

NASA Langley Airspace Surveillance Radar System Baseline

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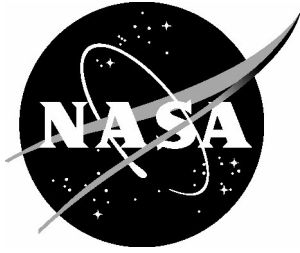
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Author Contributions

This report includes content from multiple technical disciplines across four NASA Langley Directorates. The following is a listing of the authors and their respective contributions:

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2. James Nicholson: Mission Operations and Autonomous Integration Center (MOSAIC): Overview, Operation, Interconnect, Firewall rules and IT Security; Radar Software Operation, User's Guide, Troubleshooting; Anomaly Reporting
3. David Hare: Radar Systems: Overview, Operation, Power & Installation
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12. Victoria Chung: Initial outline and direction for this report. Oversight of MOSAIC and Application Development, and Document organization

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Executive Summary

Recent increases of incursions of aircraft into restricted airspace have significantly impacted NASA rocket launches and military flight operations and created public safety concerns.

NASA's Aeronautics Research Mission Directorate (ARMD) identified the operational airspace surveillance capabilities at NASA Langley Research Center ("NASA Langley" or the "Center" in this report) to be a useful and desirable model that may be leveraged for other NASA Centers and other government organizations, particularly for non-cooperative air traffic.

This report focuses primarily upon airspace surveillance radar capabilities at NASA Langley, and includes relevant information about information systems, procedures, and facilities (in the context of Uncrewed Aircraft System (UAS) Flight Operations infrastructure) required to operate radar systems. The report also provides essential information about procurement, commissioning, operations, and future expansion of radar systems at the Center. These radar capabilities are part of, and integrated across several facilities and organizations which have much broader utility beyond airspace surveillance.

Intended audiences include ARMD missions, other NASA Centers, NASA Langley's new team members, and partners that may want to use this report as a guide for their own solutions.

NASA Langley capabilities are maturing and evolving. Information technology and security processes included in this report are an integral part of present NASA Langley capabilities and will vary across other NASA Centers and other government agencies that may want to use this report as a guide for their own solutions.

The integrated airspace surveillance capabilities at NASA Langley are unique in the Agency, and the Center is a key player in our regional AAM Digital Infrastructure ecosystem. NASA projects, State & Local governments, DOD, industry and academic partners have requested the following:

- Aggregation and sharing of Airspace Sensor Data Feeds
- Radar/System Performance Characterization
- Airspace Awareness Software Release, Interface Document and User's Guide to partners
- Airspace Awareness Software Capability Extensions (i.e., additional sensors, data fusion)
- Acquiring and commissioning airspace sensors to expand regional airspace awareness
- Research, Development, Test & Evaluation of new airspace sensor technologies

These activities align with the ARMD request to document these capabilities for internal use and make them available to other NASA Centers and other government organizations. While this report satisfies the criteria for documenting existing capability, the above activities are anticipated to continue through 2025 and beyond.

Introduction

NASA has been addressing the challenge of aircraft incursions into restricted launch site airspace for decades. In recent years, NASA issued an advisory to the public to avoid using Uncrewed Aircraft Systems (UAS) over NASA Wallops Flight Facility property.¹ A key NASA Kennedy Space Center (KSC) initiative was the deployment of Moog's Gauntlet counter-UAS system in 2020, as detailed in a report from Unmanned Systems Technology². Moog has continued work with NASA KSC for UAS Detection services through 2025.³

More locally to NASA Langley, unknown drones swarmed Langley Air Force Base in 2023.⁴ The problem is nationwide, with hundreds of drone incursions being reported at military installations over the past few years.⁵ A 2023 study sponsored by the Virginia Innovation Partnership Corporation found that small UAS continue to create problematic safety and security challenges for state and local agencies, and advised that state and local governments will be forced to establish policies for detecting, tracking, and responding to problematic small UAS flights.⁶

NASA's Aeronautics Research Mission Directorate (ARMD) identified the operational airspace surveillance capabilities at NASA Langley Research Center (NASA Langley) to be a useful and desirable model that may be leveraged for other NASA Centers and other government organizations, particularly for non-cooperative air traffic. NASA ARMD requested a report documenting airspace surveillance radar capabilities at NASA Langley. This report fulfills the request, and represents several years of research across multiple programs, culminating in the development of a unique facility at NASA Langley for beyond visual line of sight (BVLOS) tracking, testing, and prototyping.

The primary purpose of this report is four-fold:

- Provide a comprehensive roadmap that simplifies the complex path for other organizations seeking to build similar radar-enabled BVLOS capabilities.
- Document the critical stages, radar-enabled systems, and software implementations that comprise a fully functional mission control and testing center.
- Demonstrate integrated radar and sensor data feed sharing capabilities that enhance individual organizational capacities beyond what they could achieve independently.
- Provide a training tool for NASA Langley personnel to learn about the multi-disciplinary, multi-organizational capabilities for radar-enabled UAS BVLOS operations at the Center.

¹ "NASA Offers Guidance for Drone Use Viewing Antares Launch" <https://www.nasa.gov/news-release/nasa-offers-guidance-for-drone-use-viewing-antares-launch/>

² <https://www.unmannedsystemstechnology.com/2020/06/drone-detection-trials-undertaken-at-kennedy-space-center/>

³ <https://www.highergov.com/contract/80KSC020C0026/>

⁴ Wall Street Journal "Mystery Drones Swarmed a U.S. Military Base for 17 Days. The Pentagon Is Stumped." 10/12/2024. <https://www.wsj.com/politics/national-security/drones-military-pentagon-defense-331871f4>

⁵ <https://breakingdefense.com/2024/10/hundreds-of-drone-incursions-reported-at-military-installations-over-past-few-years-northcom/>

⁶ "Virginia UAV Activity Study" 12/2023. <https://vipc.org/wp-content/uploads/Virginia-UAV-Activity-Study.pdf>

This radar system baseline document may serve as a resource for industry partners and federal agencies, offering proven methodologies and lessons learned that can significantly reduce development time, costs, and technical risks when establishing comparable advanced testing environments. Through data integration and sharing capabilities, NASA Langley positions itself as a key enabler in advancing radar-enabled BVLOS technology across the broader community.

Introducing the “CERTAIN Range”

NASA Langley’s “Smart Center” is a Nationally recognized research, development, and test environment for advanced UAS operations and smart infrastructure capabilities that strategically enable NASA missions and partner collaborations. A central capability of Smart Center is the UAS operational airspace within the boundaries of NASA Langley property that has been designated the City Environment for Range Testing of Autonomous Integrated Navigation (CERTAIN) Range. The CERTAIN Range is adjacent to Langley Air Force Base (LAFB) property and is subdivided into four separate operational flight areas, shown in Figure A.

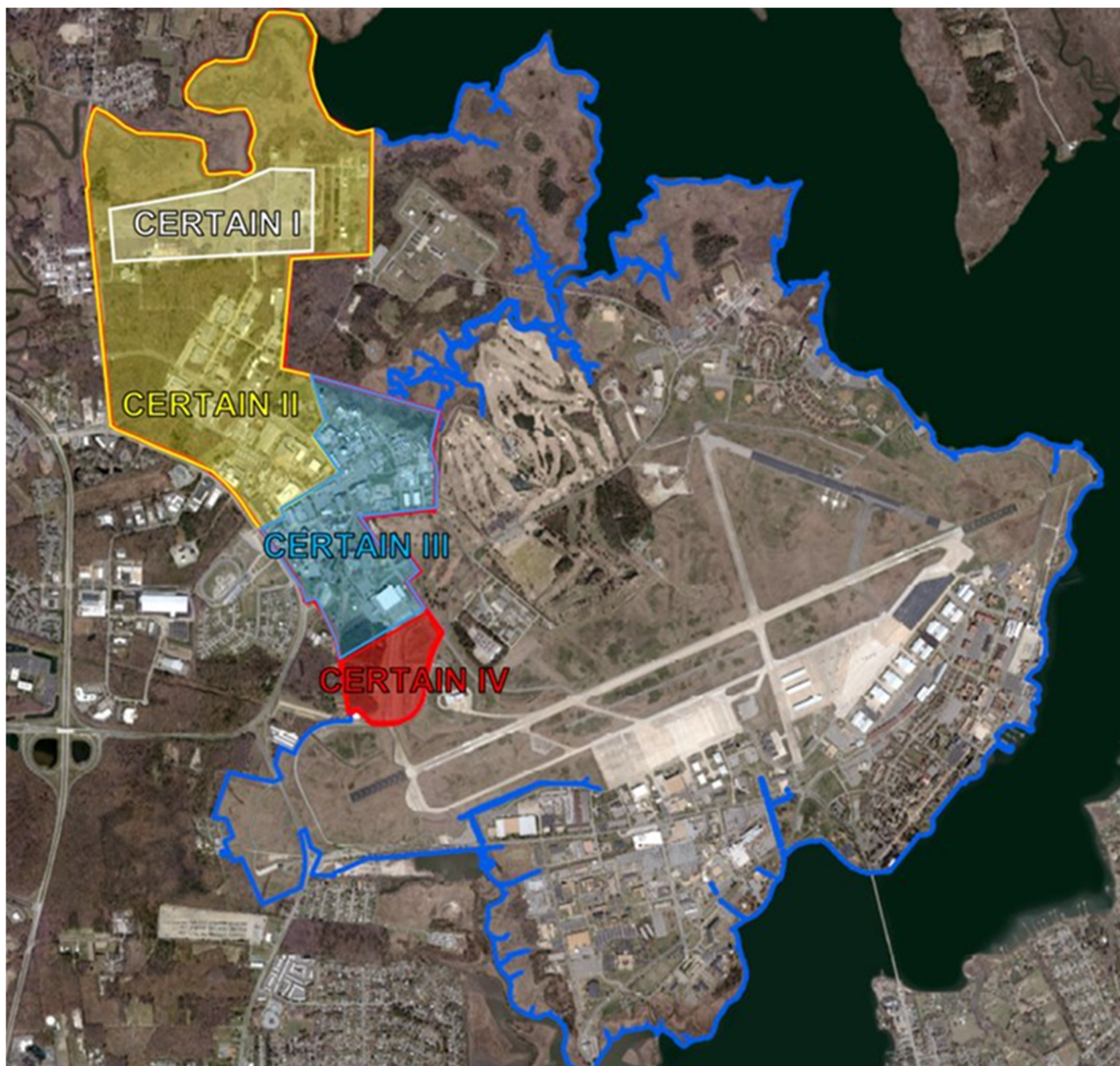


Figure A. Diagram of NASA Langley CERTAIN Range Flight Areas and Adjacent Langley Air Force Base Boundary

The entire CERTAIN Range is contained within the Langley Air Force Base Class D airspace volume. NASA Langley has a Federal Aviation Administration (FAA) Certificate of Authorization (COA) to conduct UAS operations in Class D airspace at or below 400 feet Above Ground Level (AGL) within the LAFB Class D airspace under the jurisdiction of Langley Air Force Base Airport Traffic Control Tower.⁷ Figure B shows the boundaries of CERTAIN relative to LAFB Class D Airspace. As part of the COA, NASA Langley established a Letter of Procedure (LOP) that establishes guidelines and identifies responsibilities for the safe, orderly, and expeditious operation of UAS in LAFB's Class D airspace, as well as provides instructions

⁷ 2024-ESA-14873-COA.v2 Certificate of Authorization to NASA (Waived Regulation 14 CFR §91.113(b) (BVLOS))

for operations of UAS when LAFB's Air Traffic Control Tower is closed. (Note: COA recently extended northeast, not shown in this figure.)



Figure B. Boundaries of CERTAIN Relative to LAFB Class D Airspace, outlined in red

The CERTAIN range supports pervasive use and safe integration of unmanned/autonomous flight systems and serves as a collaborative environment for advancing integrated autonomous ground and air systems with private industry, academia/institutions of higher learning, and other Federal and State Government Agencies.

The CERTAIN range includes two Operations Centers, airspace surveillance, command/control, voice communication, auxiliary navigation beacons, weather stations, Radio Frequency (RF) monitoring, application software, information systems, and drone cages. A reference for the CERTAIN range is provided in the footnote below⁸.

⁸ Matthew W. Coldsnow, "NASA Langley UAS Operations," Presentation for the WFF UAS Symposium, 10/16/2024. <https://ntrs.nasa.gov/citations/20240012433>

Comprehensive documentation used for FAA COA (2024-ESA-14873-COA.v2) may be found in the footnote below⁹.

⁹ Matthew W. Coldsnow, Louis J. Glaab, Jacob Revesz, Leslie O. Kagey, Robert G. McSwain, Jacob R. Schaefer, “Safety Case for Small Uncrewed Aircraft Systems (sUAS) Beyond Visual Line of Sight (BVLOS) Operations at NASA Langley Research Center,” NASA/TM–20230003007.

<https://ntrs.nasa.gov/api/citations/20230003007/downloads/NASA-TM-20230003007.pdf>

1.0 Capability Overview:

1.1 Airspace Surveillance Radar Systems

NASA Langley's ground-based radar surveillance is comprised of two independent pulsed Doppler-based systems. The first being Syracuse Research Corporation's (SRC) Lightweight Surveillance and Target Acquisition Radar (LSTAR) model AN/TPQ-49¹⁰ which NASA Langley obtained on loan from Ames Research Center, and the second is GroundAware's model GA-9120 purchased from Observation Without Limits (O.W.L.)^{TM11}. The LSTAR system provides a relatively large surveillance volume from a single unit given its semi omni-directional design allowing for 360° field-of-view (FOV) in azimuth. The GA-9120 system is a directional system with limited 120° FOV from a single radar panel. The GA-9120 system is expandable and may incorporate up to four radar panels connected to a single System Control Module (SCM), expanding the system's azimuth to 360°.

1.1.1 LSTAR Overview

NASA Langley implemented a single LSTAR system operating in the L-Band frequency range and provides a continuous, 360°, 3D surveillance using an electronically scanned, cylindrical phased array antenna. The antenna columns scan electronically in azimuth and use a pair of fixed-elevation beams that provide elevation coverage from the horizon to 30°. Both azimuth and elevation mono-pulse angle measurements are used to provide three-dimensional target coordinates (range, azimuth, and elevation). The system allows user-selectable transmitting frequency between 1215-1390 MHz in 1MHz increments. Detection and track data are sent via network connection to a computer and displayed to the user via SRC's Graphical User Interface (GUI) software.

SRC provided documentation for the LSTAR, which contains two basic operational setup configurations for its use¹², "Expeditionary Configuration" (Fig. 1-1) and "Fixed-Configuration" (Fig. 1-2). The expeditionary configuration allows for quick setup and removal of the system for basic field testing. This configuration served as a baseline for initial setup and testing and does protect against limited environmental conditions. However, it is not intended as a permanent installation method. After a series of initial flight tests were completed, NASA Langley implemented a more permanent fixed-site configuration. At the recommendation of SRC, NASA Langley installed the LSTAR's expeditionary configuration in a large fiberglass radome for improved long-term protection against environmental conditions.¹³

Detailed information about the NASA Langley LSTAR setup, commissioning, operation, and performance evaluation is provided in Section 3.

Detailed specifications for the LSTAR Radar are provided in Attachment 1, Table 6-3, "LSTAR Specifications".

¹⁰ <https://www.srcinc.com/products/radar/lstar-air-surveillance-radar.html>

¹¹ <https://owlknows.com/wp-content/uploads/2022/03/GA9120.pdf>

¹² Syracuse Research Corporation "Operator Guide for Radar Set LSTAR(V)2," May 4, 2015

¹³ Pacific Radomes Part # PR-128-SRC <https://www.pacificradomes.com/> or SRC Part Number SRC6443.



Figure 1-1. LSTAR "Expeditionary Configuration" Installed on NASA Langley Rooftop



Figure 1-2. LSTAR "Fixed-Configuration" Installed on NASA Langley Hanger

1.1.2 GA-9120 Overview

The GA-9120 is a 3D digital multi-beamforming radar system operating in the S-Band frequency range of 3.0-3.3GHz range whereby a single radar panel has a FOV of 120° in azimuth and 12.5° in elevation. Figure 1-3 shows a single GA-9120 panel setup during initial field tests at NASA Langley. NASA Langley currently implements two of these panels mounted in a “stacked” configuration (Fig. 1-4) with each arranged at a 90° offset in their respective headings, thereby increasing the system’s operational FOV in azimuth to 210°. Each GA-9120 panel is connected to the radar’s SCM via individual cables that contain both AC power and network data. The data

from each radar panel is synchronized within the SCM and displayed to the user over a client server connection.

Detailed information about the NASA Langley GA-9120 system setup, commissioning, operation, and performance evaluation is provided in Section 3.

Detailed specifications for the GA-9120 Radar are provided in Attachment 1, Table 6-4, GA-9120 Specifications.



Figure 1-3. GA-9120 (w/SCM mounted on rear of radar) – Initial Field Setup

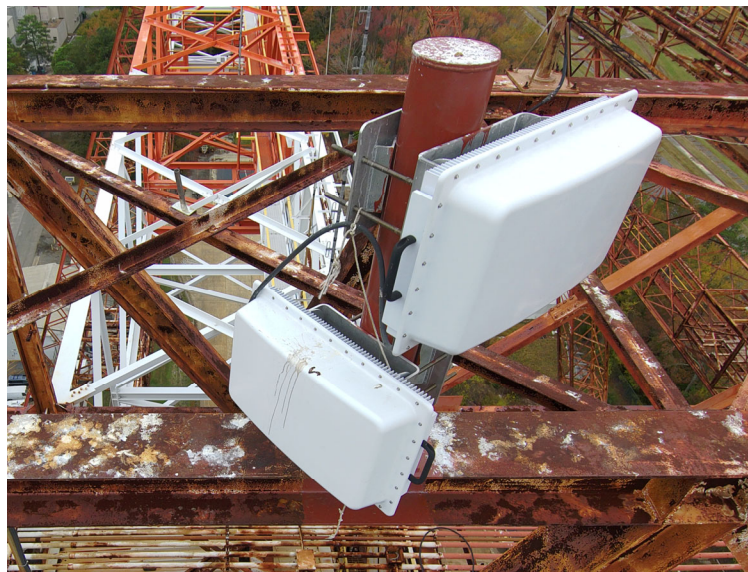


Figure 1-4. Dual GA-9120 Radars Installed on the NASA Langley Gantry¹⁴

¹⁴ J. Littell, “The NASA-Langley Gantry: A Visual History of Aircraft and Spacecraft Full-Scale Testing,” Goddard Space Flight Center Engineering Colloquium, 7/11/2023. <https://ntrs.nasa.gov/citations/20230008288>

1.1.3 Comparison of Specifications and Coverage of LSTAR and GA-9120s

A comparison of specifications for LSTAR and GA-9120s and a diagram of estimated radar coverage for General Aviation (GA) sized aircraft are provided in Table 1-1 and Figure 1-5. The table is compiled from more detailed information provided in Attachment 1, Sections 6.3 and 6.4. It's important to note that the primary NASA Langley requirement has been to detect and avoid GA sized aircraft that may not have operational Automatic Dependent Surveillance Broadcast (ADS-B) transponders installed, rather than to detect UAS.

