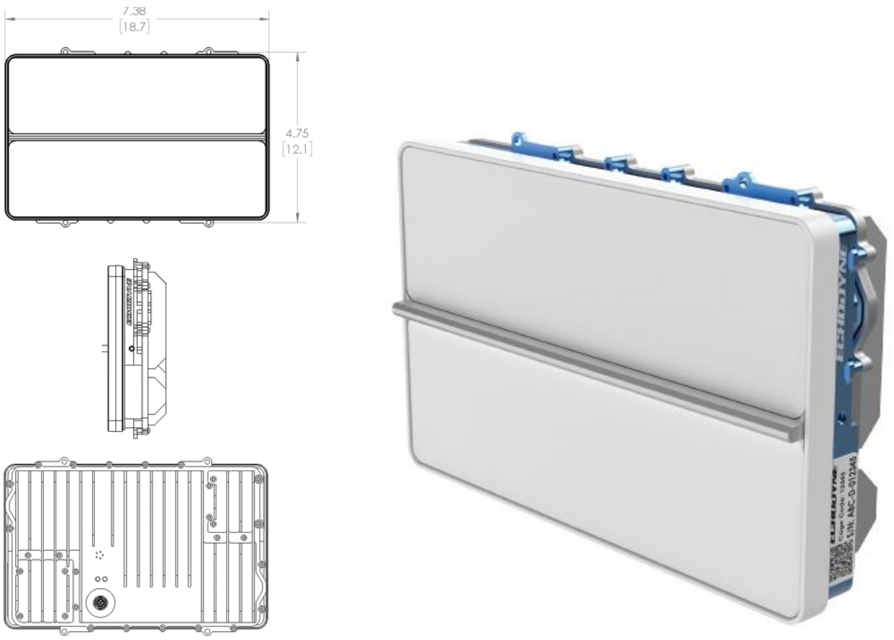


Figure 2-6. Echodyne Echoflight RADAR

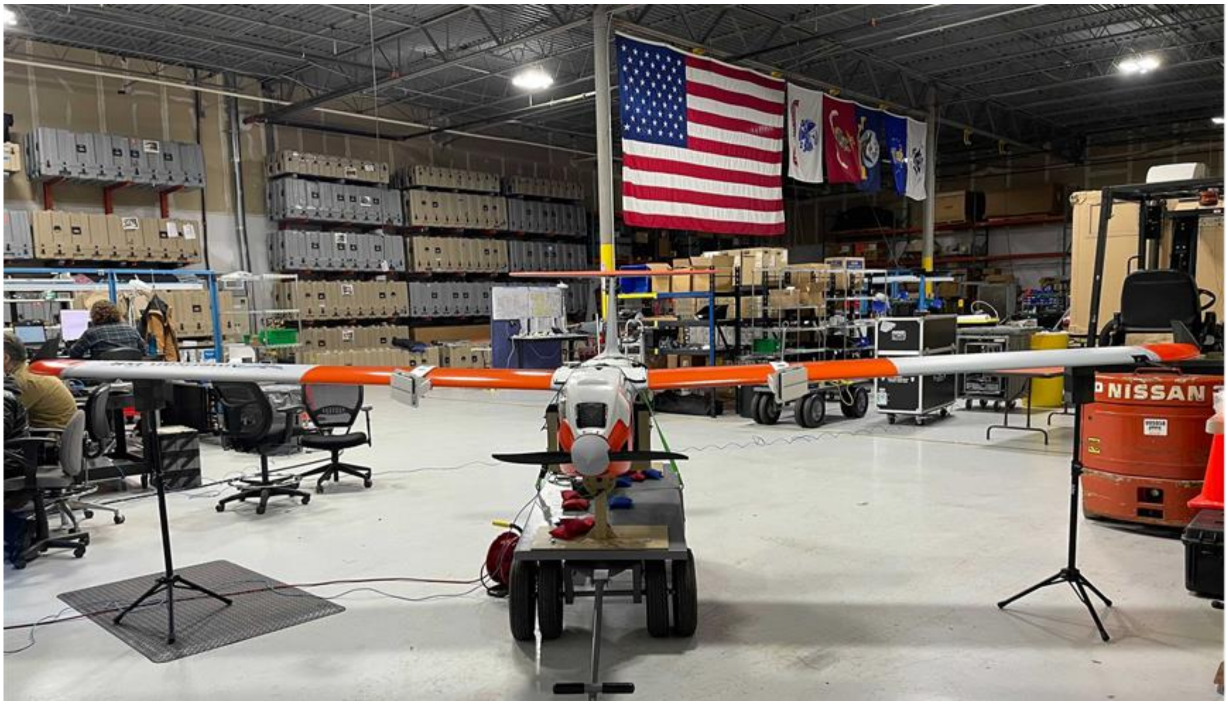


Figure 2-7. AiRanger dual RADAR configuration

2.8.2 Situational Awareness Camera

A situational awareness camera is integrated on the NASA SIO AiRanger configuration. It is mounted on the tail for optimal view with least obstruction. It has a small SWaP, with a weight of approximately 1 lbs. including cables and mounting hardware. The camera provides a view of weather, topography, and obstacles for the Pilot In Command (PIC), as well as providing the situational awareness for the PIC to perform emergency maneuvers such as emergency landings. A few different camera options were tested and considered for this campaign. In the end, the camera that provided the most utility to the PIC with the least burden to the system was chosen. The camera used during the demonstration is the ReoLink Go camera, a 1080p HD H.264 CMOS camera with 15 frames per second operation. Images in flight using this camera are shown below.

Figure 2-8. Situational Awareness imagery (on AVL)

Figure 2-9. Situational Awareness imagery (in air during a turn)

2.8.3 Aircraft color scheme

The use of novel color patterns for enhanced visibility was researched. It was determined that the FAA industry standard defines colors that are most suitable for aircraft visibility to make the AiRanger more readily visible to cooperative and non-cooperative aircraft. Fluorescent orange paint is highly visible at distances of 2.3 miles as compared to 1 mile unpainted, and should be applied to areas where sunlight hits the vehicle, and thus should be applied to the top side of the wings, wingtips, and fuselage, with alternating patches of white. Dark colors are most visible in shaded areas, resulting in the use of black paint in patches on the underside of both wings and fuselage.