Table 1-1. LSTAR and GA-9120 Specifications Comparison

Performance Parameter		LSTAR	GA-9120
Process Type		Pulsed Doppler	
Frequency		1215-1390 MHz	3150-3250 MHz
Transmit Power (Peak)		720 W	1000 W
Field of View	Azimuth	360°	120° (Single Panel)
	Elevation	0-30°	0-12.5°
Instrumented Range		26.8 NM*	8.0 NM
Detection Range (max.)	Large Aircraft (Cessna)	17.6 NM*	8.0 NM
	Small UAS (Phantom)	4.2 NM*	2.6 NM

* Based upon SRC's General Air Surveillance software

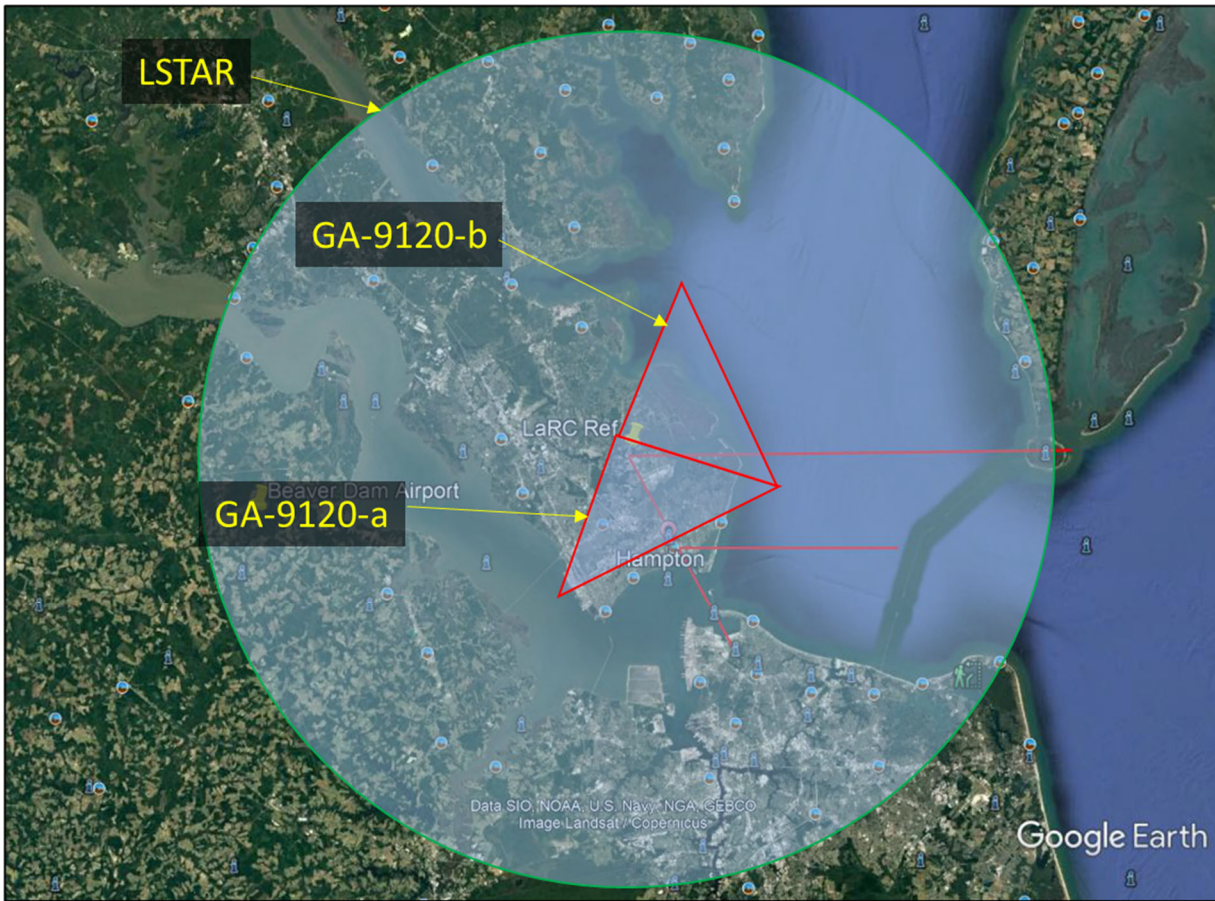


Figure 1-5. Map of NASA Langley LSTAR and GA-9120 Estimated Radar Coverage for General Aviation Sized Aircraft

1.1.4 Cooperative Airspace Sensors

In addition to the radar sensors to detect aircraft (i.e., LSTAR and dual GA-9120s), several other cooperative (i.e. non radar) surveillance sensors are also used:

- uAvionix¹⁵ “PingStation” Ground-based receivers are installed in multiple locations to identify ADS-B equipped aircraft. These ADS-B receivers are Power-Over Ethernet (PoE) type devices and are relatively easy to install. ADS-B receivers are installed on the NASA Langley Gantry¹⁶ as well as the roof of Building 1230.
- A DroneScout DS-230¹⁷ Ground-based Remote ID receiver is used to detect properly equipped drones.

¹⁵ uAvionix PingStation: <https://uavionix.com/products/pingstation-3/>

¹⁶Gantry - also known as the Landing and Impact Research Facility (LANDIR, <https://researchdirectoratelarc.nasa.gov/landing-and-impact-research-facility-landir/>) For more information see - J. Littell, “The NASA-Langley Gantry: A Visual History of Aircraft and Spacecraft Full-Scale Testing,” Goddard Space Flight Center Engineering Colloquium, 7/11/2023. <https://ntrs.nasa.gov/citations/20230008288>

¹⁷ DroneScout DS-230 Remote ID Receiver <https://dronescout.co/dronescout-remote-id-receiver/>

- A Flight Alarm (FLARM) collision warning system for properly equipped general aviation aircraft and drones¹⁸ is also used.

Figure 1-6 shows the locations of all NASA Langley airspace sensor locations. Figure 1-7 shows a photograph of the FLARM sensor installed on the CERTAIN Range Operations trailer (left) and the ADS-B sensor installed on the gantry.

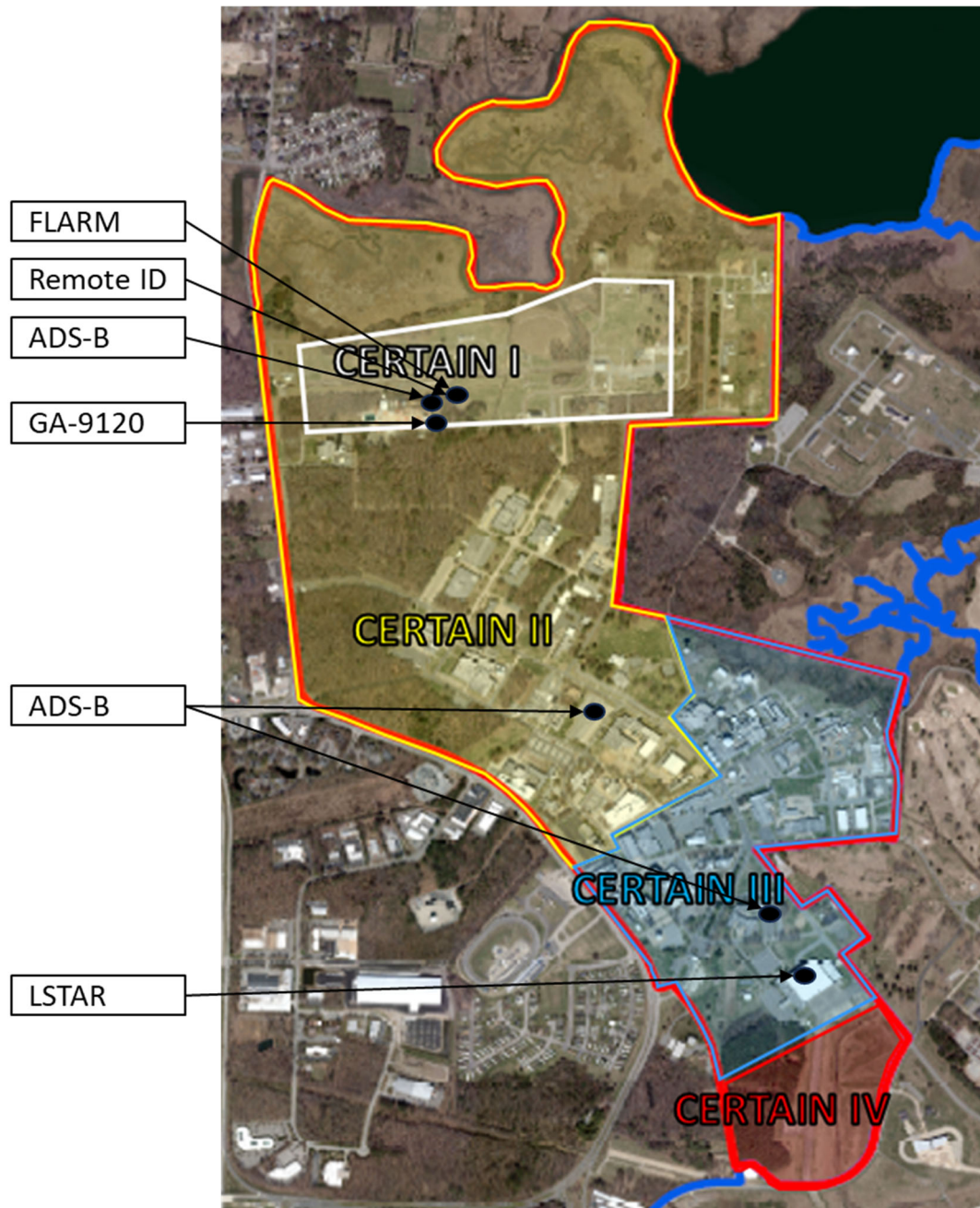


Figure 1-6. Map of NASA Langley Airspace Sensor Locations

¹⁸ Flight Alarm <https://www.flarm.com/en/>



Figure 1-7. FLARM Sensor (left) and ADS-B Sensor (right) Installed on CERTAIN Range

1.2 Mission Operations & Autonomous Integration Center (MOSAIC)

NASA Langley's airspace surveillance radars and other airspace sensors are operated from MOSAIC, which provides a centralized location from which to manage live and simulated multi-fleet BVLOS UAS flight operations conducted on the CERTAIN range (and nearby vicinity) in support of NASA operations and research.

MOSAIC, as illustrated in Figure 1-8, is a windowless UAS command center that does not require physical line of sight, comprised of three 85-inch up-front displays and six configurable computer stations with three monitors per station. MOSAIC is operated by the Simulation Development and Analysis Branch (SDAB) at NASA Langley.



Figure 1-8. The Mission Operations and Autonomous Integration Center (MOSAIC)

Each station in MOSAIC is highly reconfigurable and capable of acting as a UAS Ground Control station, Radar Operator station, Range Safety Officer station, Flight Test Lead station, Airspace Monitor station, or Mission Commander station. The three up-front displays can be reconfigured based on a given flight operation's needs and can display any view from any station. See Figure 1-9 for an overview of the current MOSAIC in the single-vehicle BVLOS configuration, and Attachment 1, Table 6-1 for a list of equipment at the MOSAIC stations.

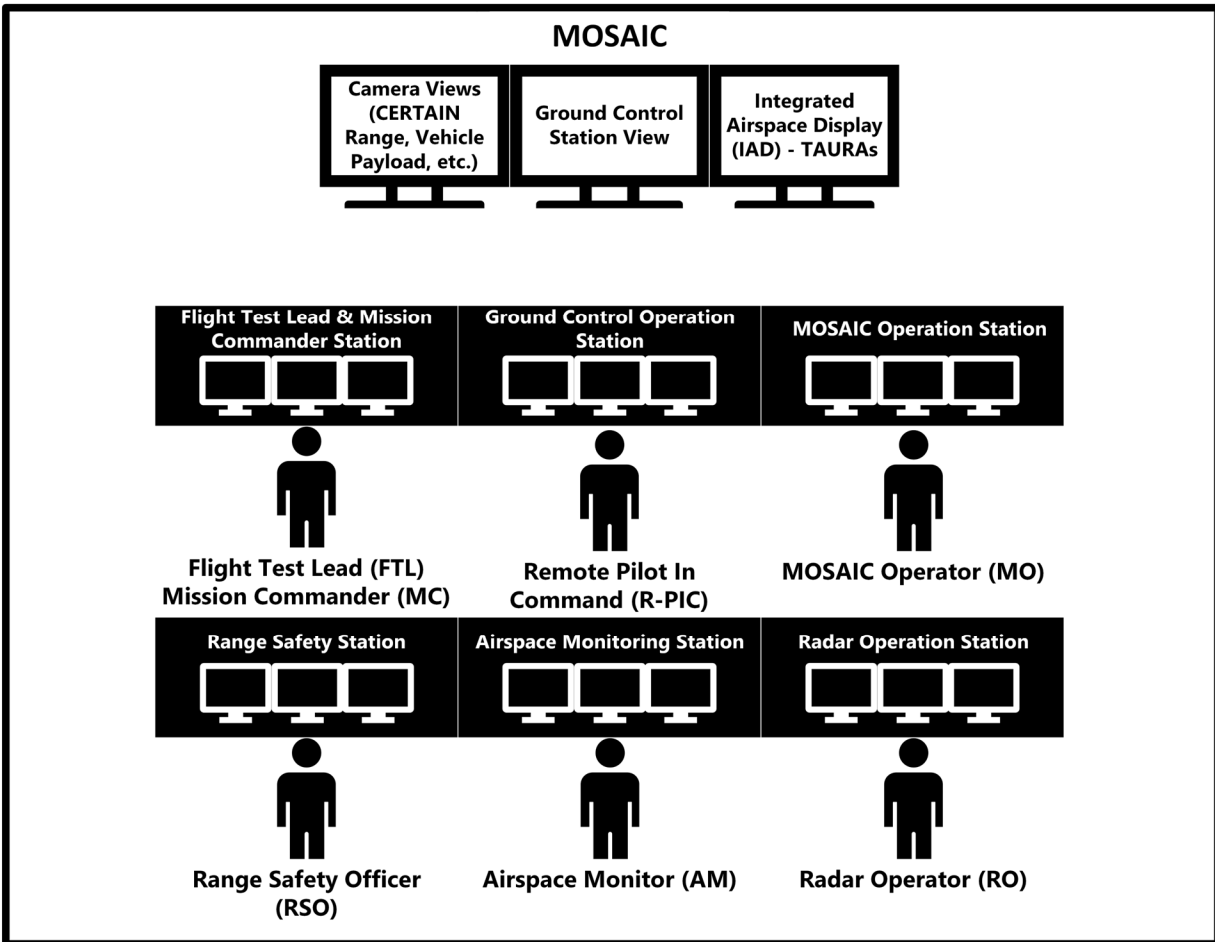


Figure 1-9. MOSAIC Crewmember Roles & Stations in the Single Vehicle BVLOS Configuration

Role Descriptions:

- Flight Test Lead (FTL): Responsible for all phases of flight activity for single-vehicle operations
- Mission Commander (MC): Responsible for all phases of flight activity for multi-vehicle operations
- Remote Pilot In Command (R-PIC): Responsible for the safe operation of the UAS by means of a Ground Control Station (GCS)
- MOSAIC Operator (MO): Responsible for the operation of all MOSAIC systems
- Range Safety Officer (RSO): Responsible for the safe conduct of the mission; gives final approval prior to each flight operation.
- Airspace Monitor (AM): Responsible for monitoring airspace to ensure noninterference between crewed and uncrewed aircraft
- Radar Operator (RO): Responsible for the operation of multiple radars; interprets radar results

Station Descriptions:

- Flight Test Lead & Mission Commander Station: Pre-flight & Post-flight checklists, test cards, UAS Mission Analysis Tool (UMAT¹⁹)
- Ground Control Operation Station: Ground Control Station software, primary and redundant vehicle command and control (C2) link, vehicle telemetry & data link, cellular-enabled Tablet (redundant vehicle link), and vehicle payload camera
- MOSAIC Operation Station: MOSAIC display configuration software, communications configuration software, server processes access
- Range Safety Station: Foreflight software, FAA Airspace Awareness and Detection System (AADS), UAS range cameras, NOTAM²⁰ system, Langley Air Force Base Air Traffic Control (ATC) radio
- Airspace Monitoring Station: Airspace Awareness Display - the Traffic Awareness and Ubiquitous Real-time Airspace Surveillance (TAURAS) utility
- Radar Operation Station: LSTAR Multi-Mode Graphical User Interface (GUI), GA-9120 Browser User Interface (BUI)

MOSAIC is a standalone facility with dedicated computing, video, audio, network, and storage resources located in an adjacent server room. The interconnections between MOSAIC and the MOSAIC server room facilitate video routing from the desktop displays to the up-front displays, audio routing for local and remote crewmember communications, network traffic routing for MOSAIC PC internet connections, radar data ingestion, real-time storage access, and backup of flight critical systems. See Figure 1-10 for the MOSAIC distribution diagram and Attachment 1, Table 6-2 for a list of equipment that comprises MOSAIC's server room.

¹⁹ Bill Buck "Concept, Design, & Implementation of a Remote Vehicle Operations Center for Autonomous Missions," NASA/TP-20240001820, 11/1/2024. <https://ntrs.nasa.gov/citations/20240001820> for UMAT, See Sec. 7.10

²⁰ Notice to Airmen. See https://www.faa.gov/about/initiatives/notam/what_is_a_notam

1.3 The Remote Operations for Autonomous Missions (ROAM) UAS Operations Center

The NASA Langley Remote Operations for Autonomous Missions (ROAM) UAS Operations Center uses a live, virtual, and constructive environment to conduct BVLOS operation of UAS vehicles and is operated by the Crew Systems and Aviation Operations Branch in the Research Directorate. NASA/TP-20240001820²¹ describes the development of the ROAM UAS Operations Center from concept through design and implementation. Radar operations on the CERTAIN range, supporting ROAM are typically conducted through MOSAIC. This section provides a limited overview of ROAM for context of its airspace surveillance capability at NASA Langley.

ROAM offers a unique capability to research advanced onboard technologies, explore air-ground technology integration, and perform human-in-the-loop experiments exploring different roles and responsibilities of remote operators managing multiple autonomous vehicles. ROAM research informs human-autonomy teaming concepts that enables m:N operations (i.e., m operators controlling N vehicles). Use cases tested using the facility focus on UAS operations (e.g., package and food delivery, emergency response surveillance and reconnaissance) and passenger-carrying operations (i.e., urban air mobility). As BVLOS operations increase, it's important to understand how humans can effectively team with autonomy in a manner that supports user business models.

The overarching design considerations for the operations center are to relocate existing field operators to the remote vehicle operation center, produce a shared situational awareness environment for participating personnel, and to provide the ability to pursue advanced vehicle operations and control supporting Advanced Air Mobility and other various research activities. The remote operations center is envisioned to provide a user training environment, flight operations planning and briefing environment, and a research facility for simulated and live operations of UAS vehicles. A part of flight operation considerations is safety of flight for the vehicle, the local airspace, and people on the ground below and near the vehicle's flight path. Safety considerations and constraints are driven by project requirements and existing NASA policies, procedures, and regulations. The overall purpose of the ROAM UAS Operations Center and its design is to support the functional transition from Field Control to Operations Center Control of UAS.

ROAM operations in NASA Langley airspace depend upon radar capabilities, setup, operation and data flows described within this report.

1.4 Airspace Surveillance Sensor Data Sharing

Dissemination of real-time radar data between NASA and its partners is facilitated by the NASA Internet of Things (IoT) Platform. (More details provided in Attachment 3.)

The NASA IoT Platform provides cloud services to accelerate development of IoT solutions and to provide a secure enterprise-scale environment for operation of NASA-developed IoT and IoT-like systems. The primary components of the NASA IoT Platform are a publish/subscribe MQTT

²¹ Bill Buck "Concept, Design, & Implementation of a Remote Vehicle Operations Center for Autonomous Missions," NASA/TP-20240001820, 11/1/2024. <https://ntrs.nasa.gov/citations/20240001820>.

message broker (Mosquitto)²², a time-series database (InfluxDB)²³, a web-based dashboard and analytics platform (Grafana)²⁴, and a data routing agent (Telegraf)²⁵. These components are fully containerized and operate within a Kubernetes²⁶ environment, are deployed to the Google commercial cloud to be accessible outside the NASA firewall, are protected by both KeyCloak²⁷ federation-capable Identity and Access Management²⁸ (IAM) web logins and X.509 certificate-based MQTT authentication, and implement Transport Layer Security (TLS) 1.2 or greater transport encryption for all interfaces. A detailed description of the NASA IoT Platform is provided in Attachment 3, and a diagram of the high-level architecture is provided in Fig.1-11.

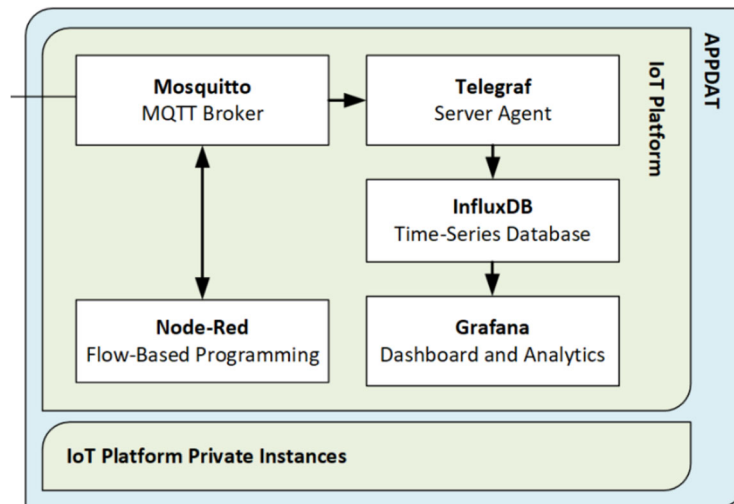


Figure 1-11. NASA IoT Platform High Level Architecture

The NASA IoT Platform supports the NASA Langley CERTAIN environment by facilitating secure streaming data connections between NASA and external partner information systems. Assuming partners have an appropriate data sharing and system use agreement in place, NASA is able to provide partners with MQTT authentication certificates for the IoT Platform. These certificates allow partners to publish data to MQTT endpoints in the commercial cloud without the burden of changing center firewall rules and the risk of exposing internal NASA systems. Internal NASA systems are then able to subscribe to these data feeds for further processing or ingestion into other systems. This method of data sharing is bidirectional, allowing for both sharing of NASA data with external partners and sharing between some or all partners, as desired.

The NASA Langley CERTAIN range currently uses the NASA IoT Platform to securely ingest live radar streams from a Skyler-2²⁹ radar system (owned by Longbow Group³⁰) to NASA's ANRA Smart Skies Control system (ANRA SS CTR, described in Sec. 1.6.2) and the TAURAS utility (described in Sec. 1.6.1). The NASA partner is responsible for development and operation

²² MQTT - <https://mosquitto.org/>

²³ InfluxDB - <https://docs.influxdata.com/influxdb/>

²⁴ Grafana - <https://grafana.com/docs/>

²⁵ Telegraf - <https://docs.influxdata.com/telegraf/>

²⁶ Kubernetes - <https://kubernetes.io/>

²⁷ KeyCloak - <https://www.keycloak.org/>

²⁸ IAM - <https://www.microsoft.com/en-us/security/business/security-101/what-is-identity-access-management-iam>

²⁹ <https://www.collinsaerospace.com/what-we-do/industries/air-traffic-management/surveillance/skyler>

³⁰ Longbow Group: <https://thelongbowgroup.com/> SAA1-34272 A1,2,3

of the component which serializes the Skyler-2 radar feed and publishes the data to the IoT Platform's MQTT endpoint. NASA is then responsible for the client which subscribes to this data stream, decoding the data, and ingesting it into the internal Fusion Engine data aggregation system. A diagram of Skyler-2 and other radar integration with ANRA SS CTR onto the NASA network is provided in Fig. 1-12, and a photograph of the Skyler-2 installation is provided in Fig. 1-13.

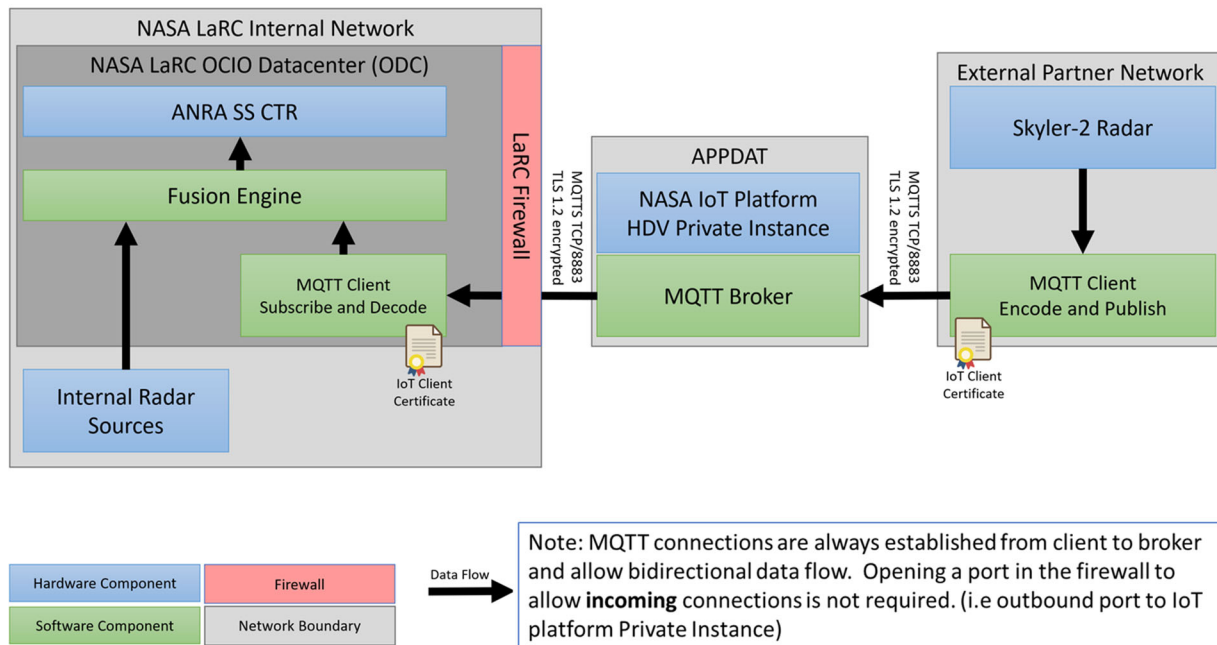


Figure 1-12. Skyler-2 Radar Integration with ANRA SS CTR Leveraging the NASA IoT Platform



Figure 1-13. Skyler-2 Radar Installed Atop Hampton Harbour Centre

1.4.1 Airspace Sensor Data Sharing – Next Steps

The NASA IoT platform may be used to exchange real-time radar data feeds (ASTERIX format) to NASA Partners via subscription certificates. Data sharing can be customized/isolated between various partners at the Controlled Unclassified Information (CUI) level. Resources have been allocated to establish import and export IoT data feeds to regional and national NASA partners.

The Virginia Flight Information eXchange (VA-FIX) is an information hub focused on providing authoritative state and local data and is part of a public digital infrastructure vision for AAM.³¹ Data from various airspace sensors may be fed into VA-FIX via an Application Programming Interface (API) Access Agreement. Some resources have been allocated to begin integration of VA-FIX into NASA Langley airspace operations and to publish NASA Langley radar feeds to VA-FIX.

Because TAURAS is government developed and government owned, it serves as an ideal platform to test the import and display of airspace surveillance data feeds (i.e. NASA IoT and VA-FIX) among NASA Partners. NASA partners have requested executable versions of TAURAS, along with software release, interface documentation and user's guide. TAURAS provides a unique tool for evaluating the fusion of existing sensor deployments along with novel, new sensor technologies in an operational environment. Some resources have been allocated to develop these new capabilities.

1.5 Interconnection diagram/IT Security

NASA Langley's Smart Center airspace surveillance and operations capability is comprised of several interconnected systems, both internal and external to the Center, whose interconnections enable UAS operations within and beyond the CERTAIN Range. See Fig. 1-14 for an overview of interconnections between these systems.

³¹ <https://virginiafix.com/index.html>

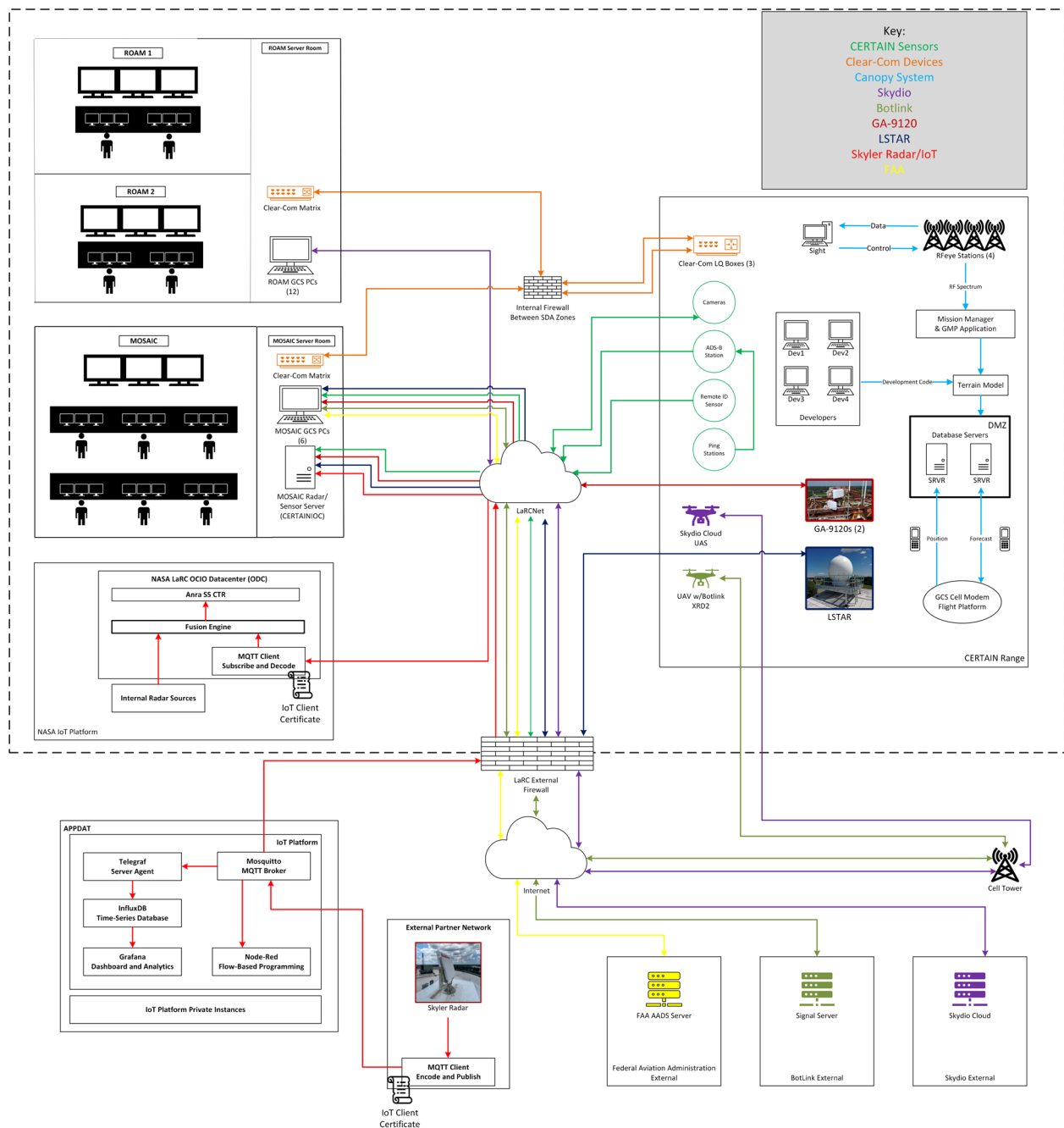


Figure 1-14. NASA Langley CERTAIN Boundary Diagram³²

³² This diagram is for reference only. For more information contact NASA Langley's Simulation Development and Analysis Branch:

https://flightsimulation.larc.nasa.gov/contact/?doing_wp_cron=1746218959.2258079051971435546875

1.6 Airspace Surveillance Software

Display of the surveillance data is accomplished using separate displays for each airspace surveillance sensor as well as two different Integrated Airspace surveillance Display (IAD) applications –TAURAS and ANRA SS CTR.

1.6.1 *Traffic Awareness and Ubiquitous Real-time Airspace Surveillance (TAURAS)*

The TAURAS utility, developed by the Simulation Development and Analysis Branch (SDAB), is designed for real-time airspace and traffic monitoring using the various traffic sensors positioned on or near the area of interest. It incorporates all airspace traffic data into a single graphical display visible in a web browser. The interactive display (shown in Figure 1-15) allows the user to reposition the map and zoom to areas of interest. Currently, TAURAS displays ADS-B, radar, GA-9120, and FLARM targets as detected by the PingStation³³/Sunhillo³⁴, LSTAR/Skyler, GA-9120, and FLARM devices respectively. Targets are removed from the display after no update has been received for 30 seconds. TAURAS offers user-defined horizontal and vertical range filtering, and layer control. Layer control allows for enabling and disabling the display of a particular sensor. Target symbology is color-coded for easy sensor identification, and a color-matched Aircraft Data Label is placed next to each target display's Callsign, Mode-S Identifier (per International Civil Aviation Organization requirements), altitude, and airspeed; the display of these labels is toggleable. "Breadcrumbs" are placed behind the targets to indicate their past positions as received by TAURAS in the last 30 seconds. Layer control allows for enabling and disabling the display of a particular sensor. TAURAS displays 3 and 5 Nautical Mile (NM) range rings centered at NASA Langley and provides visual alerts for targets. More detail about operation of TAURAS is provided in Section 4.1.3 (TAURAS Operation).

³³ <https://uavionix.com/products/pingstation-3/> ADS-B receiver located on NASA Langley Gantry

³⁴ <https://www.sunhillo.com/solutions-ads-b/> ADS-B receiver located on Longbow facility in Hampton, VA

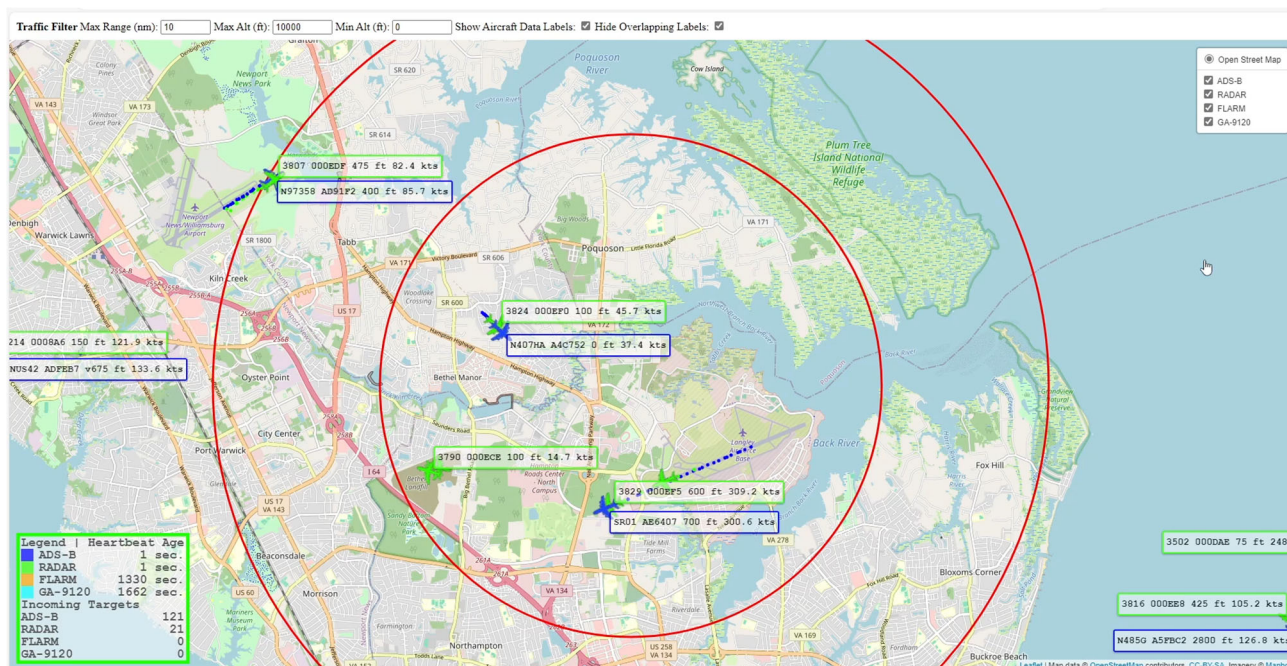


Figure 1-15. Sample TAURAS display

1.6.2 ANRA Smart Skies Control System (ANRA SS CTR)

The ANRA SS CTR System is a commercially available airspace management tool which provides data fusion for targets detected in and around NASA Langley's airspace³⁵. ANRA SS CTR is an alternative to in-house developed TAURAS, and has been further developed under contract to meet NASA specific flight mission requirements. ANRA SS CTR is typically used in ROAM, whereas TAURAS is exclusively used in MOSAIC. ANRA SS CTR is deployed as a server that provides credentialed secure access for multiple clients on NASA Langley's campus network "LaRCNet". The clients include applications that provide surveillance data feeds and secure browser-based display of operations in a geographic area. The fusion processor ingests live data feeds from local FLARM, 1090/978 MHz ADS-B ground-based receivers, Asterix format³⁶ radar data (LSTAR & GA-9120) into a single weighted average target position. This fused data output is available for view in the form of traffic targets with data tags on an interactable map within a web browser. Other clients can access the processed traffic data by subscribing to message topics with an MQTT broker. The same sensor feed client supports the NASA Langley CERTAIN Range simulation environment³⁷ which generates ADS-B and radar targets for use with UAS simulation scenarios involving autonomous technologies in air traffic avoidance. ANRA SS CTR was selected to serve as an IAD for NASA's High Density Vertiplex (HDV) sub-project due to ANRA SS CTR's ability to perform multi-sensor fusion and provide displays appropriate for UAS operations. Figure 1-16 illustrates a high traffic day during HDV operations showing ADS-B, Radar, and FLARM associated targets.

³⁵ ANRA Technologies Website: <https://www.anratechnologies.com>

³⁶ Asterix: All-purpose structured EUROCONTROL surveillance information exchange data format: <https://www.eurocontrol.int/asterix>

³⁷ UAS - Simulation Integration and Validation Lab. For more details, see https://www.nasa.gov/wp-content/uploads/2021/03/larc_flight_simulation.pdf

2.0 Procurement:

This section provides the motivations, rationale, and costs for the LSTAR, GA-9120, and interface hardware existing today at NASA Langley.

2.1 Project Background

In the Spring of 2020, the HDV subproject of the Advanced Air Mobility (AAM) project⁴⁰ within the Airspace Operations and Safety Program was undergoing project formulation. The HDV subproject objectives were to prototype and test an Urban Air Mobility (UAM) ecosystem that included representative onboard autonomous systems, ground control/fleet management systems, and air traffic management systems, along with vertiport automation systems. A phased spiral approach was taken to build up the elements of the UAM Ecosystem and leveraged small UAS (sUAS, i.e. less than 55 lbs.) as technological surrogates for the larger UAM vehicles. A separate thrust within HDV was to perform integrated autonomous system testing and safety risk assessments to produce results to accelerate UAS BVLOS operations. Within this construct, the results from HDV supported both UAM as well as UAS technological advancement thrusts.

The HDV subproject had a series of schedule work packages to progressively expand and test the fidelity and complexity of the UAM Ecosystem prototype. Each schedule of the planned three work packages lasted approximately 14 months with several months of overlap. The first phase was referred to as Advanced Onboard Autonomy and established representative prototypes for envisioned UAM vehicles and integrated airspace management systems, along with initial ground control/fleet management systems. Vertiport automation systems were very basic and provided some representative functionality and control for the vertiport manager.

The second scheduled work package was referred to as Scalable Autonomous Operations (SAO) and greatly expanded the vertiport automation system as well as added to the other UAM Ecosystem prototype elements. One of the objectives for HDV was to perform multi-vehicle BVLOS operations within the SAO schedule work package during the summer of 2023. It was identified that to perform no visual observer BVLOS (“NOVO”-BVLOS) operations, an air traffic surveillance system would be required. Initial analysis established that if an incoming aircraft assumed to be traveling 120 kts was heading directly at the operations area, and a 2-minute alert time was required to secure sUAS vehicles, then an approximate 5 NM operational surveillance area was required. This 5 NM area was defined as the LaRC Monitoring Volume (LMV) and plans proceeded to provide surveillance systems to cover this airspace volume.

Unfortunately, the HDV subproject was canceled prior to initiating the following scheduled work package “Vertiplex Operations” at the end of Fiscal Year 2023.

2.2 Radar Systems

In 2020, review of available radar systems was performed in consultation with the Virginia Tech Mid-Atlantic Aviation Partnership (MAAP) to support coverage of the LMV. Given available formulation resources, the GA-9120 radar (see Sec. 1.1.2) was selected to provide surveillance

⁴⁰ Jeffrey Homola “AAM PROJECT: HIGH DENSITY VERTIPLEX (HDV) Research and Capabilities”
https://ntrs.nasa.gov/api/citations/20230003243/downloads/AAMWG_CommunityIntegration-HDV.pdf

for non-cooperative (i.e., non-position reporting/ADS-B equipped) aircraft. Reasons for the selection included that the GA-9120 was a panel mount type of radar that did not require full 360° FOV from a single location and that the radar panels were effectively scalable enabling the complete system to be procured in phases. In 2020, two of the envisioned four required panels were procured with available funds for \$125,000 each, and subsequently mounted on the Gantry. The cost of installation for these two radar panels at NASA Langley was \$100,000. A third GA-9120 panel was procured in 2021 but was loaned to NASA Ames Research Center (ARC). The GA-9120 radars could detect GA size aircraft at 8 NM according to manufacturer's specifications.

In addition to the GA-9120s, it was identified that NASA ARC had acquired 8 decommissioned LSTAR radars (see Sec. 1.1.1) from the US Army. LSTAR radar systems had been used extensively by NASA Goddard Flight Research Center's Wallops Flight Facility and NASA ARC with proven performance and reliability metrics. The LSTAR's performance specifications aligned with the requirements necessary for providing airspace situational awareness to the UAS flight team to support BVLOS surveillance around NASA Langley's CERTAIN flight test range. The project's operational requirement for ground-based radar was to detect and track GA size aircraft within a radius of 5 NM at altitudes between 200 and 2500 ft. The LSTAR has an instrumented range of approximately 21.5 NM and provides a FOV necessary to cover the above-mentioned research requirements. The original cost of an LSTAR unit was approximately \$1M, but because decommissioned units were available, NASA Langley only needed to cover refurbishment cost (SN 175 \$56k, SN 364 \$78k). Cost of installation atop the NASA Langley hangar was \$250k.

In practice today, the GA-9120 systems can be used to cover the blind spot over the LSTAR, thereby supplementing the coverage area. The GA-9120's are designed to detect and track both GA aircraft and sUAS, operating at a shorter wavelength than the LSTAR. However, with the primary focus being on tracking GA aircraft, NASA Langley's GA-9120 system has not yet been configured to fully optimize for tracking sUAS. The LSTAR manufacturer SRC has developed a UAS software package that allows the LSTAR to detect and track sUAS. This capability has not yet been tested at NASA Langley, as the primary requirement has been to detect and avoid GA aircraft that may not have operational ADS-B transponders.

In terms of total procurement and labor, NASA Langley projects have invested nearly \$2M in refurbishments, updates, installations, evaluation flights, FAA Waiver, and NASA Airworthiness approvals for the LSTAR and interdependent airspace surveillance systems. This work was accomplished over several years.

2.3 Interface Hardware

Initially, airspace surveillance data was ingested by a Linux based Hewlett Packard Enterprise (HPE) DL380 Gen 9 server⁴¹ in the SDAB data center, which allowed radar data to be routed over SDAB's internal network to machines running TAURAS for development and testing. As the Gen 9 server was one of SDAB's core servers, the TAURAS interface was moved to a dedicated server in the form of an HPE DL360 Gen 11⁴² (Attachment 1, Table 6-2, item no. 10).