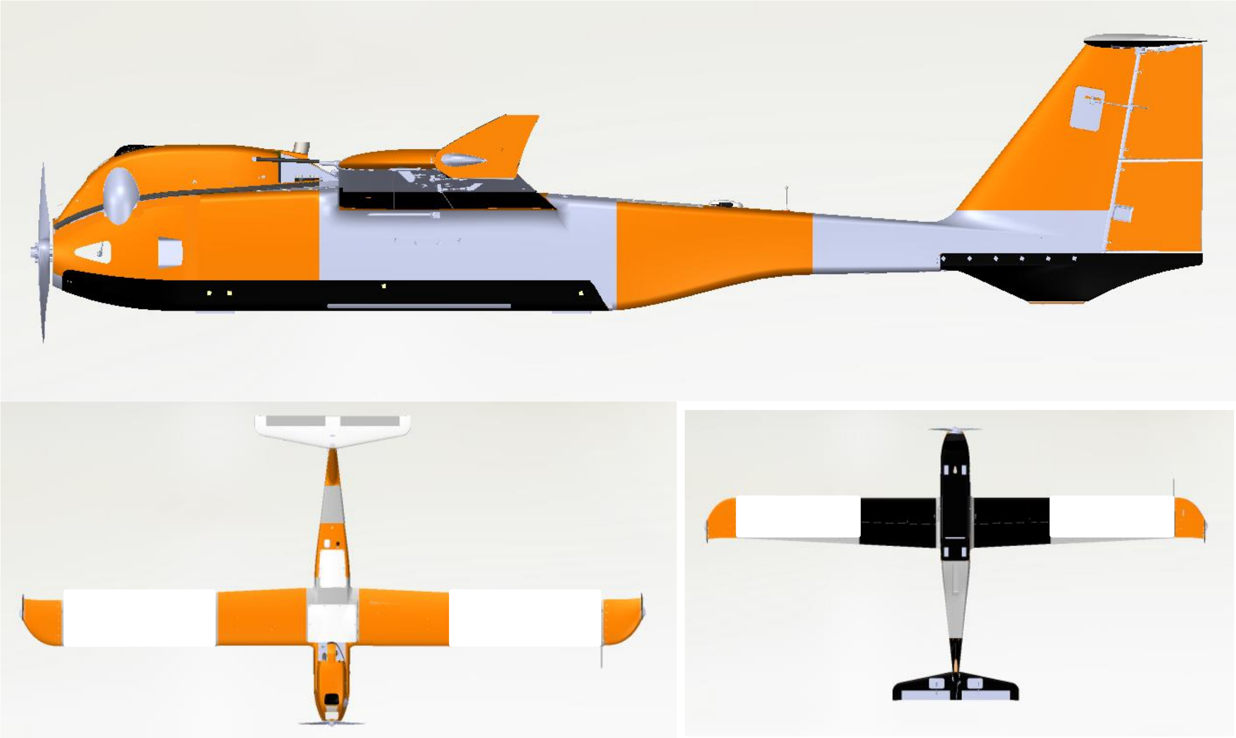


Figure 2-10. AiRanger enhanced visibility features

Figure 2-11. AiRanger enhanced visibility features

Figure 2-12. AiRanger enhanced visibility features

Figure 2-13. AiRanger enhanced visibility features

3 SIO Demonstration

3.1 Mission planning

The pilot-in-command (PIC) for this campaign produced an Independent Safety Review Brief (ISRB) as part of our Safety Process to be deemed flightworthy. This section highlights the ISRB package that was distributed on January 11, 2021. The ISRB covered the following topics: COVID Update, Flight Objectives, System Specifications, Configuration, Communications, System Readiness / Test, Test Overview / Flight Series, Schedule, Location – Flight Ops, Crew Assignments / Qualifications / Training Plan, Paperwork, and Discussion and Action Items.

The ground layout for flight operation is shown in Figure 3-1, with key components of the system setup shown in Figure 3-2.

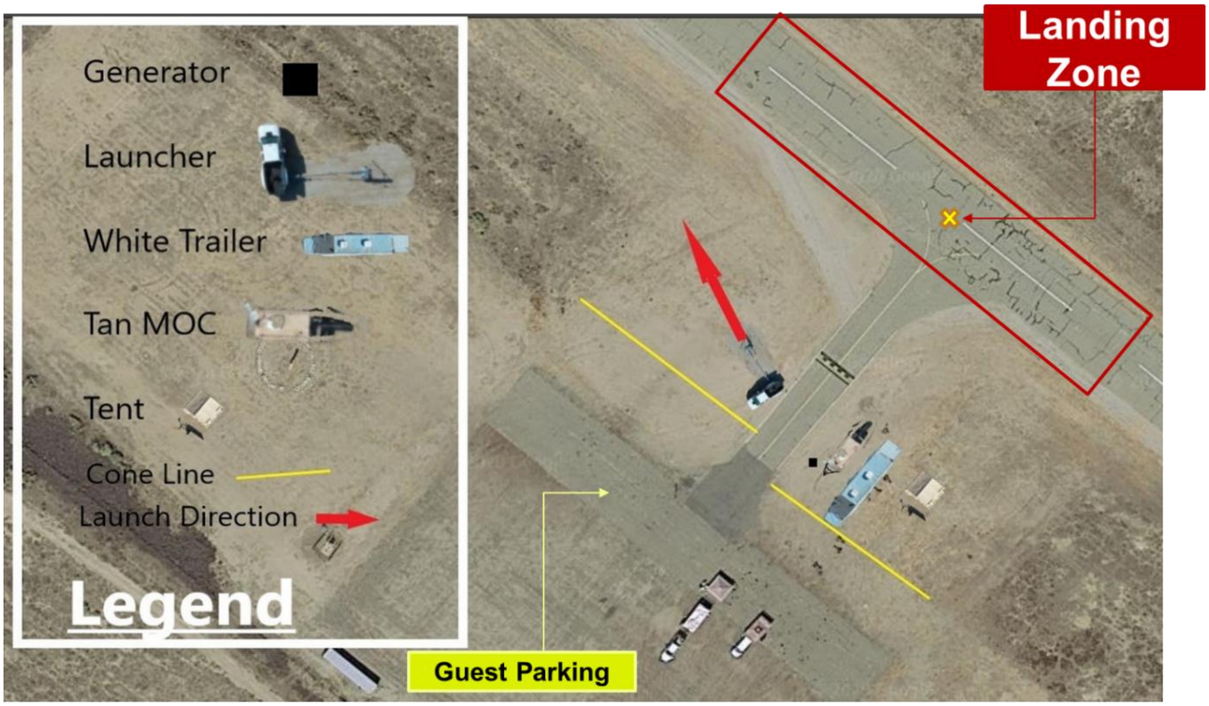
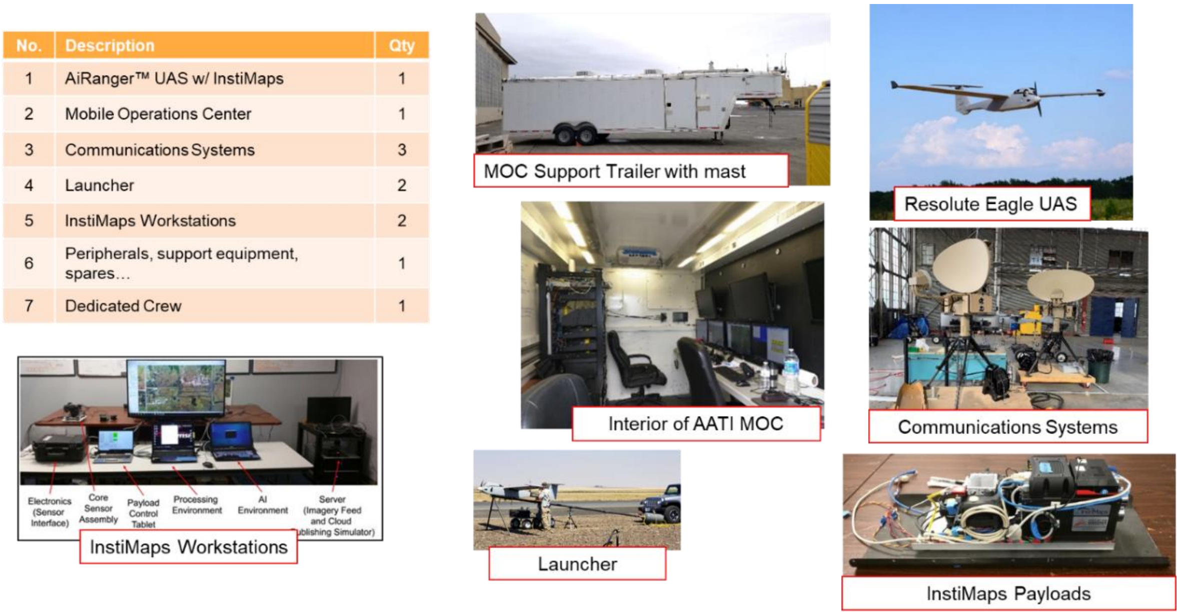


Figure 3-1. NASA SIO Ground Layout



No.	Description	Qty
1	AiRanger™ UAS w/ InstiMaps	1
2	Mobile Operations Center	1
3	Communications Systems	3
4	Launcher	2
5	InstiMaps Workstations	2
6	Peripherals, support equipment, spares…	1
7	Dedicated Crew	1

Figure 3-2. AiRanger fielded system components

3.2 Flight Profile

Flight Profile 2 (highlighted in green) was used to limit total distance from the MOC/GCS to mitigate LOS COMMS range limitations due to terrain and low flight altitude. The flight profile covers the path from Shafter to McKittrick, with approximately 40 pipeline miles total in the profile (Figure 3-3). The Farthest point from the GCS on this profile is 16 nm linear distance. The flight profile starts around an industrial area and continues over farm fields then transitions to a desert environment – all over oil pipelines. The flight passes over Route 5 and later pass near Highway 33. In terms of airspace, the flight occurs within 5nm SW of Shafter-Minter Airport (KMIT), with proximity to Victor Airway 248 and Victor Airway 137 in the beginning section of the flight profile.