⁴¹ https://support.hpe.com/connect/s/product?language=en_US&kmppmoid=7252836

⁴² https://support.hpe.com/connect/s/product?language=en_US&kmppmoid=1014696065&tab=manuals&cep=on

Cost of this server was \$14k. The use of a dedicated machine enables MOSAIC to function independently while providing necessary redundancy, system backup to the MOSAIC Storage Area Network (SAN) (Attachment 1, Table 6-2, item no. 11), and reliable up-time for flight critical utilities.

3.0 Radar System Commissioning (Initial Installation & Setup):

3.1 Radar Physical Installation Requirements

In general, radar systems require clear line-of-sight of their intended surveillance volume. When selecting an installation site, it's important to address potential RF interference sources and obstructions that may interfere with the radar's performance. To minimize installation costs, existing facilities were evaluated as to their abilities to provide/meet basic radar surveillance requirements related to their structural and electrical requirements. NASA Langley also considered accessibility for performing any required maintenance while maximizing radar height above the ground, thereby providing the most unobstructed view possible of the airspace.

3.2 RF Authorization

LSTAR and GA-9120 operate in RF bands that require authorization by the National Telecommunications and Information Administration (NTIA – Federal Government users) or Federal Communications Commission (FCC – Non-Federal users). At NASA Langley, RF transmitters must be evaluated by the Spectrum Management Office and Radiation Safety Office and approved before purchase and use. The RF Authorization (RFA) process includes review of the national RF database to select specific operational frequency channels to be used, specific installation site parameters (latitude, longitude, altitude, antenna type & height, system settings, responsible person, etc.), and coordination across the government, so that likelihood of interference is minimized. RFAs and Radiation Safety Permits were obtained prior to operation of the LSTAR and GA-9120 at NASA Langley⁴³.

3.3 Radar Locations, Mounting and Weight

The rooftop of NASA Langley's aircraft hangar facility was selected as the installation site for the LSTAR (and radome, shown in **Error! Reference source not found.**). This location provided an unobstructed view of local airspace. The radome was installed on a 15.5 ft square steel platform. Using a crane, the steel platform was lifted into place on the hangar's roof with the LSTAR radar (packed in transportation cases) secured to the platform during the lift. The platform's four support columns were then welded to the hangar's existing truss structure. Electrical conduit penetrations for AC power and network connections were routed through the radome floor near the center to minimize cable trip hazards when working around the radar. Regarding installation, please note the following points:

- LSTAR Handrails – When installing a radar system on a platform that requires handrails, it is recommended that they are made of composite material so as not to interfere with the

⁴³ LSTAR RFA NASA212004 (1249MHz). GA-9120 FCC ID QFS001-1004439 (3148-3211 MHz), Safety Permit NIR-533 3-2023.

radar's performance. NASA Langley's LSTAR platform handrails are steel but have not adversely impacted performance of intended operations.

- LSTAR Azimuth Landmark – SRC recommends that the alignment of the radome access door with a known landmark be greater than 300 meters (minimum of 100 meters) away for optical bore sighting to determine the radar's heading. NASA Langley's alignment landmark was at a distance greater than 400 meters. Since the radar uses this information to calculate the offset between the radar's beam and True North, increasing this distance improves the radar's azimuth accuracy.

NASA Langley's LSTAR is installed at 107 ft height above ground level (measured from the center of the LSTAR's radially mounted antenna columns). The combined weight of the LSTAR and radome assembly is approximately 592 lbs. (Individually, the LSTAR weighs 192 lbs and the radome weighs 400 lbs.)

Additionally, the LSTAR provides elevation coverage between the horizon and 30°, and thus has a "Cone of Silence"⁴⁴ volume directly overhead. The GA-9120 installation site was selected to provide coverage of airspace directly above the LSTAR.

Two GA-9120 radar panels were installed on top of NASA Langley's Gantry (see Fig. 1-4). This structure was chosen for its overall height above ground level at >240 ft, providing for an unhampered view of the airspace. The radar panels were installed in an "over-under" configuration, with each panel's emplacement heading 90° relative to the other, on a custom designed support structure that was bolted to the Gantry. This mounting configuration provided a 30° overlap in their respective azimuth angles, providing a total radar surveillance of 210° in azimuth. Using angular mounts purchased from O.W.L., NASA Langley chose fixed installation elevation angles for the two GA-9120 panels that differed by 5°. The northeast facing panel has a fixed elevation angle of 0° from the horizon and the southeast facing panel (which faces the LSTAR) has a fixed elevation of +5°. This increase in elevation angle provided better coverage over the LSTAR while providing less radar reflections ("scatter") from ground-based targets. The northeast panel faces out over the marsh where ground reflections are less of a problem. The heading for each radar panel was determined using optical sighting methods to align each radar to a known landmark. The GA-9120 does not provide internal capability for determining the radar's latitude and longitude coordinates, so a handheld Global Positioning System (GPS) unit was used. Emplacement heading information for each panel was obtained using an optical scope to reference to a known landmark. The radars' installed heights above ground were determined from facility and custom hardware mechanical drawings. This positional information was used later in the setup process of the system. The weight of each radar panel from the manufacturer is approximately 90 lbs and the mounting hardware adds 30 lbs per panel.

3.4 Radar Power

The LSTAR is powered by the manufacturer-provided AC-DC power supply that outputs 26 Volts of Direct Current (VDC) to the radar. The power supply's AC input is rated at 90-130/180-260 Volts of Alternating Current (VAC) and NASA Langley is powering this unit from 120 VAC on a 15A circuit breaker. The power supply (co-located under the LSTAR) is plugged into

⁴⁴ "Cone of Silence" describes the volume that is not illuminated by a rotating monostatic radar, and thereby not providing detection of targets in that volume.

a Ground Fault Circuit Interrupt (GFCI) outlet via a National Electrical Manufacturers Association (NEMA) 5-15A plug. The GFCI outlet was installed within the radome such that the outlet penetrated the floor underneath the tripod supporting the LSTAR, which made for a cleaner install and reduced trip hazards when needing to work within the radome.

The individual GA-9120 radar panels are rated at 200 W power draw at 120 VAC and each panel is connected to the SCM through individual cables. These cables contain both AC power and network data between each radar panel and the SCM. Main system power was initially fed to the SCM via a NEMA 5-15A plug connected to a GFCI Outlet. NASA Langley has recently opted for a hardwired connection, thereby removing the GFCI outlet and plug, powering the SCM directly through a single 15A 120 VAC circuit breaker. This change was made due to possible moisture accumulation within the electrical outlet resulting in frequent tripping of the GFCI.

3.5 Radar Data Interfaces

Network traffic between the radar systems and the end-user devices that host the manufacturer supplied GUIs is conducted over NASA Langley's campus network, "LaRCNet". Connections to LaRCNet take the form of Cat5e/Cat6 ethernet patch cord connections between the radars and designated ethernet drops and/or switches.

3.5.1 *LSTAR Data Interfaces*

The LSTAR has power and data connections on the bottom of the unit's central cylinder enclosure. LaRCNet is connected to the port labeled "ENET". When connecting the LSTAR directly to a local computer, a crossover Ethernet cable is required.

3.5.2 *GA-9120 Data Interfaces*

The GA-9120 radar panels are installed about 25 feet above where the SCM is mounted. While access to the SCM is rarely necessary under normal operation, it is recommended that the SCM be mounted such that routine maintenance can be performed (i.e., annual cleaning of cooling inlet filter if mounted outside). During the system install, each radar cable was connected between the individual panel and their respective channels (R1, R2) on the SCM (See Fig. 3-1). The GA-9120 system uses the SCM to communicate directly with individual radar panels. Each Radar panel has two Ethernet cables within the one cable – one Ethernet cable connects to a synchronizer within the SCM, and one Ethernet connection connects directly to the SCM computer. The synchronizer is used to sync data from multiple Radar panels (up to 3). Radar panels are assigned individual network addresses on the SCM subnet (i.e., individual radar panels are *not* on LaRCNet). The SCM's AC power was hardwired and the Ethernet cable to LaRCNet was connected to Port 0 on the SCM's computer (Nuvo 7006LP-PoE), as typically users access the system on Port 0 or Port 7 of the SCM computer (see Fig. 3-2).

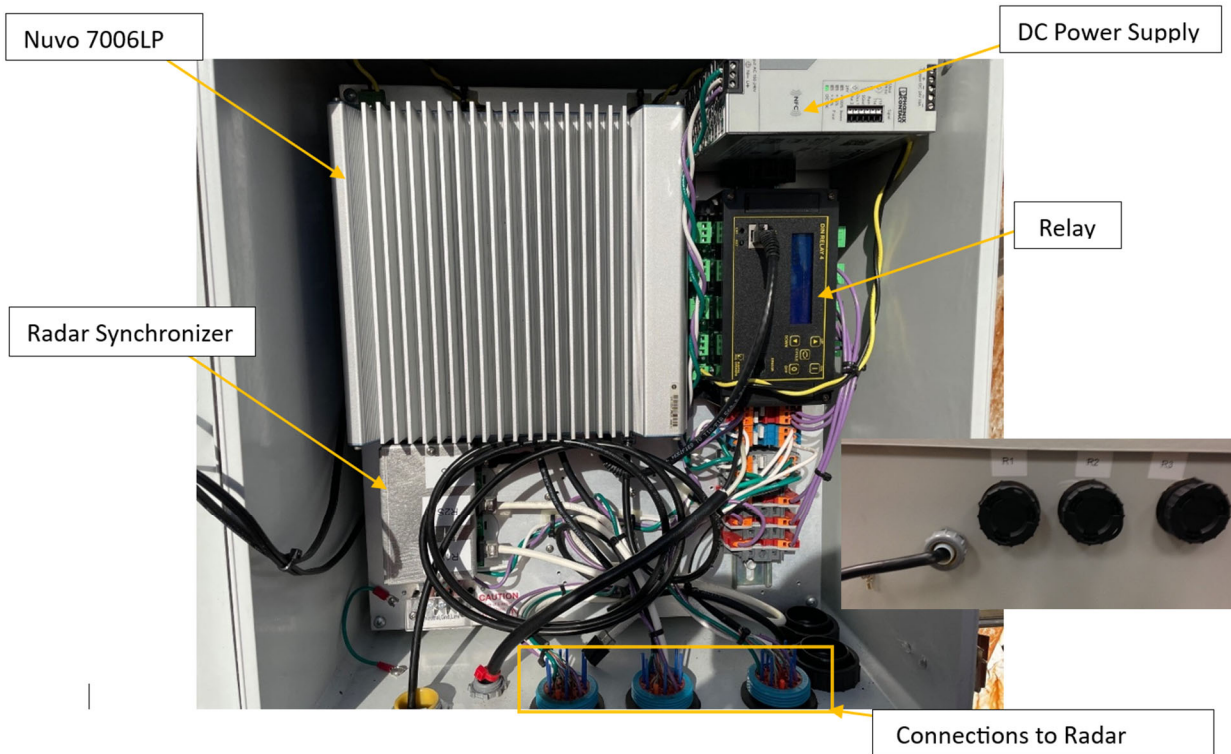


Figure 3-1. GA-9120 SCM Layout (inset photo shows external connections for 3 radar panels)



Figure 3-2. SCM Computer – Model: Nuvo 7006LP-PoE

3.5.3 *LaRCNet Firewall Requirements for LSTAR and GA-9120*

LaRCNet is a Software-Defined Access (SDA) network comprised of several network fabric zones with varying base configurations, firewall rules, and access lists. Devices on different segments of the SDA may require firewall rule changes to properly communicate.

Further, the network traffic between the radars and the servers that ingest and distribute radar data to TAURAS & ANRA Smart Skies for real-time utilization and archiving is conducted over LaRCNet.

The Radar GUIs and servers that ingest and distribute radar data to TAURAS and ANRA for real-time utilization and archiving utilize several communication protocols over designated or user-configurable ports as described in Tables 3-1 and 3-2. Once network traffic is permitted, end-user devices will be able to connect to the radars. Scripts for data ingestion, translation, recording, and distribution were developed using the manufacturer supplied Interface Control Documents and run on the radar data ingestion and distribution server in MOSAIC, the CERTAIN Input/Output Concentrator (CERTAINIOC), to enable the function of TAURAS and the long-term storage and archiving of radar detection and track data. Fig. 1-14 (NASA Langley CERTAIN Boundary Diagram) provides a high-level overview of the interconnections between the radars, end-user devices, and servers.

Table 3-1. LSTAR Firewall Requirements

LSTAR Firewall Requirements				
Protocol	Port	Source	Destination	Purpose
UDP ⁴⁵	13001	LSTAR IP Address	Server IP Address	Radar Results Data (ASTERIX Cat 48)
UDP	30010	LSTAR IP Address	Server IP Address	Radar Results Data (ASTERIX Cat 48)
ICMP ²⁶	N/A	MOSAIC PC IP Addresses	LSTAR IP Address	Multi-Mode GUI Connection to Radar
SSH ²⁶	N/A	MOSAIC PC IP Addresses	LSTAR IP Address	Multi-Mode GUI Connection to Radar
TCP ²⁶	5410	MOSAIC PC IP Addresses	LSTAR IP Address	Multi-Mode GUI Connection to Radar

Table 3-2. GA-9120 Firewall Requirements

GA-9120 Firewall Requirements				
Protocol	Port	Source	Destination	Purpose
SSH	22	MOSAIC PC IP Addresses	GA-9120 IP Address	Browser GUI Connection to Radar
TCP	80	MOSAIC PC IP Addresses	GA-9120 IP Address	Browser GUI Connection to Radar

⁴⁵ UDP (User Datagram Protocol), ICMP (Internet Control Message Protocol), SSH (Secure Shell Protocol), TCP (Transmission Control Protocol)

TCP	16381	GA-9120 IP Address	Server IP Address	Radar Results Data (ZeroMQ)
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3.6 Radar Software Application Initial Configuration/Setup

This section describes general guidelines associated with configuring and using above mentioned radar systems. Refer to the operator's manuals^{46,47} for more detailed setup instructions. Software interface menus, referenced within this document, may vary from what is shown due to software updates that may have occurred. At the time this document was written, the Radar Operation LSTAR (V)2 Operator Training document had not been updated by SRC to address the newer Multi-Mode software training. The Multi-Mode software GUI replaced the older LSTAR(V)2 software.

3.6.1 LSTAR Setup

From a windows-based computer, install and run the Multi-Mode software. Reference the instructions within the radar software startup section of SRC's LSTAR operator guide to complete the initial device setup prior to operating the system. Below are listed several general steps necessary to get the system up and running.

1. After completing the hardware assembly of the LSTAR, and verifying the system is level using the T-level mounted to the underside of the tripod interface, the radar's emplacement information (e.g., heading, GPS coordinates, and height above ground level) can be obtained manually using the bore sighting method and using a reliable source for both GPS coordinates and height above ground. If the radar uses SRC's optional Inertial Navigation System (INS) package, the emplacement data can be obtained automatically. Currently this method is not used as emplacement information is entered manually.
2. Prior to connecting the power and network cables to the radar, ensure that the radar's power supply and main power switches are in the OFF position. Once connections have been established, power may be applied to the system. The system will take approximately 3-5 minutes to complete the bootup process.
3. Given this is the initial system setup, the user will need to add the specific radar hardware into the GUI by selecting FILE>ADD>MULTI-MODE>Radar-(*n*) within the main track display of the GUI, where *n* represents an incremented integer as additional radars are added in the software (**Error! Reference source not found.**).

⁴⁶ Syracuse Research Corporation "LSTAR (V)2 Operator Training Part 5 Radar Operation" PR 15-2197

⁴⁷ Observation Without Limits "GroundAware Software Installation Guide"

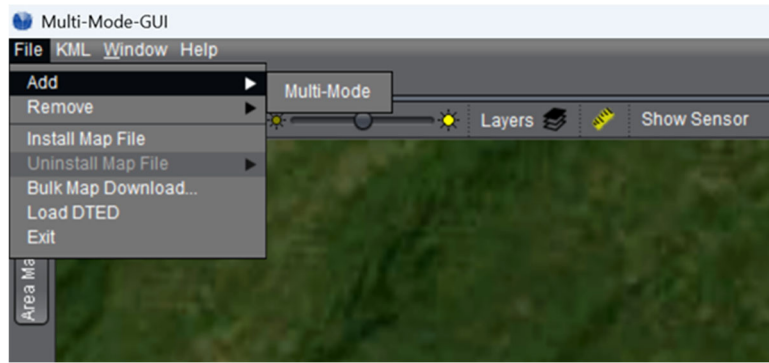


Figure 3-3. Multi-Mode GUI - Add Radar to System

4. This process will create a new radar window where all radar settings specific to that LSTAR can be configured. Network communication between the radar and the radar operator's computer will need to be established by entering the IP of the radar under the settings tab labeled "General" (Fig. 3-4). To enable this IP address change, you will need to click the "submit" button at the bottom of the screen. (The user will be required to click "submit" for any changes to be written to the system.)

Note: Prior to modifying the IP address within the above-mentioned General Setting menu, confirm that the radar's network tab is configured properly.

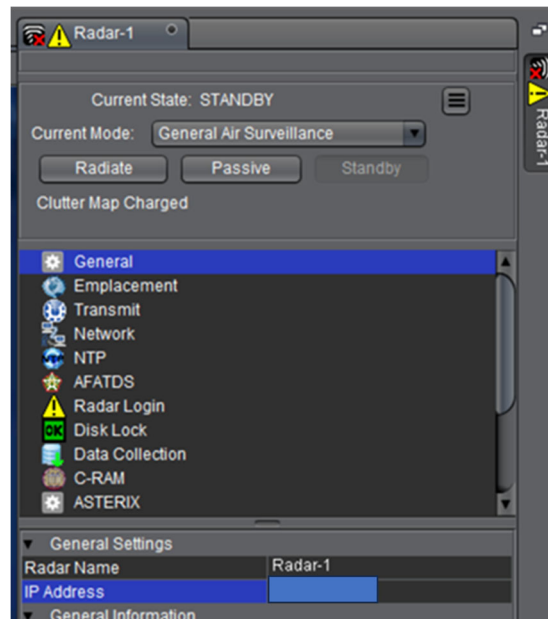


Figure 3-4. General Settings Menu Used to Set IP Address on LSTAR

5. After establishing communications, there are additional parameters the user must properly configure during initial setup of the system. These parameters include setting the radar's authorized transmit frequency and emplacement information. While LSTAR has the capability of transmitting between 1215-1390 MHz, NASA Langley has two RFAs that are authorized for LSTAR Operations (1249 or 1363 MHz). These RFAs are managed by NASA Langley's Spectrum office.

6. The “Transmit” settings tab (Fig. 3-5) is where users enter the LSTAR’s transmit or operating frequency. This tab is also where the user can select/change the radar coverage settings. Users can choose to “blank” certain areas or transmit across the entire 360° field of view.

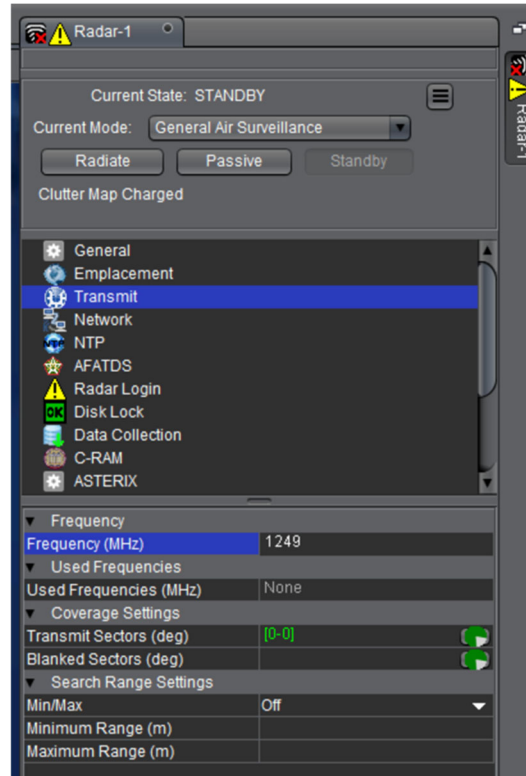


Figure 3-5. Transmit Settings Menu Used to Set Radar’s Frequency and Coverage

7. The radar’s emplacement data can be entered into the system using the “Emplacement” settings tab. Users may select to enter this information manually or automatically (if the inertial navigation system is installed on the radar). See Fig. 3-6.