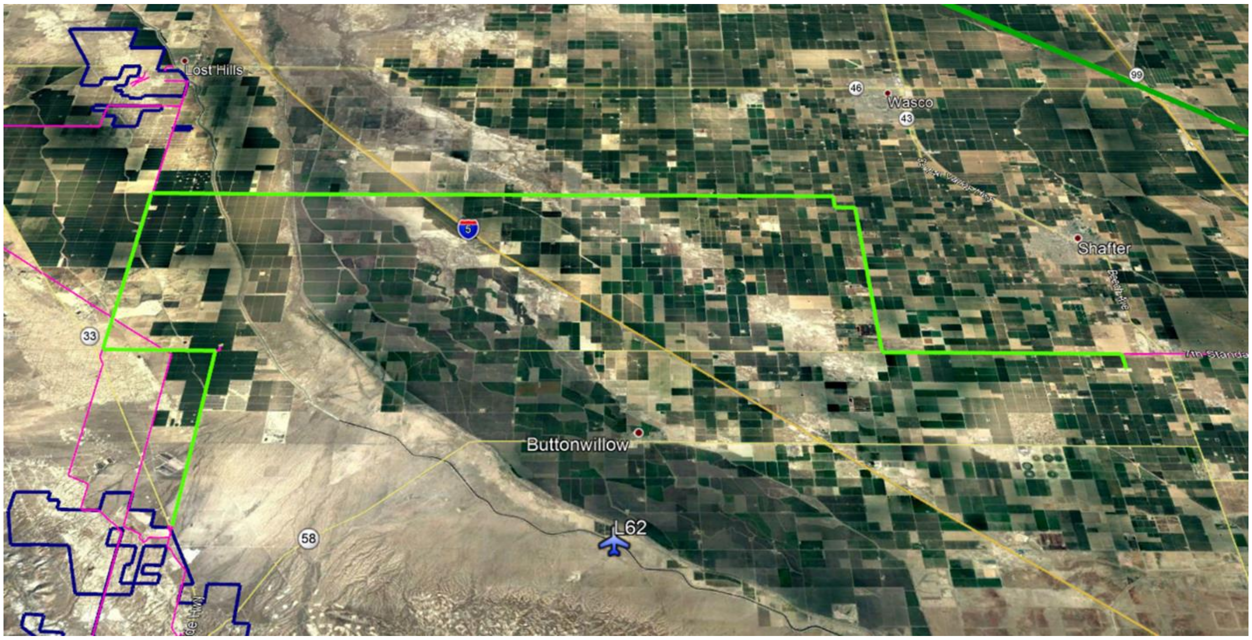


Figure 3-3. NASA SIO Demonstration Flight Plan

3.3 Pre-flight COMMS range analysis

Maintaining line-of-sight to ensure a robust COMMS link is critical to any commercial mission to identify regions where lost link is more likely or where C2 is expected to degrade. As part of our mission preparation, OneSky performed a LOS radio analysis for both the MMT and CNPC radios based on the Troll antenna location/height and the proposed flight paths at 2,000 ft AGL using their mission planning software. Results are provided below for both flight paths proposed for the mission. The coverage map in Figure 3-4 depicts the received CN0 of the MMT radio, from the aircraft, dependent on aircraft location, legend units are in dB-MHz. Based on this analysis, the MMT radio demonstrates little loss, clutter, or ground curvature effects out to approximately 50 miles in the direction of the flight plan.

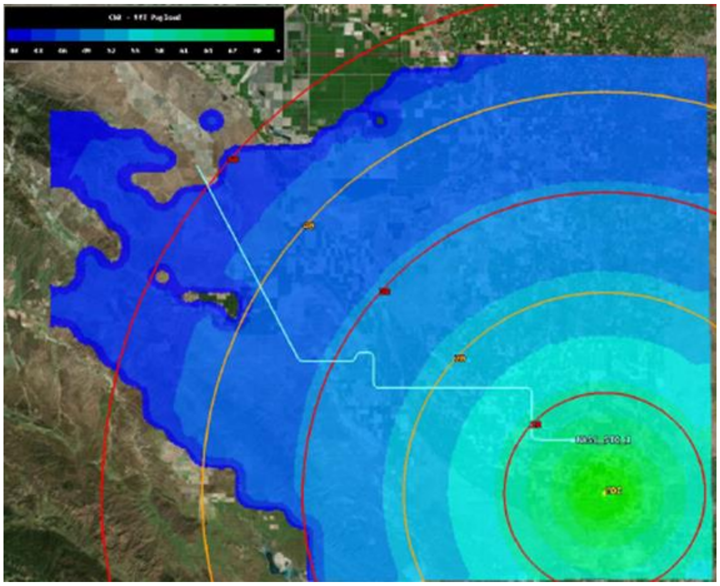


Figure 3-4. MMT L/S-band payload radio LOS and dB signal analysis

Figure 3-4 depicts the coverage map depicts the received CN0 of the CNPC-5000 radio, from the aircraft, dependent on aircraft location. CN0 ranged from 103 to 122 dBHz (43-61 dB-MHz). Similar to the MMT radio, the CNPC-5000 radio shows good coverage over the proposed flight path with minimal loss of LOS expected.

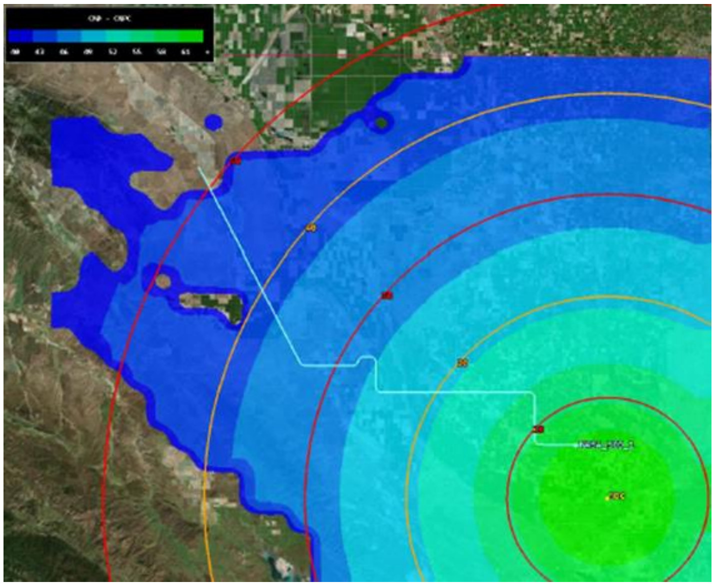


Figure 3-5. CNPC-5000 C-band C2 radio LOS and dB signal analysis

3.4 Flight Team and Chase Operation

The operator, observer, and crew attended daily Mission Commander's briefings prior to daily launch. All members of the crew have the authority and are encouraged to discuss safety issues, mitigation requirements, and to recommend scrubbing the launch during the mission briefing and prior to a launch of aircraft. The crew maintained direct radio voice contact with the PIC during the mission. For added safety, all UA maneuvers were planned ahead of time and announced prior to execution. Airborne Observers for the UAS keep the Air Vehicle in sight at all times and maintain radio communications with the PIC and the Range Safety Officer / Mission Coordinator. The PIC advised Observers when the UA was moving from one observation sector to a new one. While not using a chase vehicle (local only), an Observer on-site maintained sight of the UA and informed a receiving Observer of approximate position, heading and altitude. The receiving Observer then states when the UA is in sight and has positive identification.

KCSI Aerial Patrol provided Chase Operations during the mission. During Chase Operations, the PIC announces any abrupt or unplanned maneuvers with acknowledgement from the chase crew - prior to maneuver execution. Chase crew contacted ATC/range control as applicable as soon as practical and maintain contact as directed during operations. KCSI also advised if the flight path indicates a possible conflict with weather. Pictures of the AiRanger with KCSI in chase are shown below in Figure 3-6 through Figure 3-8.