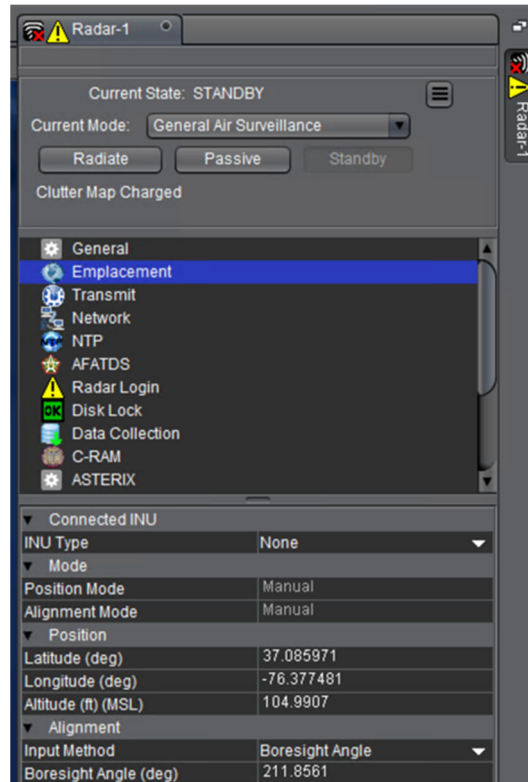


Figure 3-6. Emplacement Settings Menu Used to Set Radar’s Location

3.6.2 GA-9120 Setup

Users interface with the SCM system via a client-based GUI that is accessed through a web browser (i.e. BUI) on LaRCNet. Users configure the IP settings for both the server (within the SCM) and the radars by using the “Admin Tools” button on the main track display (see Fig. 3-7). The BUI Track Display provides graphical track information, radar status indicators, manages alert flight zones, and provides access to the “administrative tools” button where various setup and configurational changes are managed within the system and open to the menu shown in Figure 3-8.

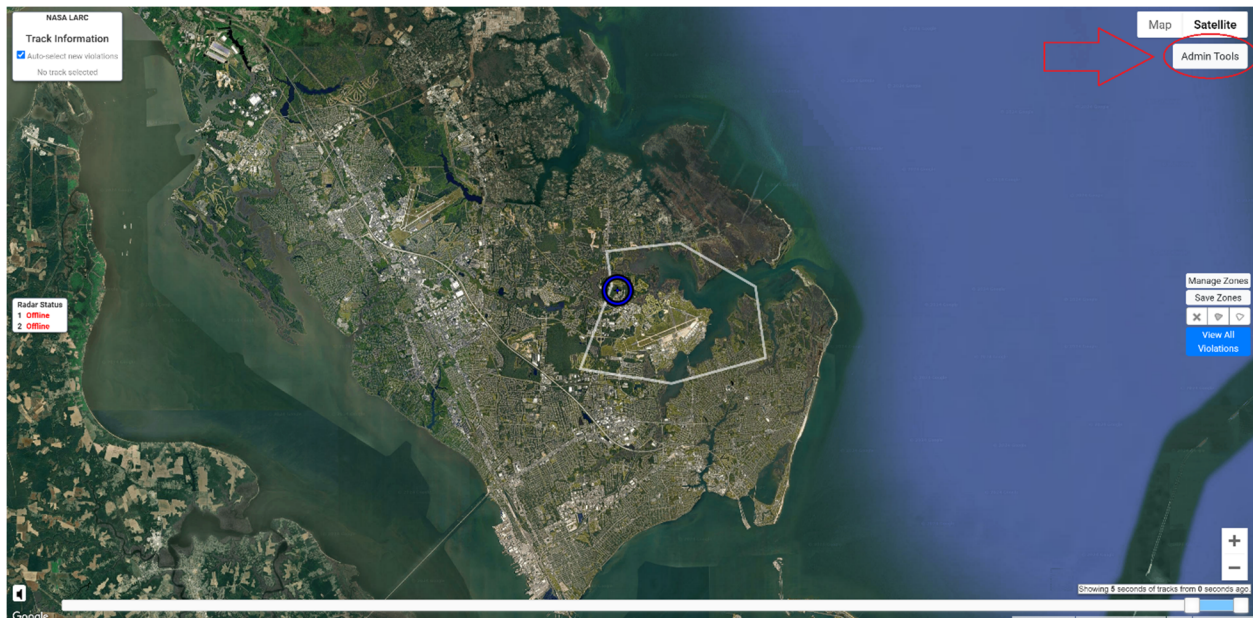


Figure 3-7. GA-9120 BUI Track Display

GROUNDWARE® Admin Tools Menu

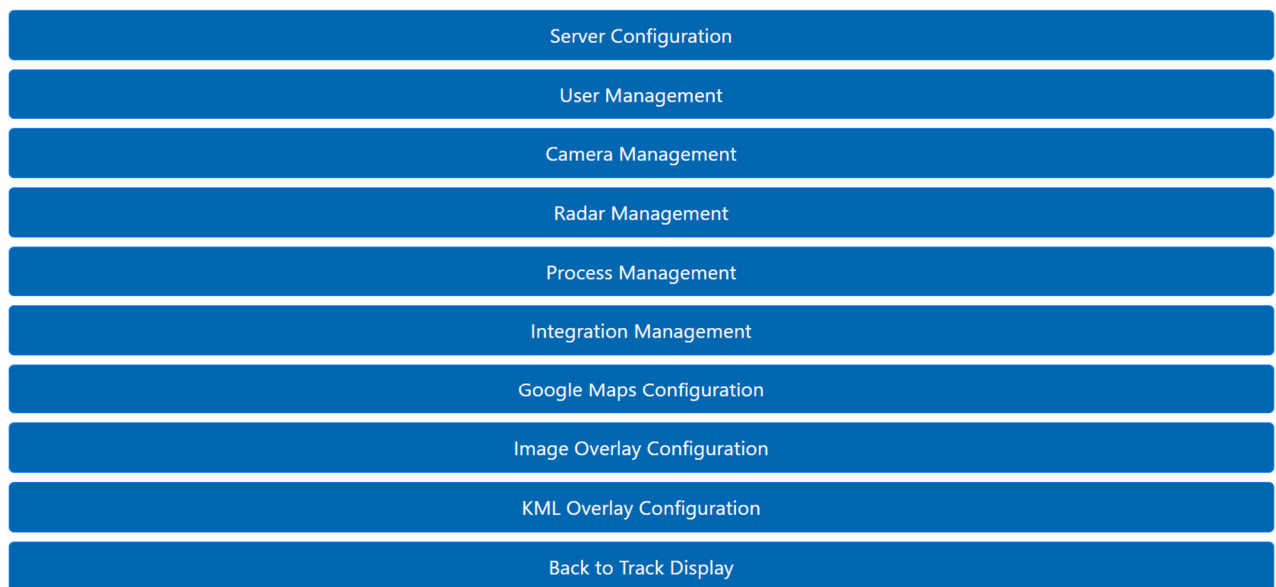


Figure 3-8. GA-9120 Admin Tools Menu

When setting up a new GroundAware system, it is important to configure the settings within the admin tools menu in the specific order listed below.

A. Configure server IP settings on the Server Configuration Setup page (Fig. 3-9).

The IP settings typically come preconfigured from the manufacturer and should not be changed unless certain of their value. Additional functions from this tab include the following: time zone changes, synchronize GroundAware server with a Network Time Protocol (NTP) server, and setting site information.

Server Configuration

IP Settings	Current	New
MAC Address:		
IPv4 Address:	192.168.0.44	
Netmask:	255.255.255.0	255.255.255.0 (/24) 
Gateway:		(optional)
Primary DNS:		(optional)
Secondary DNS:		(optional)

Figure 3-9. GA-9120 Server Configuration Menu

B. Configure system users on the User Management page (Fig. 3-10).

The user management page is where users with different privileges can be added or removed from the system. Usernames must be different. There are three user groups within the system that define specific privileges:

- Viewer – Can observe the system display.
- Operator – Viewer’s abilities, plus control cameras and view system states.
- Administrator – Operator’s abilities, plus access to install-tools configuration and configuring system zones.

User Management

Username	User Group		
admin	admin	Remove	Set Password
operator	operator	Remove	Set Password
viewer	viewer	Remove	Set Password

User Name:

Password:

Confirm Password:

User Group:

Viewer ▾

Refresh List

Add User

Figure 3-10. GA-9120 User Management Menu

C. Add new cameras using the Camera Management page.

NASA Langley has not incorporated cameras into the installation of the GA-9120. However, the camera management page is where you would add or remove network cameras into the system to enhance surveillance capabilities. Refer to the O.W.L.'s GroundAware Software Installation Guide for additional setup information.

D. Add new radars to the system on the Radar Management page (Fig. 3-11).

To add a new radar to the system you will need to enter a valid id, IP address, and port. Click the "Add Radar" button and the table will update with the new radar information. The user will need to enter each radar's positional information (e.g., Latitude, Longitude, Altitude, Heading and Tilt angle) by selecting the "Location Settings" Tab for each radar. The radar does not have GPS or heading capabilities so the user will need to determine these parameters and enter them manually and then save this information.

Radar Management

Name	ID	IP	Port	Type	Frequency Channel			
(Not Set)	1	192.168.2.221	16381	9000	21	Remove	Location Settings ▶	Read Cal
(Not Set)	2	192.168.2.225	16382	9000	25	Remove	Location Settings ▶	Read Cal

Processing Computer: Local Remote

Radar Model:

ID number:

Name:

IP address:

Frequency Channel:

Port:

Refresh List
Add Radar

Figure 3-11. GA-9120 Radar Management Menu

3.7 Performance Evaluation and Simulation Testing

A series of evaluation flight tests were conducted using NASA Langley aircraft as targets between 2021 and 2024. These aircraft (Cirrus SR-22, B-200 Kingair, and Lancair LC40 Columbia 300) are representative of the size of aircraft that could potentially intrude on Langley Air Force Base airspace and require evasive maneuvers for UAS operations. GPS position was recorded onboard each aircraft for post flight analysis of surveillance system performance.

3.7.1 *LSTAR SN175 Flight Test Data (From 4/4/2024. Unit operational at time of this report.)*

Initial testing of the LSTAR SN175 was conducted with the radar installed on the roof of Building 1230 at NASA Langley for easy access (see Fig. 1-1 LSTAR "Expeditionary Configuration" Installed on NASA Langley Rooftop).

An SR-22 aircraft was flown in a wheel and spoke pattern out to 5 NM. Results from these tests indicated large areas with dropouts. These dropouts were suspected to be from geographical obstructions and interference. This indicated the need to install the radar at a higher elevation.⁴⁸

The LSTAR was then moved to its final location on top of the Hangar building 1244 (see Fig. 1-2). The evaluation flights were repeated from this location, the dropout issues were resolved, and

⁴⁸ N. Gaug, A. Tang “Lightweight Surveillance and Target Acquisition Radar Characterization for High Density Vertiplex Beyond Visual Line of Sight Operations,” 2022 IEEE/AIAA 41st Digital Avionics Systems Conference (DASC). <https://ntrs.nasa.gov/citations/20220013172>

operational requirements for azimuth tracking were met in all directions, even beyond 5 NM. However, the mean elevation error was 3.4 degrees which led to significant altitude errors. This was nearly twice the manufacturer's specification, ± 1.5 degrees, for elevation error. In early 2023, LSTAR SN175 was removed and sent back to the manufacturer for refurbishment. A second LSTAR unit (SN364) was installed and operational between May 2023 and Jan 2024, and data are provided in the next section (3.7.2 - LSTAR SN364 Flight Test Data).

In January 2024, LSTAR SN175 returned from refurbishment, was again installed on the Hangar building 1244, and an evaluation flight was performed. The aircraft used was the SR-22, which flew a wheel and spoke flight pattern at 3 and 5 NM circles with 8 spoke patterns at 1000 ft and 2000 ft AGL. Data are provided in Figures 3-12 and 3-13. LSTAR SN175 is operational at the time of this report.

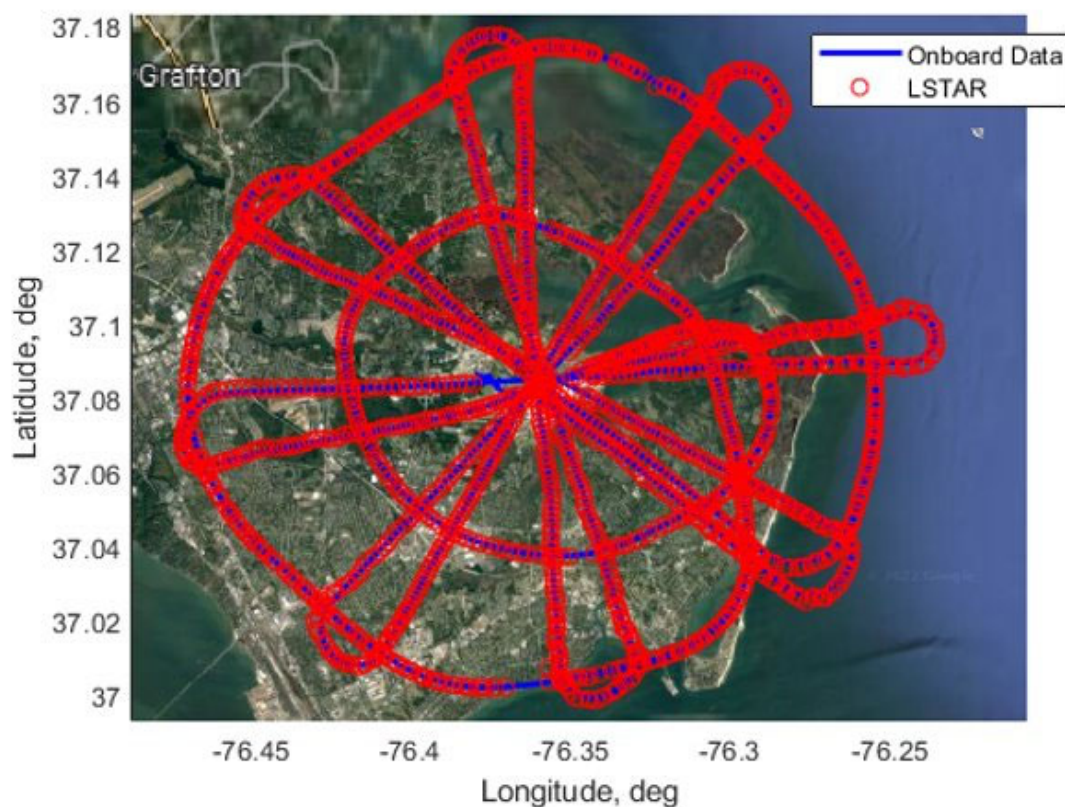


Figure 3-12. Lat/Lon Flight Data From LSTAR SN175 (4/4/2024, Post Refurb)

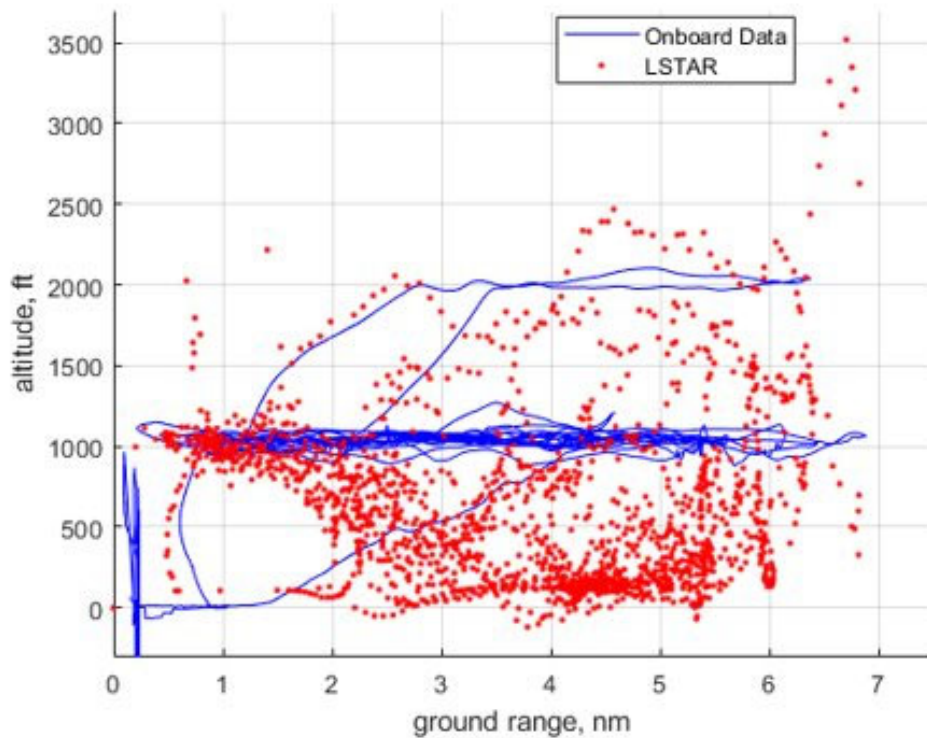


Figure 3-13. Range/Altitude Flight Data From LSTAR SN175 (4/4/2024, Post Refurb)

3.7.2 *LSTAR SN364 Flight Test Data (From 7/21/2023. Unit removed January 2024)*

In early 2023, LSTAR 364 was installed and evaluated against the SR-22 and LC-40 Columbia 300. This radar performed very well and had a mean elevation error of 0.3 degrees, a mean azimuth error of 0.1 degrees, and a mean range error of 12 meters. All parameters were well within the radar's specifications. Data are provided in Figures 3-14 and 3-15.

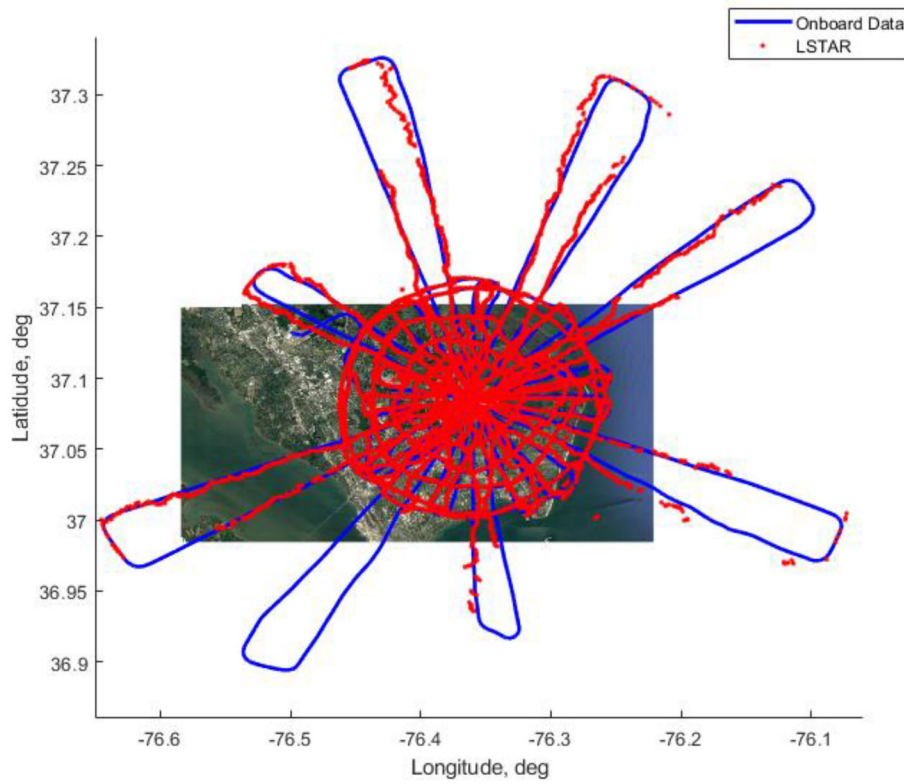


Figure 3-14. Lat/Lon Flight Data From LSTAR SN364 (7/21/2023)

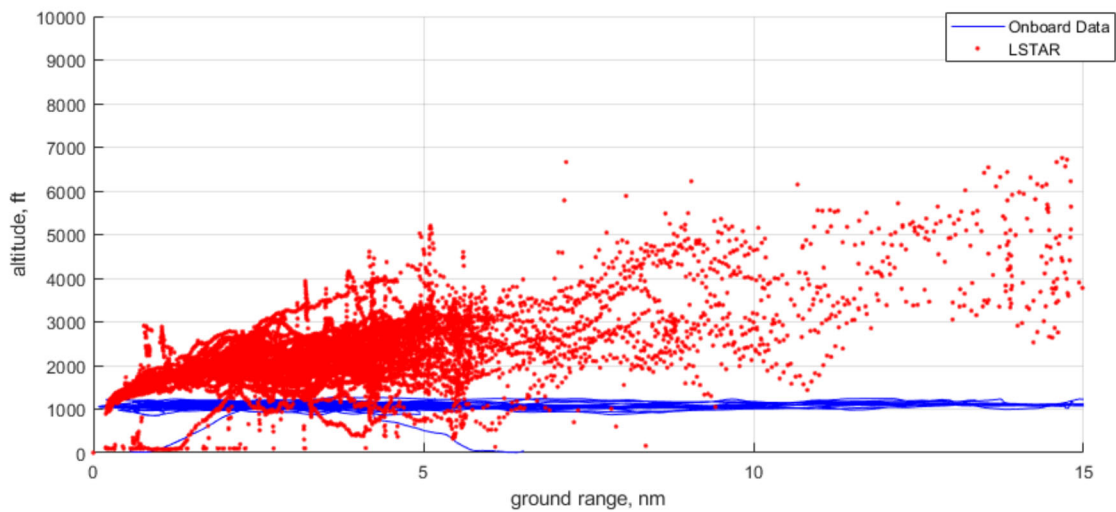


Figure 3-15. Range/Altitude Flight Data From LSTAR SN364 (7/21/2023)

After these evaluation flights, the radar was deemed operational and used for BVLOS flight operations⁴⁹. During 2023, this radar began experiencing column failures that slowly became more consistent over time. In early 2024, an attempt to update the firmware to resolve some of these issues resulted in the unit becoming non-operational. This unit was then removed and sent back to the manufacturer for refurbishment.