Figure 3-6. AiRanger fielded system components

Figure 3-7. AiRanger fielded system components

Figure 3-8. AiRanger view from Chase vehicle

3.5 UTM integration: OneSky

AATI integrated with OneSky for real time display and mission planning. OneSky's software capabilities provide a time dynamic, three-dimensional geospatial engine that integrates multi-source data and provides real time situational awareness coupled with dynamic analysis to give the operator a complete view of their BVLOS flight and enhance operational decision making in the event of contingencies.

The solution architecture is shown below in Figure 3-9. The OneSky Adapter Framework (OAF) provides a common data model and flexible system interface to enable sharing information between multiple disparate systems in a scalable manner. Telemetry data from the Piccolo GCS was picked up on the local network by the GCS Adapter and translated into the common data model. The OAF also interfaced directly with the Echodyne radars via the airborne network and a local ADS-B receiver. All of this data was then shared to the UTM Server as well as the local situational awareness display on site. The UTM server then streamed the data to remote web viewers through the OneSky Portal. Both the web portal and local application also integrate other data such as real time weather radar data, the national ADS-B feed, airspace information such as classification, constraints and restrictions and mission specific data such as flight intention and in this case the inspection pipeline target.

Figure 3-10 through Figure 3-13 are shown below, displaying the vehicle flight path (yellow line with blue circle arrow indicating heading), compliant intruders from the ADS-B In feed (blue/white aircraft icons), and RADAR hits as green triangles. Most of the RADAR tracks were determined to be ground clutter related due to our low altitude. The UTM system is a key enabler in operations scalability, allowing a single operator to monitor multiple aircraft and deconflict missions. During the SIO demonstration, engineers in Sterling, VA and Conshohocken, PA logged into the dynamic OneSky web portal and were able to monitor the aircraft in flight in real-time.

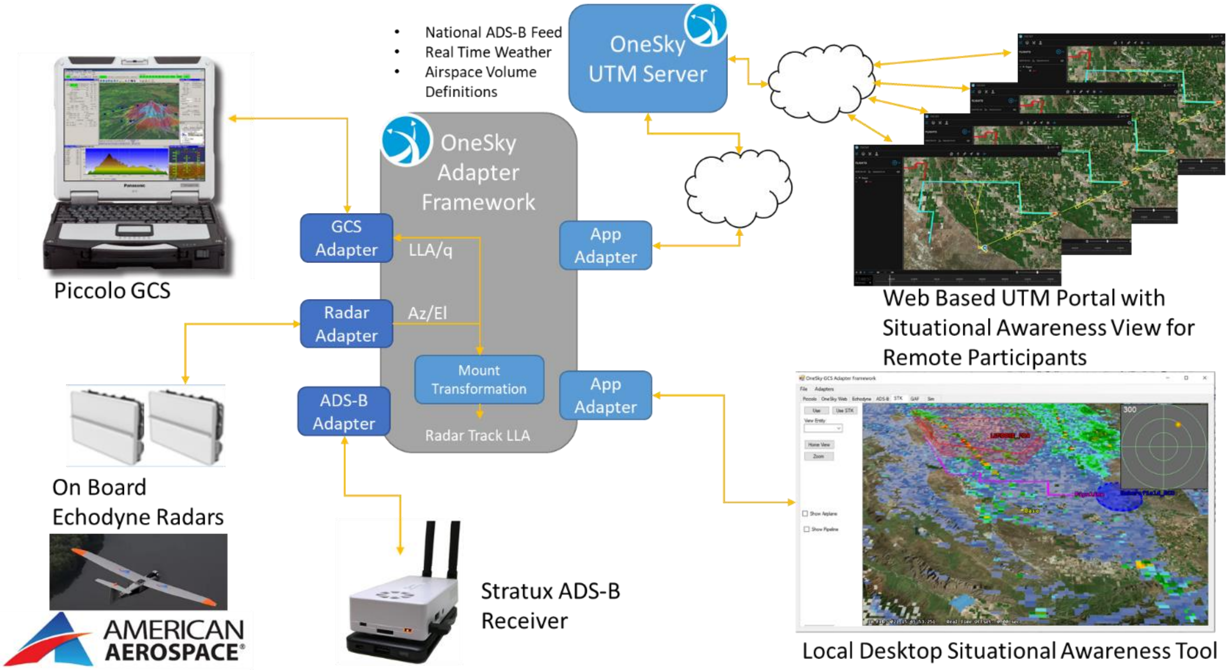


Figure 3-9. OneSky UTM integration block diagram

The integration of Echodyne radars as a flight demonstrator represents an incremental advancement towards the realization of on board Detect And Avoid (DAA) capabilities. The intent of the demonstration was to successfully capture real time data from the radars and demonstrate that the system is safe to operate on board the Air Ranger vehicle. The data provided by the Echodyne radars is in the radar frame which means the tracks are provided relative to the face of the radar as would be seen in a typical radar azimuth ring display. The Echodyne radars do not natively report track information in a world geodetic system. OneSky's software framework was able to take the AirRanger telemetry data from Piccolo and based on the interpolated position and orientation of the aircraft, transform the radar coordinates from the radar frame into Latitude, Longitude and Altitude coordinates so that the radar tracks could also be visualized within the time dynamic 3D display along with the other data.

Figure 3-10 through Figure 3-13 are shown below, displaying the vehicle flight path (yellow line with blue circle arrow indicating heading), compliant intruders from the ADS-B In feed (white aircraft icons), and RADAR hits as green triangles. Most of the RADAR tracks were determined to be ground clutter and other noise due to our low altitude.

Figure 3-10. OneSky UTM display integrated with AiRanger

Pipeline
Name: Pipeline
Type: CZML
Visible Yes
URL: https://s3-ap-southeast-1.amazonaws.com/s3.oneskyasia.com/NASA_SIO_1.czml

Figure 3-11. OneSky UTM display integrated with AiRanger

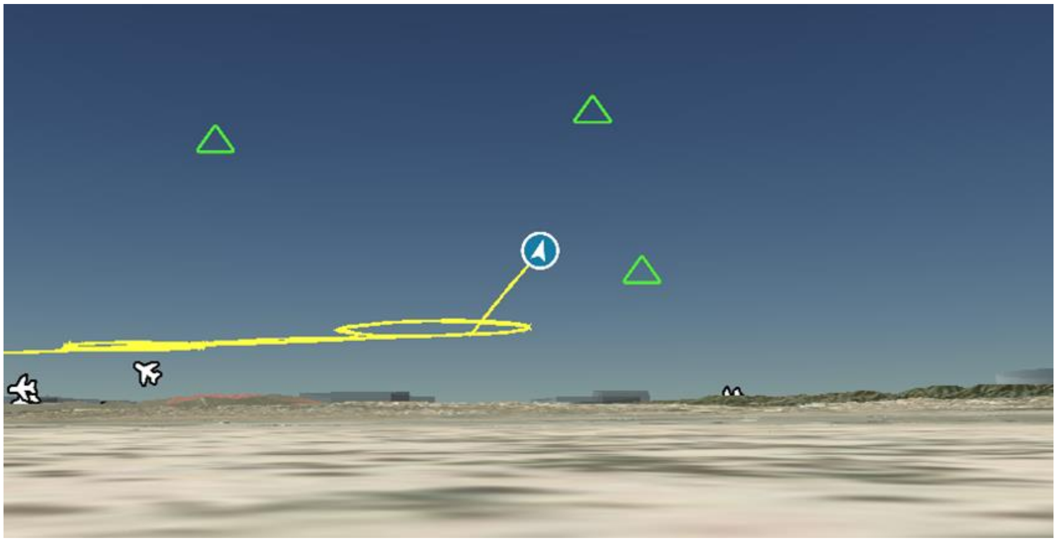


Figure 3-12. OneSky UTM display integrated w/AiRanger; green arrows are RADAR hits

Figure 3-13. OneSky display for full NASA SIO Demo

4 NASA SIO Demonstration Activities and Results

4.1 Mission Data

InstiMaps Near Real-Time (nRT) image streaming and threat detection are shown in Figure 4-1 through Figure 4-6. Red boxes indicate the automatically identified threats to the pipeline, including vehicles and digging equipment. Images are automatically geo-referenced using the InstiMaps payload on-board processing.

LWIR Min: 1986

LWIR Max: 4730

Mem: Tot 27,202

Prv 186,396

35° 31' 38.47" N 119° 23' 1.28" W

35° 31' 39.30" N 119° 23' 1.48" W

Min: 1986 Max: 4730 File Max: 4730

Latitude - Longitude: 35° 31' 43.28" N, 119° 23' 6.58" W

Lead: X 5006, Y 1850, RGB 255-0-0

Figure 4-1. InstiMaps Viewer with Near Real-Time (nRT) threat detections

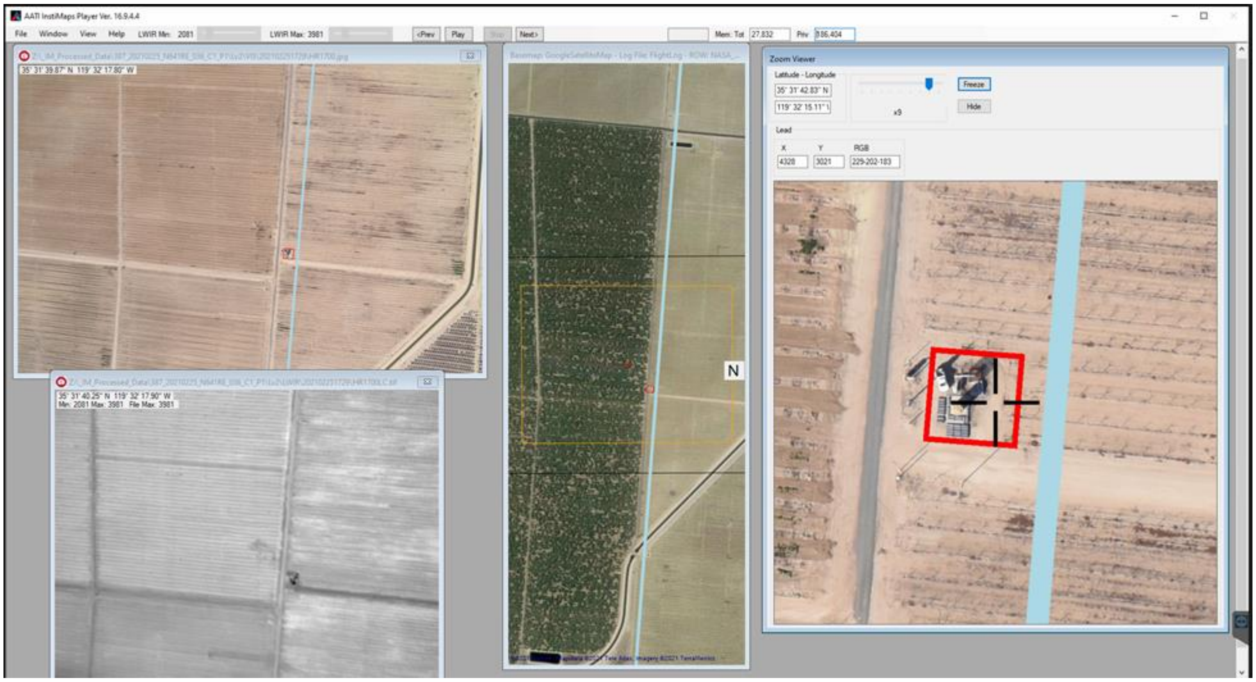


Figure 4-2. InstiMaps Viewer with Near Real-Time (nRT) threat detections

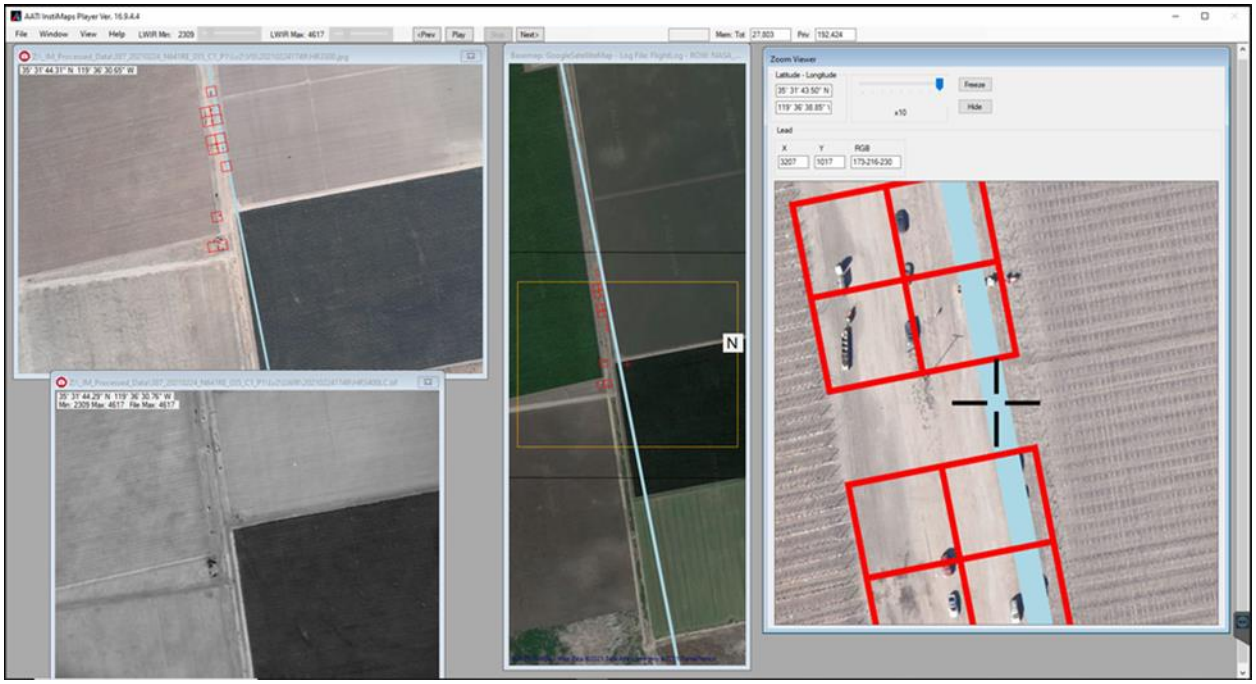
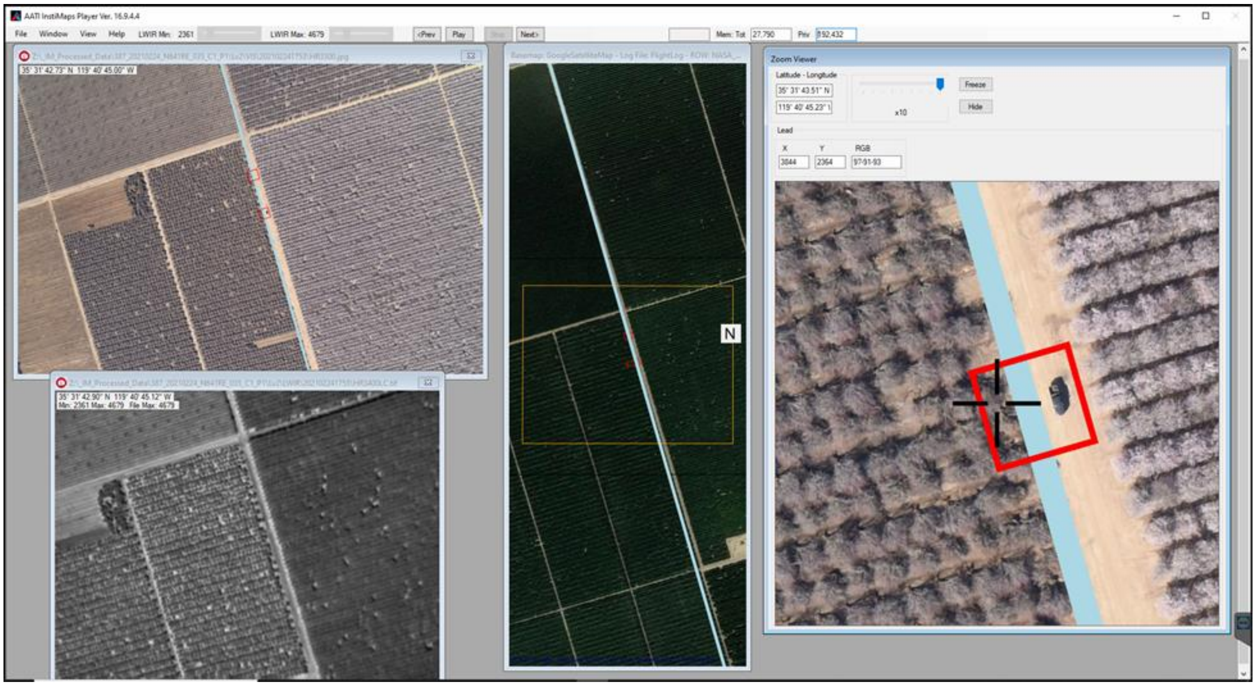
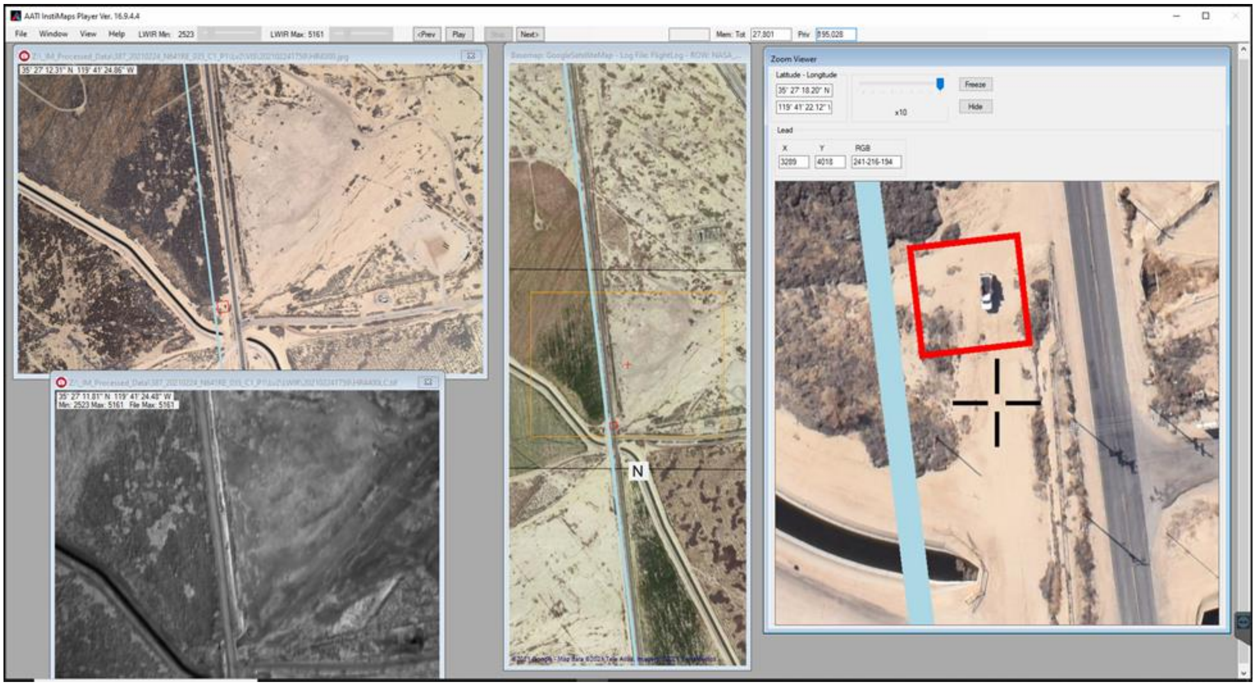