A summary of the performance of the radar from these tests is provided in Table 3-3 below, compared to the specifications provided by the manufacturer. While unit SN175 is not performing as well as SN364 did, all parameters are within specifications. This unit was then deemed operational and continues to be used for BVLOS flight operations at the time of this report.

Table 3-3. LSTAR Performance Comparisons to Manufacturer Specification

Parameter	SRC Spec	LSTAR 364 (through Jan 2024)	LSTAR 175 (Jan 2024 to present)
Azimuth (mean), deg	+/- 0.8	0.1	-0.4
Elevation (mean), deg	+/- 1.5	-0.3	-1.25
Range (mean), m	+/- 25	-12	18
Azimuth (std), deg		1.1	0.8
Elevation (std), deg		1.2	1.1
Range (std), m		140	170

3.7.3 *GA-9120 Radar Performance*

Initial checkout testing with the GA-9120 focused upon low-altitude, close detection of UAS. A single GA-9120 panel was set up approximately 10 ft off the ground and facing east toward the UAS takeoff and landing area at NASA Langley. Two sUAS were flown in the vicinity at approximately a quarter of a mile distance. The first was a NASA LA-7 aircraft which is an approximately 15-lb foam tiltwing aircraft⁵⁰. The second aircraft was a Freefly Alta 8 multi-rotor weighing approximately 30 lbs⁵¹. Both aircraft were tracked by the GA-9120. Figure 3-16 is an image from the radar testing showing the tracking of the LA-7 aircraft, square target, flying a circular pattern in front of the radar. In a separate test, the Alta 8 was flown radially from the radar and was tracked from approximately 1000 to 3000 ft away.

⁴⁹M. Coldsnow, L. Glaab, J. Revesz, L. Kagey, R. McSwain, J. Schaefer, "Safety Case for Small Uncrewed Aircraft Systems (sUAS) BVLOS Operations at NASA Langley Research Center." NASA/TM-20230003007. June 2023. <https://ntrs.nasa.gov/api/citations/20230003007/downloads/NASA-TM-20230003007.pdf>

⁵⁰ R. McSwain et al. "An Experimental Approach to a Rapid Propulsion and Aeronautics Concepts Testbed," NASA/TM-2020-220437. See page 30 for LA-7 specifications. <https://ntrs.nasa.gov/citations/20200000698>

⁵¹ <https://freeflysystems.com/knowledge-base/alta-8-discontinued>

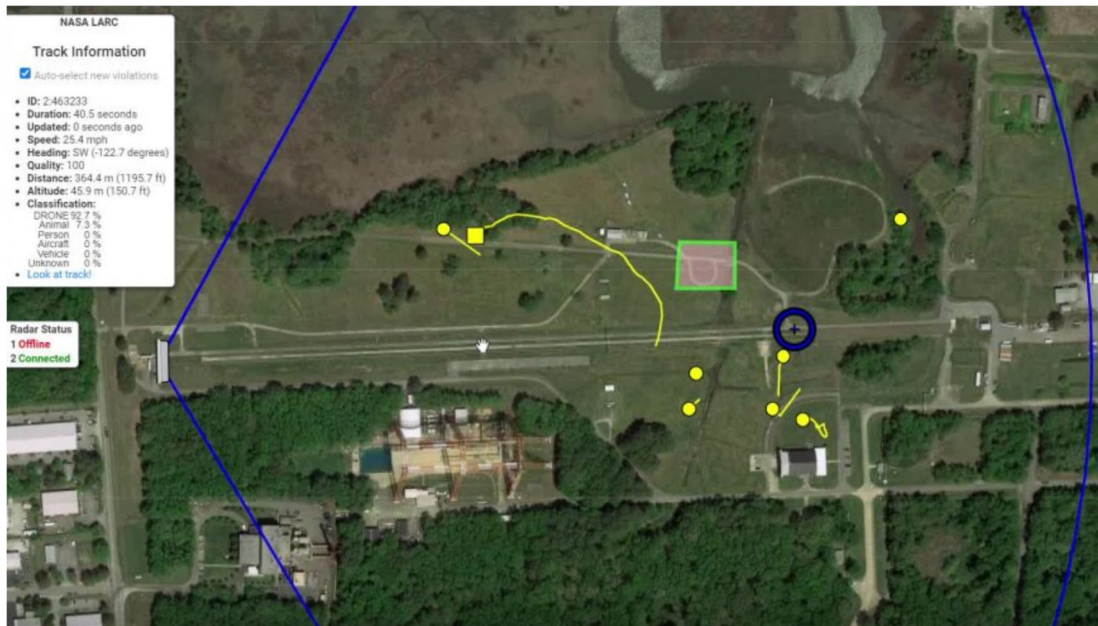


Figure 3-16. GA-9120 Close Range UAS Testing with LA-7

The GA-9120s were evaluated against general aviation sized aircraft during the LSTAR radar evaluation flights. The performance of the GA-9120s was highly variable and required iterations of radar parameter tuning. Figure 3-17 below shows the data recorded on the GA-9120s during one of the radar flights. Green showing radar hits from the north-easterly facing panel, and red showing the South-Easterly facing panel.

The performance meets operational requirements at the 1-2 NM range but diminishes greatly beyond 3 NM. For the BVLOS safety case, the GA-9120s were only required to observe the airspace above the LSTAR, within its Cone of Silence (see Sec. 3.3 footnote). For this purpose, the south-easterly facing GA-9120 panel accomplished that task. For use with wider scale airspace surveillance, the GA-9120s require further tuning, that as of the date of this publication, has not been completed.

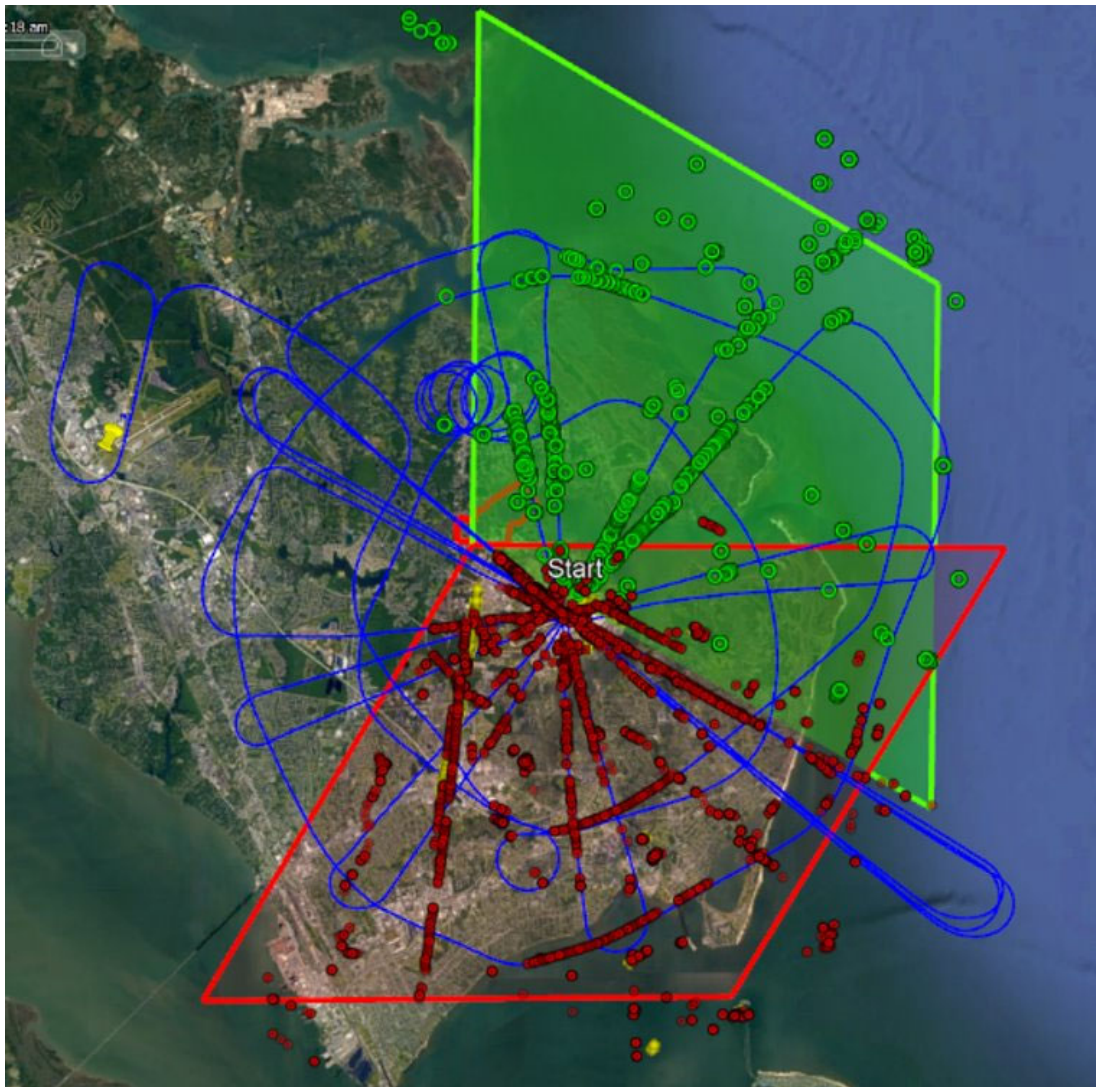


Figure 3-17. GA-9120 Radar evaluation flight

3.7.4 *ADS-B Coverage*

The ADS-B sensor mounted to the Gantry at NASA Langley was also tested during the surveillance system evaluation flights. Figure 3-18 shows the data recorded for the ADS-B sensor. Operationally acceptable coverage was seen across the area with small dropouts to the south between 3 and 5 NM, and at altitudes below 1500 ft. This is likely due to blockage from the Gantry, as the sensor is mounted on the northern side of the Gantry structure.

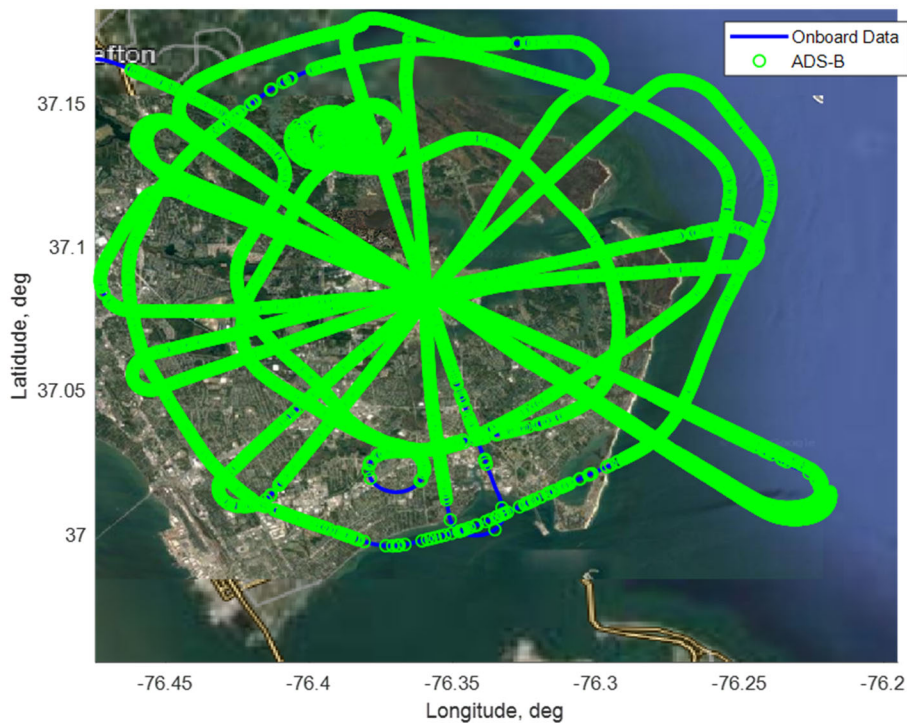


Figure 3-18. ADS-B Versus Onboard GPS Position Data From Radar Evaluation Flight

3.7.5 *Simulation*

Virginia Tech MAAp provided a Ground-Based Detect and Avoid (GBDAA) simulation in support of NASA Langley in 2023, as part of the HDV BVLOS sub-project⁵². The simulation used the results from the radar evaluation flights, coupled with a dynamic simulator to evaluate flight characteristics for avoidance maneuvering. The sensors (GA-9120, L-Star, and Skyler) were found to provide adequate coverage for the intended area of operations.

3.7.6 *Radar Performance Evaluation Next Steps*

ADSB-equipped aircraft routinely operate within the detect and track volume of the LSTAR, GA-9120 and Skyler radars. NASA Langley UAS operations are additionally equipped with RID and FLARM systems. These cooperative sensors provide opportunity to perform historical data analysis to quantify azimuth, elevation, range and velocity accuracy and latency of operational radar systems. This work is now underway and will be published in a subsequent report.

Additionally, a NASA Langley drone is being modified to carry a 32"-diameter radar calibration (truncated) sphere, which can be used to consistently evaluate performance of radar systems throughout their coverage volumes, further enabling assessment of similar radar systems installed in different geographic locations.

⁵² NASA Grant # 80NSSC22K1432 "GBDAA Simulation in Support of NASA LaRC HDV BVLOS Corridor Project," 7/14/2023.

4.0 Radar Operations

This section provides a user's guide for daily operations, standard troubleshooting procedures and known issues, and where to find manufacturer assistance and report anomalies. Instructions for the initial setup of the radar display GUIs and requirements for providing new users access are located in Attachment 2 "Supplemental Information – Procedures."

4.1 User's Guide for Daily Operations

4.1.1 LSTAR Operations

Upon first launching the Multi-Mode GUI application, the user will see a display similar to Figure 4-1 when the radar is in Standby or Passive Mode.

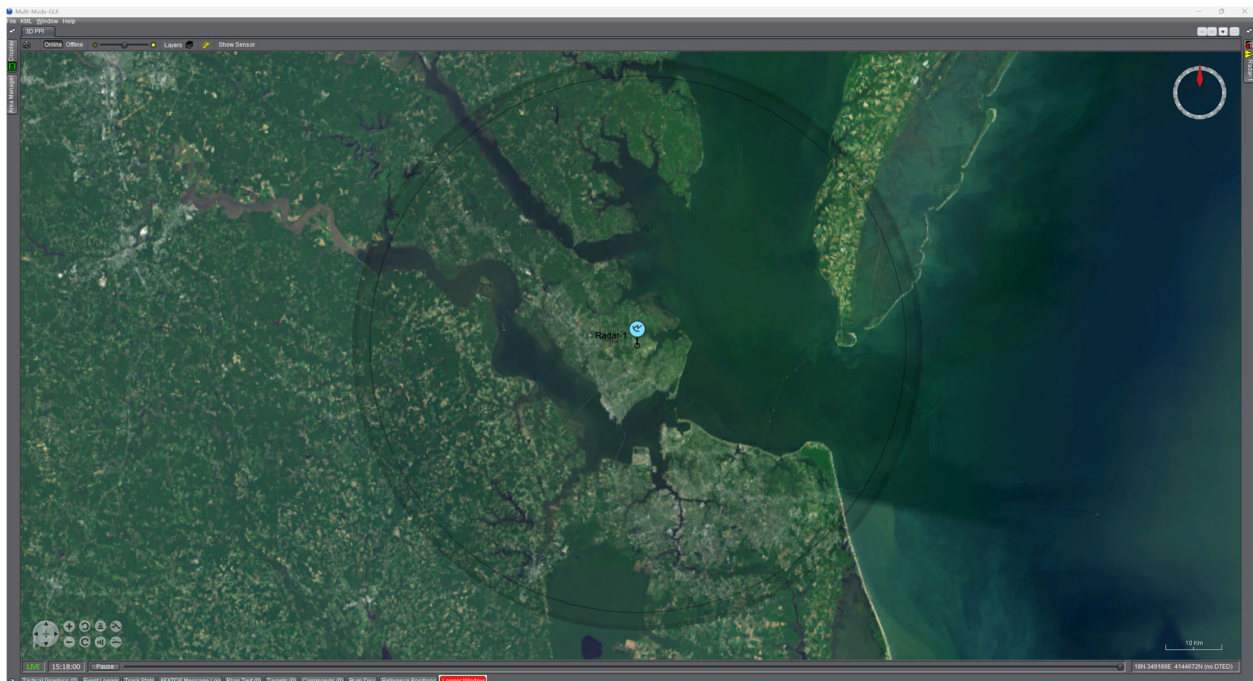


Figure 4-1. LSTAR GUI – Radar Connected in Standby or Passive Mode

In the top-right corner of the LSTAR GUI, the radar options menu can be opened by clicking on "Radar-1," the current state of the radar will be listed as Radiate, Passive, or Standby (see Fig. 4-2 below). To change the current mode of the radar while the radar is in passive or standby, select the current mode drop-down menu and select one of the following:

- Unmanned Air Surveillance
- Counterfire Track Acquisition
- General Air Surveillance *

*NASA Langley primarily uses General Air Surveillance mode to deconflict UAS operations with crewed aircraft. Once a radar mode is selected, click the radiate button to initiate radar emission.

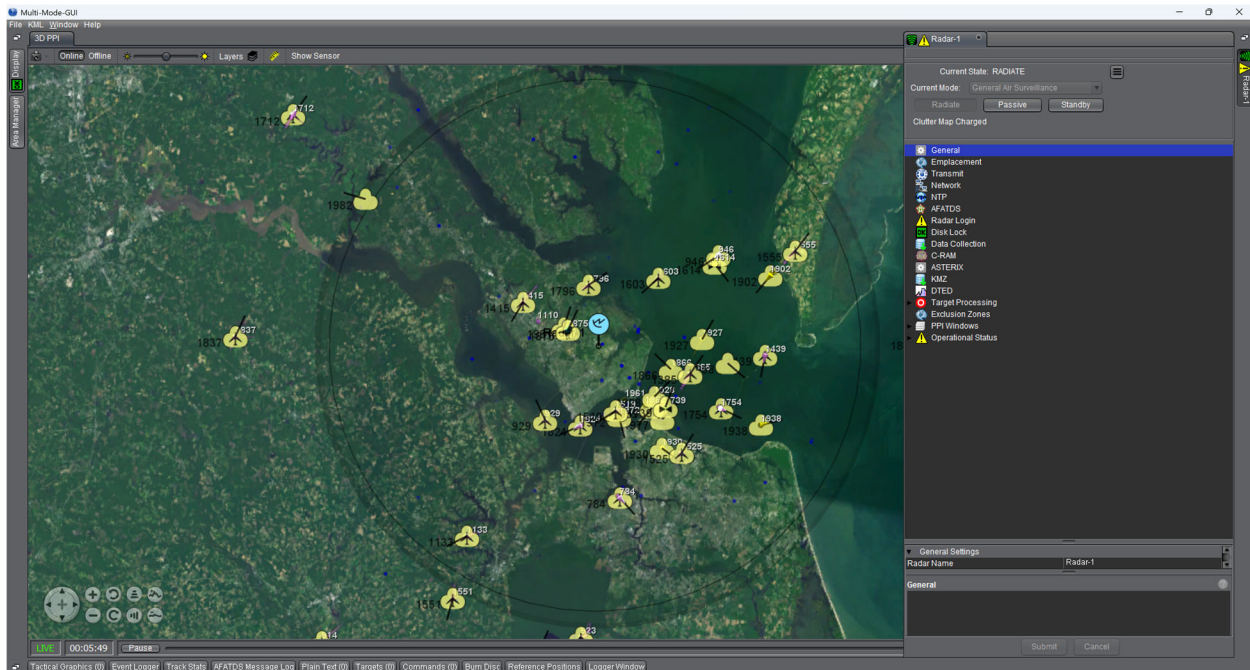


Figure 4-2. LSTAR GUI – Radar Radiating in “General Air Surveillance” Mode

To reduce clutter, it is recommended to disable “Enable 2525C” which disables the MIL-STD-2525C Common Warfighting Symbolology⁵³ applied to radar tracks, as seen in Figure 4.2 (☼). In the radar options menu, navigate to Plan Position Indicator (PPI) Windows, expand the menu, expand 3D PPI, and click on “Symbology Layer.” Deselect “Enable 2525C” and click “Submit.”

Radar Detections appear as blue dots in the GUI. (See Fig. 4-3 Radar Classification Settings.) An object that is persistently detected transitions from a Detection to a Tracked Target and is assigned a unique numerical track ID, which is displayed next to the Tracked Target (arrowhead shape in direction of velocity vector). Detections that do not transition to Tracked Targets will stop being displayed. All Tracked Targets are initially classified as “Pending” and colored yellow. Once classified, tracked targets change color depending on their classification. The target classifications can be viewed in the radar settings menu by navigating to PPI Windows, expanding the menu, expanding 3D PPI, and clicking on “Track Layer.” The LSTAR classifies tracked targets as Pending, Unknown, Projectile, UAV, Bird, Ground Vehicle, Fixed Wing, or Rotary Wing. By default, all target classifications are enabled. To disable a classification, in the track layer section of the radar options menu, deselect “show labels” and set the “fade time (sec)” to 0 for the desired classification and click “Submit.”

⁵³ MIL-STD-2525C, Department of Defense Interface Standard: Common Warfighting Symbolology

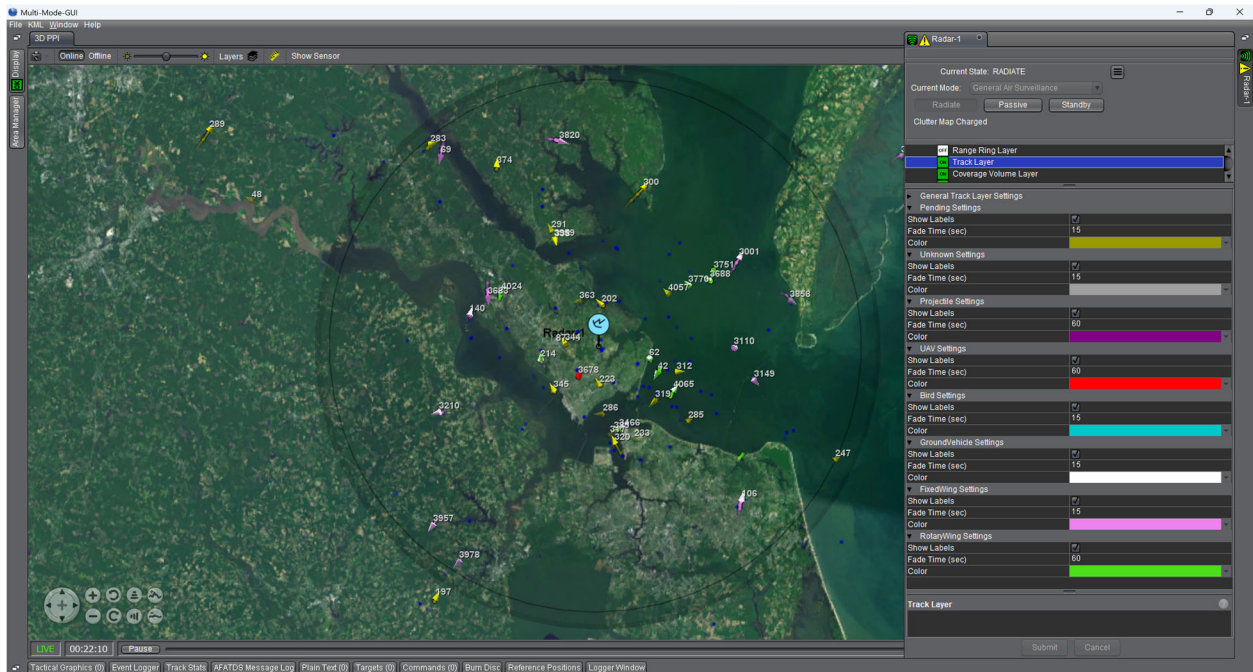


Figure 4-3. LSTAR GUI – Radar Classification Settings

For flight operations, NASA Langley enables the range ring layer in the range ring layer section of the radar options menu and places range rings at distances of 3 NM and 5 NM from the radar per the LMV, as shown in Figure 4-4 (Range Ring Layer Settings).

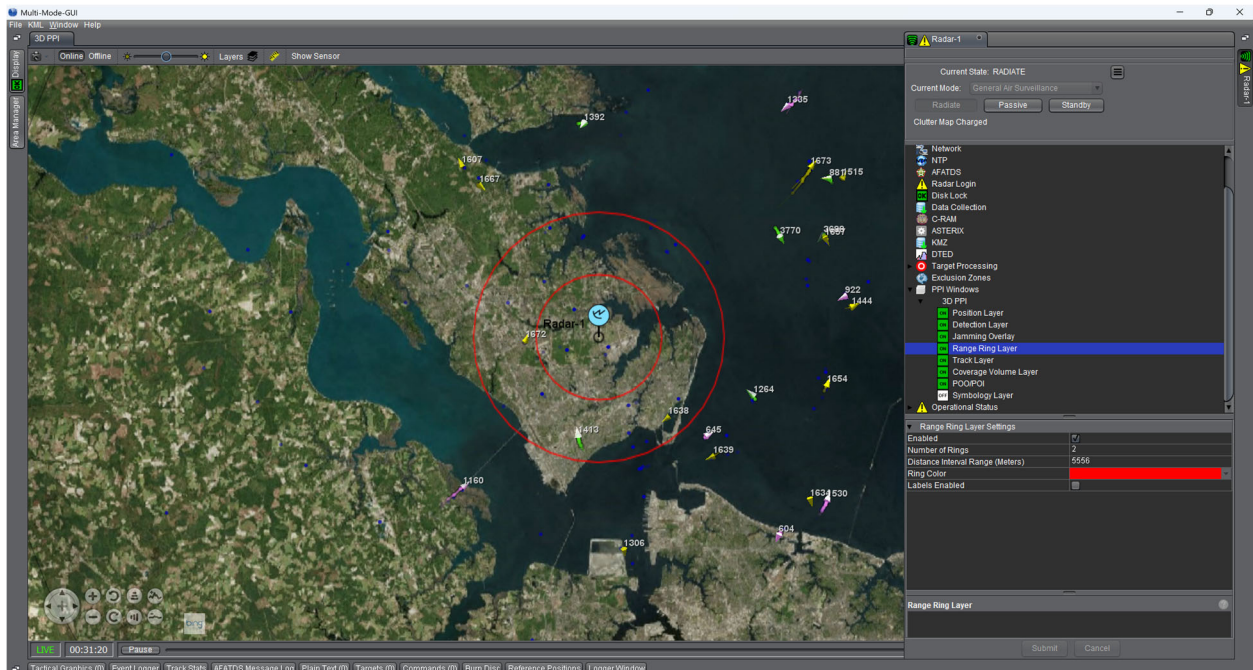


Figure 4-4. LSTAR GUI – Range Ring Layer Settings

Once a radar detection transitions to a Tracked Target, the user can click on the target to add it to the “Track Stats” tab in the bottom-left corner of the radar GUI (see Fig 4-5). To expand the “Track Stats” tab, hover over and click on the tab; once the tab is expanded, real-time track stats are displayed for all added tracked targets. A real-time plot of the quantitative track stats versus time can be generated by clicking on the three dots next to the particular Track Stat. The “Relative Height” Track Stat is useful for determining if a tracked target is climbing or descending (also shown in Fig. 4-5).

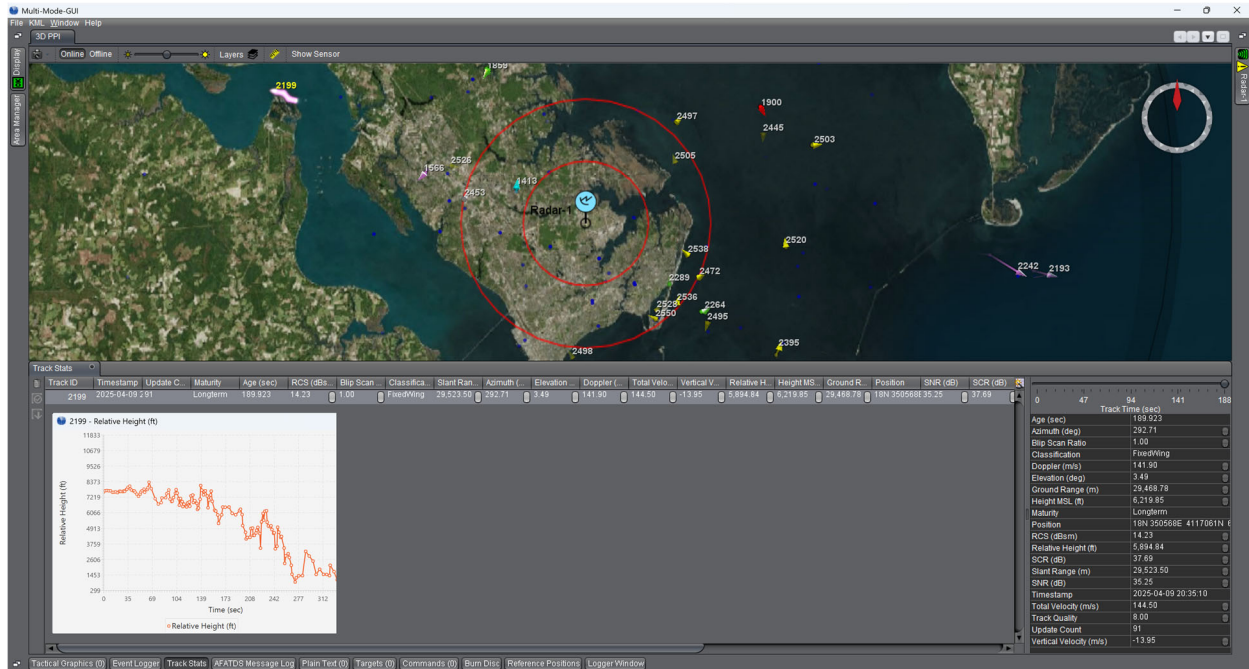


Figure 4-5. LSTAR GUI – Track Stats

The LSTAR GUI by default starts in the top-down view. Viewing perspective can be changed by holding right-click and pushing back on the mouse. From the perspective view, the LSTAR's Cone of Silence above the radar is visualized in three-dimensions; further, the relative altitude above ground level of tracked targets is better visualized for reference during operations. (See Fig. 4-6 LSTAR GUI - Perspective View.)

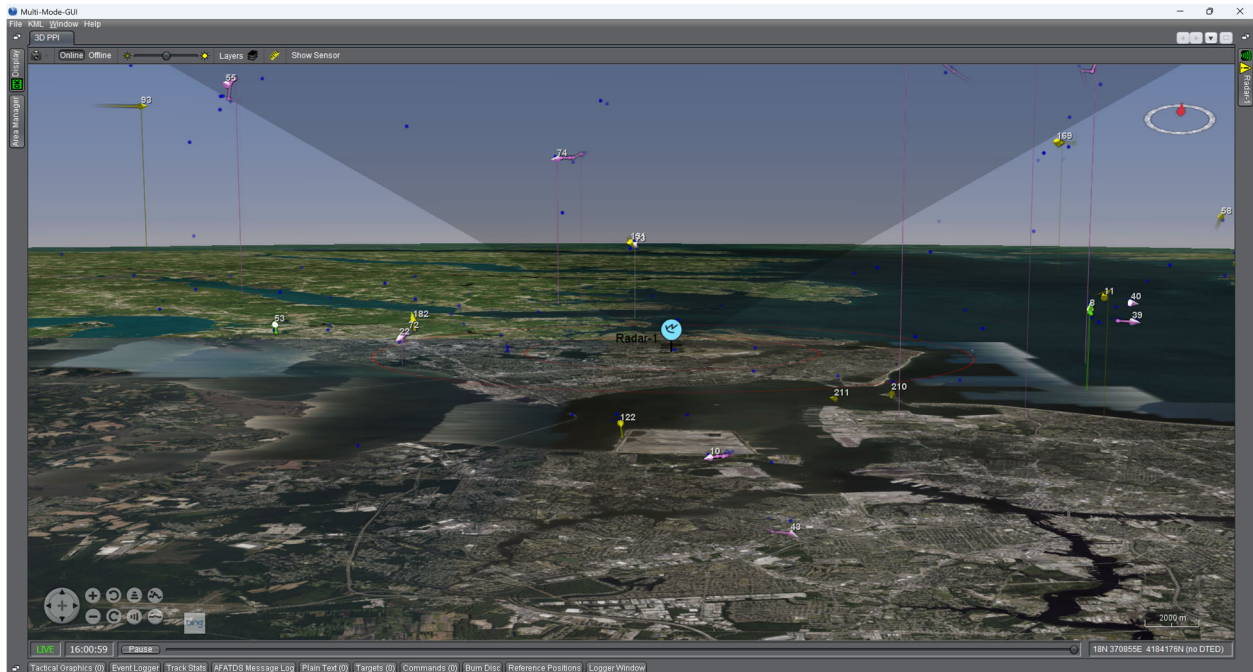


Figure 4-6. LSTAR GUI – Perspective View

4.1.2 GA-9120 Operations

As shown in Figure 4-7, in the top-right corner of the radar BUI, the admin tools menu can be opened by clicking on “Admin Tools.” Within the admin tools menu there are separate menus for Server Configuration, User Management, Camera Management, Radar Management, Process Management, Integration Management, and configuration for Google maps, image overlays, and Keyhole Markup Language (KML) overlays. Radar Management is used to add/remove radars for first-time setup. Server Configuration is used for first-time server configuration and server-side settings (enabling/disabling track classification icons, enabling/disabling alarm zone alerts, etc.).

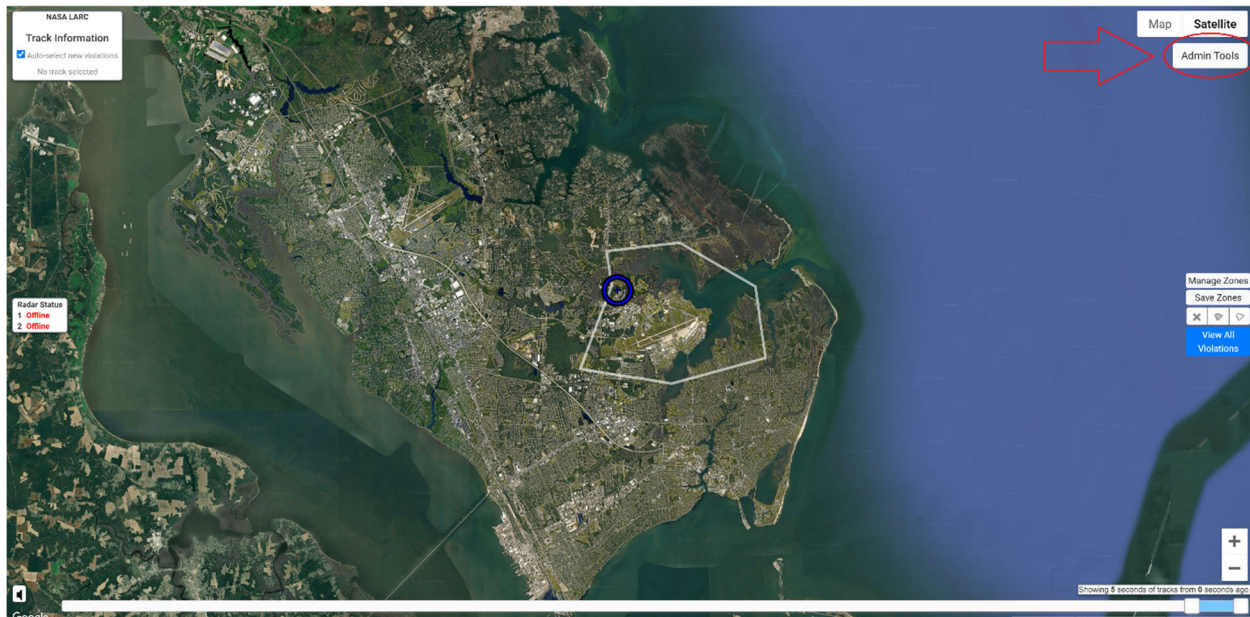


Figure 4-7. GA-9120 BUI Track Display (shown with radar panels offline)

The most frequently used menu within the admin tools menu for routine operations is the “Process Management” menu, as shown in Fig. 4-8. Within the Process Management menu, the individual process status is listed: radar(s) can be stopped (i.e., put into standby) or restarted (i.e., made to radiate). Further, local server data logging processes can be enabled and disabled. The log box at the bottom of the page contains a downloadable record of user-initiated or automated changes to process status.

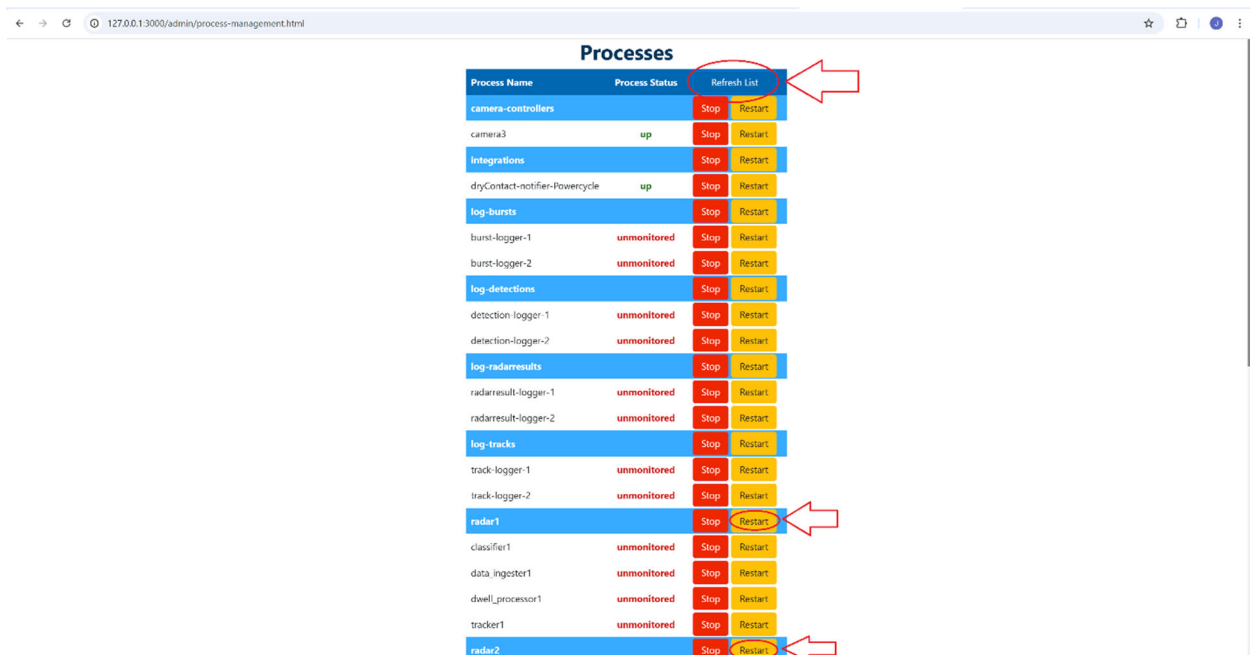


Figure 4-8. GA-9120 BUI – Process Management Menu

Once the radar(s) are radiating, radar tracks will begin populating; tracks begin as pending and transition to Person, Vehicle, Animal, Drone, Aircraft, or Unknown classifications, as shown in Fig. 4-9 (Track Information, Alarm Zone Configuration). Clicking on a radar track will populate track information in the top left of the BUI. On the right side of the radar BUI, alarm zones can be added by drawing them onto the map. Once an alarm zone is added, the alarm zone configuration menu can be accessed by clicking on the bounds of the alarm zone. If a radar track is within the bounds of the alarm zone and auto-select new violations are enabled, track information will automatically pop up for the newest alarm zone violation.

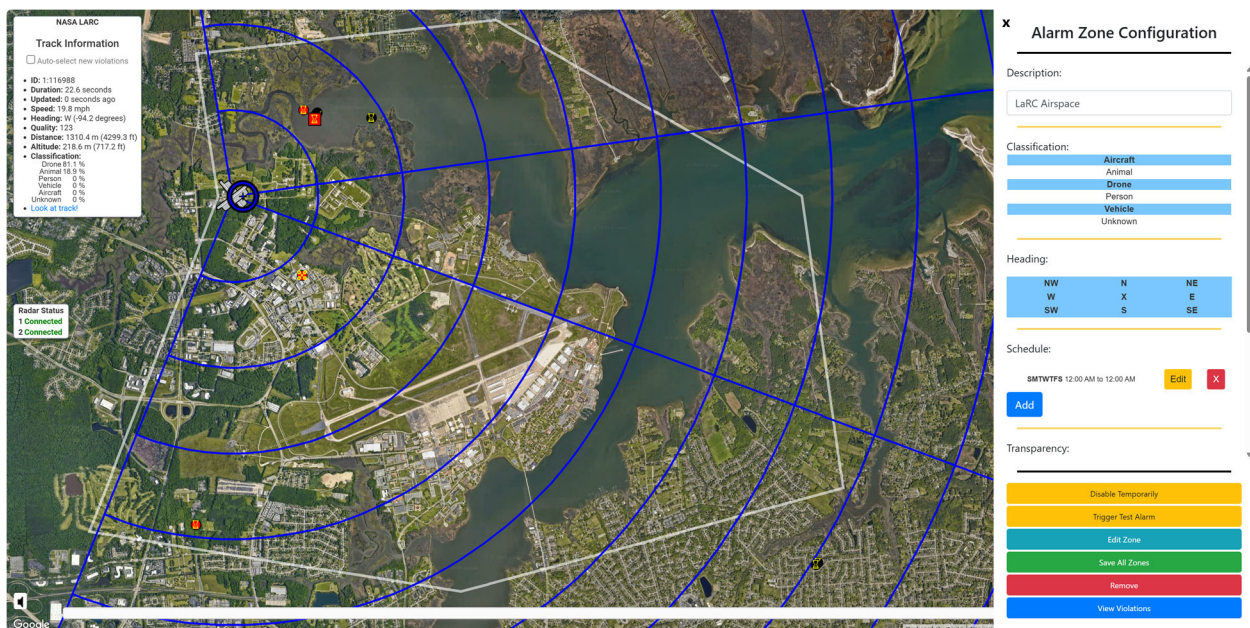


Figure 4-9. GA-9120 BUI – Track Information, Alarm Zone Configuration

4.1.3 TAURAS Operations

TAURAS was introduced in Section 1.6. Revisiting Figure 1-15 (TAURAS display) will be helpful for reading this section. Figure 4-10 (below) provides a close-up of the top of the TAURAS display where the traffic range filtering input fields are shown. These text fields allow control over which targets are visible on the display. Targets positioned outside of the selected horizontal and vertical ranges are hidden from view. These traffic range filters are applied to each display layer.