Figure 4-3. InstiMaps Viewer with Near Real-Time (nRT) threat detections



LWIR Min: 2361
LWIR Max: 4679
Mem: Tot 27,790
Priv 192,432
35° 31' 42.73" N 119° 40' 45.00" W
35° 31' 42.90" N 119° 40' 45.12" W
Min: 2361 Max: 4679 File Max: 4679
Latitude - Longitude
35° 31' 43.51" N
119° 40' 45.23"
Lead
X 3844
Y 2364
RGB 97-91-93

Figure 4-4. InstiMaps Viewer with Near Real-Time (nRT) threat detections



LWIR Min: 2523
LWIR Max: 5161
Mem: Tot 27,801
Priv 195,028
35° 27' 12.31" N 119° 41' 24.86" W
35° 27' 11.81" N 119° 41' 24.40" W
Min: 2523 Max: 5161 File Max: 5161
Latitude - Longitude
35° 27' 18.20" N
119° 41' 22.12"
Lead
X 3289
Y 4018
RGB 241-216-194

Figure 4-5. InstiMaps Viewer with Near Real-Time (nRT) threat detections

Figure 4-6. Additional imagery captured by InstiMaps showing unique surface topology

4.2 Echodyne Echoflight RADAR tracks

Echodyne Echoflight dual RADAR tracks were recorded using the Echodyne Graphical User Interface. Tracks are plotted as a function of degrees in both Elevation (Figure 4-7) and Azimuth (Figure 4-8). A significant amount of clutter exists due to proximity to the vehicle's proximity to the ground, and the detections were limited to the upper elevations due to cropping of the bottom 20 degrees intended to mitigate reflections from the ground. AATI has planned a series of test events to tune the RADARs in-flight to optimize their performance and validate the use of the RADAR models in the ACAS-Xu DEGAS simulations provided by MIT LL.

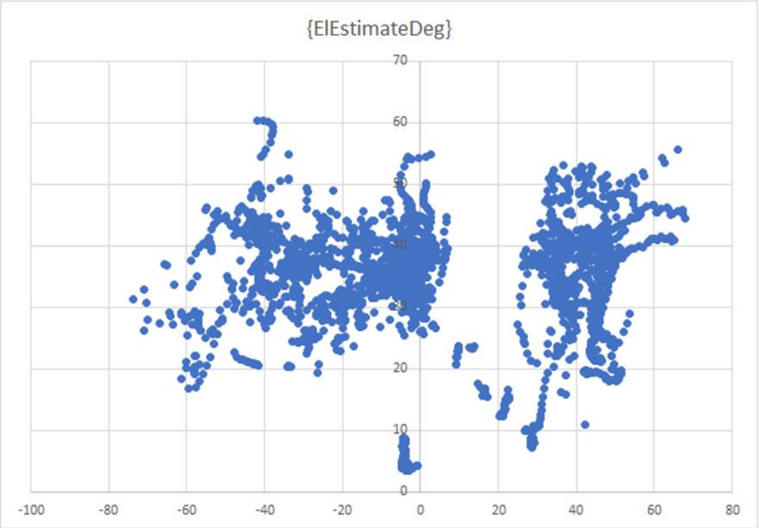


Figure 4-7. Echodyne Echoflight RADAR elevation track estimates

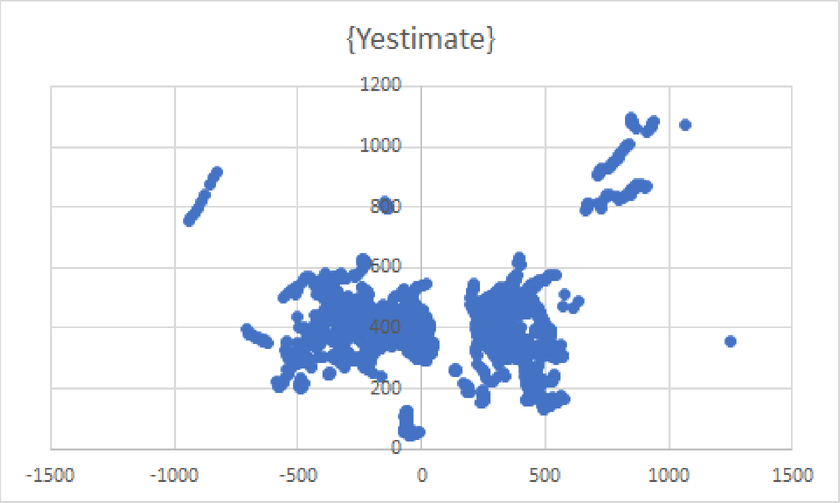
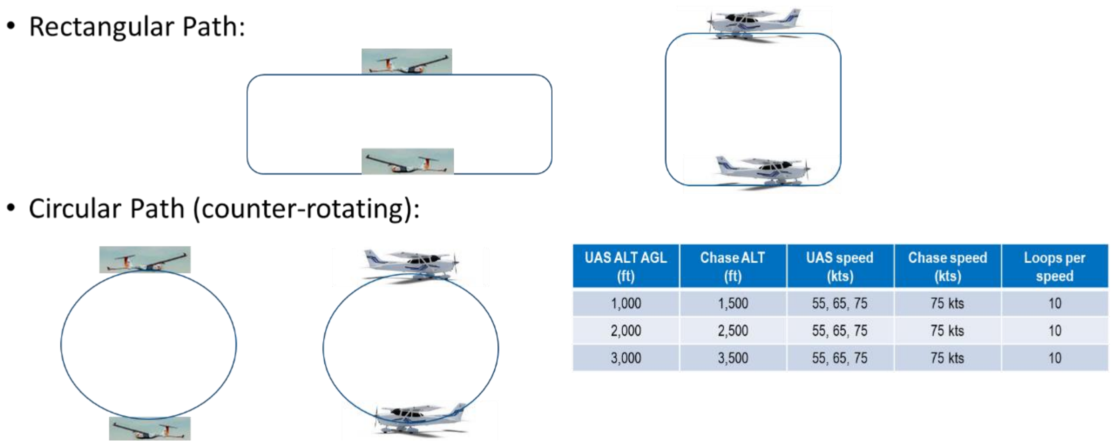


Figure 4-8. Echodyne Echoflight RADAR azimuth track estimates

Follow-on RADAR tuning data collections and testing will be conducted in the following three planned phases, with the proposed flight paths and test matrix depicted in Figure 4-9. The objectives will be to 1) reduce and remove ground clutter; 2) validate detection of intruder vehicles at altitude; and 3) simulate avoidance maneuvers to validate ACAS-Xu-like performance.

- Phase I (Q2 2021):
    - Dual RADAR recording in RAW mode
    - Chase vehicle (75 kts) @ 500 ft above AiRanger (65 kts)
    - AiRanger @ 2,000 ft, 3,000 ft, and 4,000 ft to assess ground clutter
    - Record RADAR data and tracks, ownship GPS, intruder GPS for correlation
- Phase II (Q2-Q3 2021):
    - Evaluate data obtained and tune to reduce clutter and fine tune RADAR parameters
    - Work with OEM Echodyne to optimize parameters through data sharing effort
- Phase III (Q3 2021-Q1 2022):
    - Repeat Phase I test in RAW and real-time modes to:
    - Validate updated parameters
    - Evaluate avoidance maneuver efficacy
    - Record RADAR data and tracks, ownship GPS, intruder GPS for correlation



UAS ALT AGL (ft)	Chase ALT (ft)	UAS speed (kts)	Chase speed (kts)	Loops per speed
1,000	1,500	55, 65, 75	75 kts	10
2,000	2,500	55, 65, 75	75 kts	10
3,000	3,500	55, 65, 75	75 kts	10

Figure 4-9. DAA RADAR test encounter plan

5 Type Certification Progress

AATI with assistance from End State Solutions, Inc., continue to be optimistic regarding progress with the FAA’s Type Certification. Ongoing meetings with the FAA continue in the Safety Case Development for elimination of chase aircraft through the Type Certification process. The Project Specific Certification Plan (PSCP) has been submitted to the FAA, and a draft of the G1 paper, the airworthiness means of compliance basis, is in discussion between AATI and the FAA as of 1Q21. AATI continues to drive an aggressive schedule.

The PSCP is a major step in achieving Type Certification, which is the design approval of the aircraft and all component parts which signifies the design is in compliance with applicable FAA airworthiness, noise, fuel venting, and exhaust emissions standards, among other standards. In addition, AATI has begun the parallel process with the FAA for Production Certification approval to manufacture duplicate products under an FAA-approved type design and will signify that AATI and its personnel, facilities, and quality system can produce the AiRanger in a manner that conforms to its approved design. AATI anticipates achieving its Type Certification in mid-2022. The following illustration depicts the schedule anticipated.

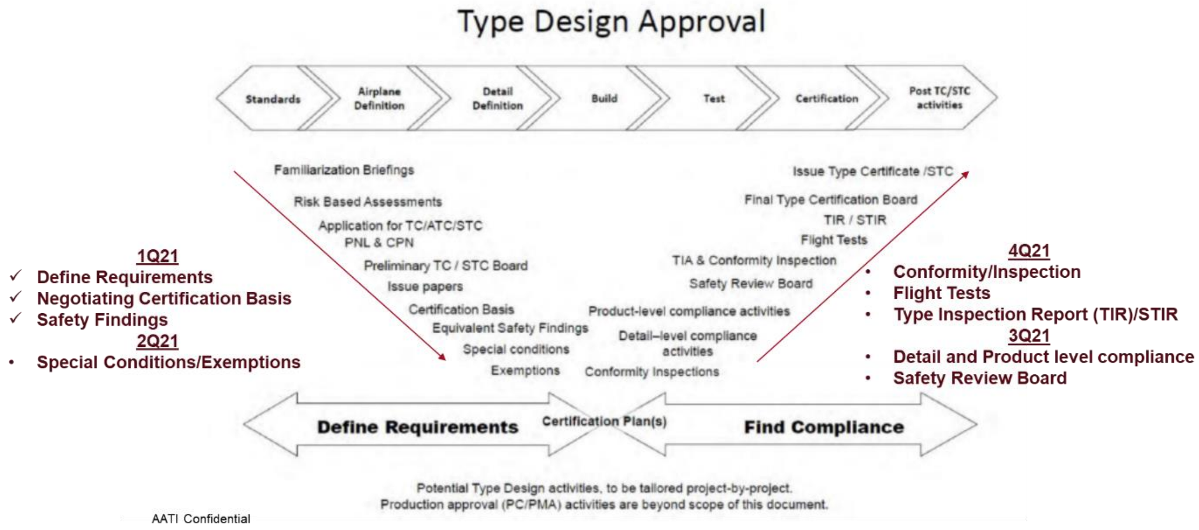


Figure 6-1: Type Certification Approval plan

Expected Certifications Challenges associated with routine NAS integration are primarily in three areas:

- Integration of existing, stand-alone components into fully integrated and functional systems. The existence of technology under parallel type certification applications is not relatively known, so it takes time to locate components to integrate onto aircraft that meet the minimum ASTM standards for type certification.
- The exponential pace of technology evolution versus the development of standards enabling certification. Our ability to participate in shaping the standards is exhaustive with both participation in AUVSI and through direct engagement in FAA HQ and regional meetings and submittal of white papers on specific topics requested.
- The goal of 2Q22 for an awarded Type Certification is aggressive but achievable if the FAA continues to be actively supportive as it has through the SIO program. AATI continues to invest significant time, labor, and assets on the path to achieve the goal of manufacturing an airworthy UAS for commercial BVLOS operations in the NAS. AATI will incorporate design updates and changes in the Type Certification plan as requested during the FAA review of the PSCP, Rule by Rule analysis, and development of the G1 and G2 means of compliance.

AATI has achieved Airworthiness Approval for flight under COAs

- 2020-WSA-6333-COA for SJV, CA (4350 square miles)
- 2020-ESA-6229-COA for South Jersey (804 square miles)
- 2021-CSA-8033-COA for GOM, LA (7,000 square miles)
- Path to Type Certification: Detect and Avoid (DAA) operating on aircraft

Test Site Protocols:

AATI worked with University of Alaska Fairbanks, Alaska Center for Unmanned Aircraft Systems Integration (ACUASI), who oversees the Pan Pacific UAS Test Range Complex (PPUTRC) test range facilities, including the 14,000 Square Mile Test Range located in Pendleton, Oregon during the initial onboarding of the SIO program. Increased wildfires in the Pacific Northwest in 2020 required AATI to establish a secondary site to conduct the demonstration due to decreased visibility in the north from thick smoke and dangerous air quality for safe crew operations during the R&D flight test program.

AATI was able to secure a Certificate of Authorization (2020-WSA-6333-COA) from the New Jersey Institute of Technology (NJIT) for the San Joaquin Valley (SJV) in California in late 2020. This 4,350 square miles COA range was south of the fires plaguing Oregon and allowed for resumed operations. AATI has worked with NJIT for nearly a decade throughout the nation, including California, so they were able to quickly step in to solve the airspace authorization in time to facilitate the SIO demonstration. NJIT has been on the cutting edge of drone technology and enabling drone usage for everyday use, so their hands-on safety oversight was valued added to the AiRanger platform.

The Kern County Director of Airports was instrumental in supporting the growth opportunity with establishing a launch/landing zone at the Elk-Hills Buttonwillow Airport (L62), which is a remote public airport about 25 miles outside of Bakersfield, CA. L62 is an optimal site to resume testing and conduct the demonstration over pipelines.

Overall, AATI was pleased to work with the Pendleton UAS Test Site, Kern County Airports, and NJIT on this project as their support was invaluable in ensuring safety and readiness of the UAS. Their willingness and flexibility to work closely with their Safety officials to facilitate the demonstration was integral to a successful mission.

6 Summary and Conclusions

Our mission during the SIO demonstration successfully provided pipeline inspection at a customer site with on-board DAA and a TSO aligned C2 solution. The AiRanger commercial solution provides automated surveillance, a viable alternative to current manned operations that come with a much larger burden to the operator and environment. The technology used for this mission, InstiMaps, a sensor developed by AATI, has the capability to far surpass the detection capabilities currently employed in the field and make critical infrastructure inspections safer, more effective and automated, and with reduced carbon footprint. The DAA and C2 components leverage RTCA and ASTM standards to ensure safe operation in the NAS.

Several takeaways and lessons learned were identified during this campaign and demonstration:

1) **C2 Radio:** The CNPC-5000 is a well-designed radio. During the NASA SIO demonstration, the CNPC link degraded at 15 miles range for the flown flight profile due to the AiRanger low flight altitude and the nature of the terrain. The operator reset the Troll antenna to attempt to improve this link, which caused the Troll to lose its encoder position and move into INS Mode, causing a loss of link lock with the aircraft antennas and GPS

location. The PIC moved into the lost link procedures, and the team followed the appropriate SOPs to regain COMMS. Once COMMS were regained, the team returned to the flight path; however, the Troll had lost its reference during the INS initialization process and never fully regained proper tracking capability with the aircraft. The team returned to base, following AiRanger SOPs to ensure safe operation. This isolated issue did allow us the opportunity to effectively demonstrate execution of lost-link procedures. However, an important result of the demonstration is that the CNPC-5000 best suited for vehicles operating within a 10-mile radius or at higher elevations. Given the lower propagation properties of C-band (high-frequencies cannot travel as far as lower frequencies) and the low altitude of the AiRanger vehicle, a maximum range of 15 miles is anticipated, with an upper end range of 30 miles with some modifications. 30 miles is woefully inadequate for our commercial mission ConOps, and thus precipitates the need to move to a SATCOM or LTE solution for C2 in pursuit of Type Certification. AATI is currently evaluating and beginning testing on LTE (Q1-Q2 2021) and SATCOM (Q2-Q3 2021).

2) **Payload Radio:** The MMT radio in L/S-band performed with high signal-to-noise-ratio (SNR) at approximately 20 miles from the GCS, providing more than the 15 MBPS needed for real-time operation of the system in the mission configuration, allowing for real-time high-resolution imagery to be displayed on the InstiMaps Viewer software. Based on an SNR of 35-40 dB above the noise floor, the system demonstrated the ability to function reliably at 4-5 times this distance. The overall distance is of course limited by LOS limitations due to surface topology and the effect of curvature of the Earth. The simplest solution to this problem is to raise the GCS antenna to a height of 40+ feet, which is difficult with the robust Troll antenna due to its weight and raises concerns at airports.
3) **Situational Awareness Camera:** The SA camera, located on the tail of the aircraft, allowed a view of the vehicle and the region proximal to the aircraft. The operator did not find the camera to be of great use, as his focus is on the PCC interface. However, the camera did provide a usable view of the area ahead of the vehicle in case of an emergency landing to verify that an emergency landing could occur without damage to people or property. It is also useful for avoiding nearby patches of inclement weather, although integration with the UTM system provides first line of defense in avoiding these regions. Overall, it was deemed a necessary component, but only as a peripheral and not a core piece of the DAA solution.
4) **Cooperative DAA:** The Sagetech MXS Transponder operates in a very similar manner to its predecessor technologies, which facilitated simple and easy integration into the AiRanger platform. The only drawback was that a Piccolo autopilot plug-in had not yet been developed for the transponder and it was therefore necessary to operate the transponder through the payload radio. There is a plan to remediate this issue soon. All in all, the transponder provides reliable communication between compliant vehicles to ensure proper mission planning and avoidance. Although, we did not have authorization to transmit on ADS-B Out, the system was validated to be capable of performing this function. The MXS Transponder will be replaced with a combination transponder interrogator which will provide validated ADS-B tracks in compliance with ACAS MOPS. The planned onboard ACAS computer will give an integrated situational awareness picture

combining cooperative and non-cooperative intruders, as well as standardized "remain well clear" and "resolution advisory" alerts to the PIC and/or directly to the autopilot.

5) **Non-cooperative DAA:** The dual Echoflight RADARs perform well overall. The key challenge to operating the RADARs in this architecture is mitigation of clutter as compared with vehicle detections. The RADAR signal is highly sensitive, and as a result we will likely need to filter out the smaller threats, i.e. birds, etc., and focus the RADAR on only the larger threats, i.e. Cessna, crop-duster, etc. There is also an inherent issue with ground clutter, as the RADAR has a long enough range (~2 km) that even at 2,000 ft it can easily see the ground when pointed directly forward. Thus, additional work is necessary to ensure that the ground is not detected. AATI has developed a plan to work with Echodyne on real-time in-flight tuning to optimize the RADARs. Once the RADARs have been tuned, we will validate their detection range and overall accuracy to support DEGAS simulations conducted by MIT Lincoln Laboratory.

AiRanger is a perfect complement to the other NASA vehicle partners, as it is designed for commercial application in the medium altitude range and has a well-defined and established commercial mission. AiRanger is a mission ready platform, capable of long mission range and duration with a high payload capacity. By incorporating Detect and Avoid Technologies, including dual Echodyne Echoflight RADARs and the Sagetech MXS Transponder, AATI has brought the industry closer to a compliant solution for safe operation in the National Airspace. This demonstration is a huge step forward in our Type Certification process. The NASA SIO program has fostered a relationship between AATI, the FAA, and the RTCA to facilitate compliance with FAA current and future certification requirements.

AATI is continuing the Type Certification process and using the NASA SIO demonstration vehicle as the basis for Type Certification. Through ongoing engagement with the FAA, we will provide the necessary documentation and testing needed to obtain Type Certification. The FAA and NASA have been instrumental in the demonstration from day 1, guiding us to ensure that we build a robust safety case. There have been significant trades between operational and safety considerations where their intimate knowledge of the certification process and key performance metrics have been invaluable.

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14. ABSTRACT

National Aeronautics and Space Administration (NASA) awarded a Cooperative Agreement to American Aerospace, and two other companies, under the Unmanned Aircraft Systems Integration and Operationalization (SIO) demonstration with the goal of accelerating routine unmanned aircraft systems (UAS) operations in the national airspace (NAS). The team lead by American Aerospace Technologies Inc (AATI) demonstrated its UAS AiRanger™ successfully on February 25 as part of NASA's SIO program.

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