In Figure 4-10, the Max (horizontal) Range input field, Maximum Altitude filter input field, Minimum Altitude filter input field, and target Aircraft Data Label display checkbox are shown from left-to-right. Finally, the “Hide Overlapping Labels” checkbox will hide any labels which overlap, making it easier to identify a target and reduce screen clutter. An orange ring is displayed on the TAURAS display to indicate the current Max Range value chosen by the user. The values allowed for these fields are as seen in Table 4-1. The Min and Max altitude fields automatically adjust by 25 ft if the minimum altitude is set below or equal to the maximum altitude, and vice versa.

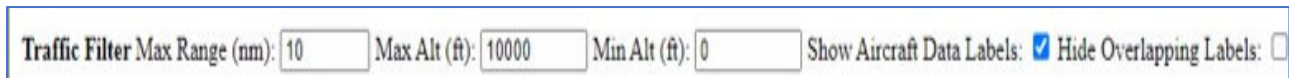


Figure 4-10. TAURAS Range Filter Input Fields

Table 4-1. TAURAS Traffic Range Filters

	Default Value	Minimum Value	Maximum Value	Units
Max Range	10	1	150	nm
Max Altitude	10000	25	50000	ft MSL
Min Altitude	0	0	49975	ft MSL
Show Aircraft State Labels	True	N/A	N/A	boolean
Hide Overlapping Labels	False	N/A	N/A	boolean

Located at the top right of the TAURAS display are the layer control checkboxes. (See Fig. 4-11 TAURAS Layer Control.) These checkboxes toggle the visibility of the selected type of target (ADS-B, RADAR, FLARM, and GA-9120) on the display. By default, all layers are enabled. To toggle the display of a particular type of target, simply click the desired checkbox. For this version of TAURAS, the “RADAR” layer shows LSTAR and Skyler Radar data, and the “UAS” layer shows FLARM and Remote ID data. User can hover over a target to determine the data source.

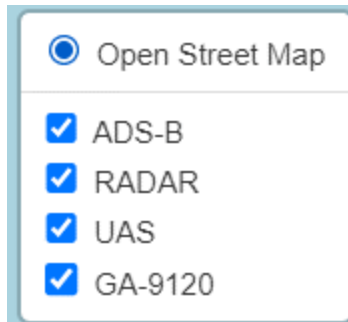


Figure 4-11. TAURAS Layer Control

Located at the bottom left of the TAURAS display is the legend. (See Fig. 4-12.) The legend displays key information regarding the overall health and quantity of incoming targets to TAURAS. To the left of each sensor type is the corresponding symbology color for the icons on the display (For example, ADS-B targets are displayed in a dark blue color). To the right of the sensor type is the number of seconds which have elapsed since receiving *any* target for that sensor type. The “Incoming Targets” lines display the number of unique targets sent to TAURAS within the last 1Hz cycle. This number is independent of the current Traffic Filter settings.

Legend Heartbeat Age	
■ ADS-B	1 sec.
■ RADAR	1 sec.
■ UAS	5 sec.
■ GA-9120	5 sec.
Incoming Targets	
ADS-B	183
RADAR	39
UAS	0
GA-9120	0

Figure 4-12. TAURAS Legend

Each target icon on the TAURAS display contains the target’s Callsign (when available), Mode-S Identifier, Altitude (feet), and Air Speed (knots). (See Fig. 4-13 for a close-up view of a representative ADS-B track.) In the case of the RADAR (LSTAR and Skyler) and GA-9120 devices, where ADS-B Callsign is unavailable, the Track ID is shown instead. A “v” is prepended to the altitude to indicate the target is descending, while a “^” will be prepended if the target is ascending. No symbol is prepended during level flight. Clicking on the target’s icon will identify the specific sensor which identified it (i.e., LSTAR or Skyler) via a popup checkbox.

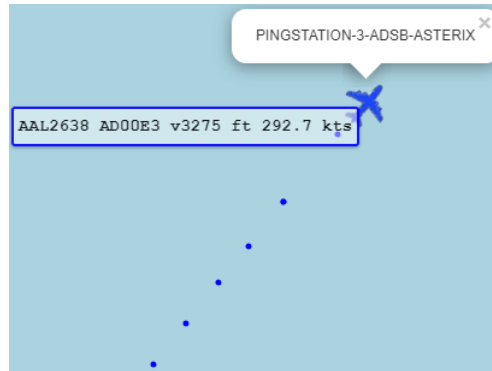


Figure 4-13. An ADS-B Target Showcasing Breadcrumbs, Sensor ID, and Descent Indication

4.2 Radar Operations Troubleshooting and Known Issues

Several common issues encountered by operators of NASA Langley’s LSTAR and GA-9120’s are provided here, along with suggestions and solutions.

4.2.1 *LSTAR Troubleshooting and Known Issues*

- If the LSTAR radar does not appear upon initial launch of the Multi-Mode application, ensure that the correct IP address for the LSTAR radar is present in the “General” section of the radar options menu. If it is not present or is incorrect, add or modify the entry and click “Submit.”
- If no targets are appearing on the LSTAR Multi-Mode GUI, ensure the following:
 - The current state of the LSTAR is set to RADIATE (i.e., not STANDBY or PASSIVE).
 - Tracked targets are enabled in the “General Track Layer Settings.” In the track layer section of the radar options menu, select “show labels” and set the “fade time (sec)” to a value greater than zero for the classifications of interest to display and click “Submit.”
- To ensure proper operational status of the LSTAR radar prior to use in operations, navigate to the “Operational Status” section in the radar options menu and expand “Components,” “Central Enclosure,” and “Columns.” The status of each column is listed; ensure all columns are “OK” prior to use of the LSTAR in operations.
- If interference is suspected (i.e., multiple erroneous detections and tracks along a given radial), it is suggested to manually switch to an authorized frequency by navigating to the “Operational Status” section in the radar options menu, expand “External,” and select “Interference.” If there is interference along a radial, that radial will be red; no interference is indicated by a green radial.
- If the LSTAR radar fails to transition from standby or passive to radiate, contact SRC for further assistance.

4.2.2 *GA-9120 Troubleshooting and Known Issues*

- If the GA-9120 radar does not appear upon initial login to the radar BUI, ensure that the correct IP address for the GA-9120 radar is present in the radar management sub-menu of the admin tools menu.
- If no targets are appearing on the GA-9120 BUI, ensure the radar status of the GA-9120 radar(s) is “Connected.” If the radar(s) are timing out or disconnected, navigate to the admin tools menu, process management menu, and restart radar1 (and radar2, radar3, etc.).
- If the radar status is disconnected and restarting the radars does not resolve the issue, verify that the host server’s storage is not nearly full; the GA-9120 radars will automatically shut down if the host server’s storage reaches ~95% capacity – this can occur if the radars are left running and local data logging to the server is enabled.
- If the GA-9120 radar is stuck in a timing out to disconnected loop, there is likely something wrong with the configuration files on the host server. Contact O.W.L. for further assistance.

4.2.3 *TAURAS Troubleshooting and Known Issues*

- If no targets are appearing on TAURAS, ensure the following:
 - Traffic Filter ranges are set to reasonable values. The default values are set to a reasonable general-use scenario. Try setting the Max Range very large and setting the Min and Max altitudes to their lowest and highest values, respectively.
 - There are targets incoming from at least one traffic sensor. This can be verified by looking at the Heartbeat Age within the legend. If these values are growing, it indicates the sensors may be offline. Contact NASA Langley’s SDAB for assistance.
- To quickly reset TAURAS to its initial state, simply refresh its page in the web browser. If both above steps have been verified, and the display is still not showing targets, contact SDAB for assistance.

4.3 Anomaly reporting

Contact information for LSTAR, GA-9120 and TAURAS are provided here for technical assistance and anomaly reporting.

- LSTAR
 - <https://www.srcinc.com/forms/contact.aspx>
 - (315) 452-8000
- GA-9120
 - <https://www.owlknows.com/contact/>
 - (256) 268-5239

- TAURAS
 - Contact NASA Langley’s Simulation Development and Analysis Branch:
https://flightsimulation.larc.nasa.gov/contact/?doing_wp_cron=1746218959.2258079051971435546875
- ANRA SS CTR
 - <https://www.anratechnologies.com/home/contact-us/>

5.0 Conclusion and Future Plans

This report provides a comprehensive overview of airspace surveillance radar capabilities at NASA Langley at the time of publication. Intended audiences include ARMD missions, other NASA Centers, NASA Langley’s new team members, and partners that may want to use this report as a guide for their own solutions. Detailed information about the specific radar systems, information systems, procedures, and facilities are provided in the context of UAS Flight operations infrastructure required to operate radar systems. The report also provides details about procurement, commissioning, and operations of the radar systems.

NASA Langley airspace surveillance capabilities are maturing and evolving and are integrated across several facilities and organizations and support a broad range of NASA mission needs. Information technology and security processes included in this report are an integral part of present NASA Langley capabilities and will vary across other NASA Centers and other government agencies.

The integrated airspace awareness capabilities at NASA Langley are unique in the Agency, and the Center is a key player in our regional AAM Digital Infrastructure ecosystem. NASA projects, State & Local governments, DOD, industry, and academic partners have requested the following⁵⁴:

- Aggregation and sharing of Airspace Sensor Data Feeds (i.e., to/from NASA Langley via NASA IoT Platform, VA-FIX)
- Radar/System Performance Characterization for FAA BVLOS Safety Cases
- TAURAS Software Release, Interface Document, and User's Guide to partners
- TAURAS Capability Extensions (i.e., additional sensors, data fusion)
- Acquiring and commissioning airspace sensors to expand regional airspace awareness
- Research, Development, and Test & Evaluation of new airspace sensor technologies

These activities align with the ARMD request to document these capabilities for internal use and make them available to other NASA Centers and other government organizations. While this report satisfies the criteria for documenting existing capability, the above activities are anticipated to continue through 2025 and beyond.

⁵⁴ See Sec. 1.4.1 “Airspace Sensor Data Sharing – Next Steps” and Sec. 3.7.6 “Performance Evaluation Next Steps”

6.0 Attachment 1: Supplemental Information – Systems

This attachment contains supplemental technical information that was determined to be too detailed for the main report body, but helpful to the reader seeking to operate these systems or implement similar capability elsewhere. The table and figure numbers are cited in the relevant sections of the report's main body.

6.1 MOSAIC Command Center Equipment List (See Section 1.2)

Table 6-1. MOSAIC Command Center Equipment List

MOSAIC Command Center Equipment List					
Item No.	Manufacturer	Description	Part Number	Quantity	Purpose
1	Samsung	85" Up-Front Displays	QB85R-N	3	Control Room Displays for GCS, Airspace Awareness Display, Range Cameras, UAS Camera, etc.
2	Dell	32" Desktop Displays	3223QE	18	Desktop Displays for GCS, Radar, etc.
3	Dell	Backup GCS Tablet - Cellular Network (AT&T FirstNet)	Latitude 7220	2	Standalone Redundant C2 Link to UAS; Connected to Network Via Cellular (AT&T FirstNet)
4	StarTech	8 Outlet Surge Protector	8N515S12-POWER-STRIP	6	Power for Desktop Displays, USB Extenders, Radios, Tablets
5	StarTech	4-Port USB Cat5/6 Extender (TX)	USB2004EXTV	6	MOSAIC PC USB Hub for Keyboard/Mouse/Headset
6	IOGEAR	Smart Card Reader	GSR202	6	End-User Credentialing
7	Logitech	Keyboard & Mouse	K750/M705	6	User Input to MOSAIC PCs
8	Logitech	GCS Hand Controller	F310	6	Remote Pilot Manual Control over UAS
9	Jabra	USB Single Ear Headset	HSC016	6	GCS Audio Alerts
10	Clear-Com	12 Channel Desktop VoIP Communications Lever Panel	V12LDD	6	Primary Crewmember Communications
11	Clear-Com	Single-Ear Headset for VoIP Comms	CC-300-X4	6	Headset for V12LDD
12	ICOM	Airband Radio	IC-A120	1	ATC Communications
13	Motorola	VHF Radio	XPR 5550e	1	Backup Crewmember Communications
14	Cisco	Desk Phone	CP-8853	6	Backup Crewmember Communications

6.2 MOSAIC Server Room Equipment List (See Sections 1.2 and 2.3.)

Table 6-2. MOSAIC Server Room Equipment List

MOSAIC Server Room Equipment List					
Item No.	Manufacturer	Description	Part Number	Quantity	Purpose
1	N/A	Windows 11 PCs	N/A	6	Ground Control Stations; Multi-Purpose Workstations
2	VuWall	Audio/Video-over-IP Encoder	E-240-2	5	Workstation Video Source Capture
3	VuWall	Audio/Video-over-IP Decoder	PAK-40-2	2	Video Distribution to Front Displays
4	VuWall	Audio/Video-over-IP Server	VW-ApplicationServer-1U-R-4	1	Video Routing & Front Display Configuration
5	Clear-Com	Eclipse HX-Delta Matrix Frame	Eclipse-HX-Delta-32P	1	Crewmember Communications Network Configuration & Routing
6	Clear-Com	Audio IP Interface Card	E-IPA-64HX	2	Audio over IP Network Interface & Channel Licenses
7	Clear-Com	Analog Audio Interface Card	MVX-A16-HX	1	Local Analog Audio Input/Output
8	Clear-Com	Radio Relay Interface Control Module	FOR-22	1	Airband and VHF Radio Integration to Crewmember Communications Network
9	Hewlett Packard Enterprise	HPE 5130 Series Network Switch	JG937A	1	Equipment Network Access
10	Hewlett Packard Enterprise	HPE DL360 Gen 11 Server	P52499-B21	3	Ubuntu: Radar/Sensor data ingestion, routing. Windows: SAN data access interface. Linux: SAN data backup.
11	Hewlett Packard Enterprise	Storage Area Network (SAN)	HPE Alletra 5030 (R4U34A)	1	Storage
12	Hewlett Packard Enterprise	Fibre Channel Switch	R8P28A	2	SAN data routing between HPE Alletra 5030 and Servers
13	Raritan	Keyboard, Video, Mouse (KVM) Switch	DKX3-108	1	HPE Server Access
14	Raritan	KVM VGA & USB Computer Interface Module	D2CIM-VUSB	3	KVM Switch Interface to Servers
15	StarTech	4-Port USB Cat5/6 Extender (RX)	USB2004EXTV	6	MOSAIC PC USB Hub for Keyboard/Mouse/Headset

6.3 LSTAR Specifications and Configuration Details

The LSTAR V(2) has a peak transmit power of 720W, and a minimum 18 ft minimum operational stand-off distance for personnel. Detailed specifications published in a prior NASA report⁵⁵ are provided in Table 6-3. Further information may be found in the manufacturer’s documentation^{56,57}.

Table 6-3. LSTAR Specifications (Ref. Section 1.1.1)

Performance Parameter	Specification
Frequency range	1215 – 1390 MHz
Prime power	90 – 260 VAC, 24 VDC, 40 – 400 Hz
Azimuth coverage	0 – 360°
Elevation coverage	Horizon – 30°
Airspeed	7 – 335 Knots
Azimuth detection/Track accuracy	1.25° / 0.8°
Elevation detection/Track accuracy	2° / 1.5°
Range detection/Track accuracy	30m / 25m
Probability of detection (1m ² target)	85%
Probability of track	94%
Probability of classification	85%
Track false alarm rate	1.0E-05
Track capacity	300
Instrumented range	~41km

⁵⁵ Matthew W. Coldsnow, et al. “Safety Case for Small Uncrewed Aircraft Systems (sUAS) Beyond Visual Line of Sight (BVLOS) Operations at NASA Langley Research Center,” NASA/TM–20230003007. (See Table 22.) <https://ntrs.nasa.gov/api/citations/20230003007/downloads/NASA-TM-20230003007.pdf>

⁵⁶Syracuse Research Corporation TD 21-1272 “Detection and Range Performance of the Counterfire, General Air Surveillance Mode, and the C-UAS Radar Modes for the AN/TPQ-49 and AN/TPQ-49A,” March 13, 2021.

⁵⁷ Syracuse Research Corporation “Operator Guide for Radar Set LSTAR(V)2,” May 4, 2015

6.4 GA-9120 Specifications, Configuration Details and Firewall Rules

Table 6-4 provides a summary of specifications in the publicly released GA-9120 Specification Sheet⁵⁸.

Table 6-4. GA-9120 Specifications (Ref. Section 1.1.2.)

Performance Parameter	Capability
Processing Type	Pulsed Doppler
Frequency Range	S-Band (3150 to 3250 MHz)
Range Resolution	10 or 20 m (adjustable)
Transmit Power	1KW
Minimum Operational Stand-off Distance for Personnel	>15 ft
Instrumented Range	15 Km
Detection Range	Large Aircraft 15 Km Small Drone (DJI Phantom) 5 Km
FOV	Azimuth 120° Elevation 12.5°
Minimum Detectable Velocity	0.25 – 1 mph
Dimensions	36" x 21" x 9"
Weight	90 lbs
Power Draw	200 W
Operating Temperature	–4°F to +122°F

⁵⁸ <https://owlknows.com/wp-content/uploads/2022/03/GA9120.pdf>

7.0 Attachment 2: Supplemental Information – Procedures

7.1 GA-9120 Radar Display Initial Setup & New User Access⁵⁹

The following instructions are for first-time setup of the GA-9120 radar display using PuttyCAC to connect to the GA-9120s and are tailored to NASA Langley users.

New users will need to be given read access to the GA-9120 host PC by the System Administrator.

- Launch Pageant SSH Authentication Agent⁶⁰
- Insert your Smartcard
- In the bottom-right corner of your screen, left click/open the app tray (the ^ icon).
- Locate the Pageant icon and right click it.
- Left click “Add CAPI Cert”
- A windows security dialogue box will appear. Ensure that the selected credentials are yours.
 - If the credentials of someone else appear, select “more choices” and scroll down until you see your credentials. Left click/select your credentials.
- Left click “OK”
- If prompted, enter your PIV Smartcard/NDC Account PIN.
- Launch Putty.
- Enter the GA-9120 radar’s hostname and/or IP address into the “Host Name” (or IP Address) entry.
 - Enter “GA-9120” in the “saved Sessions” entry.
 - Left click the “save” button.
- On the left-hand side, left click the “+” icon next to “SSH” to expand the SSH menu.
 - Left click the word “Auth” to open the certificate options menu.
 - Left click the box for “Allow agent forwarding” and ensure that it’s checked.
- On the left-hand side, left-click the word “Tunnels”
 - In the “Source Port” entry, enter “3000”
 - In the “Destination” entry, enter “127.0.0.1:80”
 - Left click “Add”
 - If successful, the “Forwarded ports:” box will be filled with the entry “L3000 127.0.0.1:80”
- On the left-hand side, scroll up to the top and left click on the word “Session”
 - Left click “GA-9120” under saved sessions and ensure it is highlighted in blue.
 - Left click “Save”
 - Left click “Open”
- A Putty terminal window will open. Login with your AuID.
 - A dialogue box will appear; left-click “Accept”

⁵⁹ For GA-9120 User’s Guide contact <https://www.owlknows.com/contact/> or (256) 268-5239

⁶⁰ https://winscp.net/eng/docs/ui_pageant

- A windows security dialogue box will appear. Ensure that the selected credentials are yours.
 - If the credentials of someone else appear, select “more choices” and scroll down until you see your credentials. Left click/select your credentials.
- Left click “OK”
- When prompted, enter your PIV Smartcard/NDC Account PIN.
- Minimize the Putty terminal window.
- Open a web browser of your choice.
- Navigate to the following address by entering it in the search bar at the top of the web browser: 127.0.0.1:3000
- A pop-up window will appear asking for a username and password. The below credentials are set by default:
 - Username: admin
 - Password: admin
- After the credentials have been entered, the “GROUNDWARE” logo will appear; wait a few seconds and then click anywhere within the web browser to proceed to the radar display. If successful, the GA-9120 radar display should now be displayed.

7.2 LSTAR Radar Display Initial Setup & New User Access⁶¹

The following instructions are for first-time setup of the LSTAR Multi-Mode radar display and are tailored to NASA Langley users.

Note: The Multi-Mode GUI is dependent on the Java Runtime Environment (JRE); NASA Langley utilizes Amazon Corretto OpenJDK.

New users require access to a device with the LSTAR Multi-Mode GUI installed & configured to talk with the LSTAR radar (i.e., no user account setup required).

- On the desktop, left click the “Multi-Mode-GUI” icon to launch the LSTAR Display software.
- After the radar display has completed launching, in the top left-hand corner, left click:
 - File
 - Add
 - Multi-Mode
- On the right-side of the radar display screen, left click “Radar-1” to expand the radar options. Left click on “General.”
 - In the General Settings Box, modify the “IP Address” entry to read the IP address of the LSTAR radar.
 - Hit the “Enter” key.
 - Click “Submit” at the bottom right.
- If successful, the LSTAR should now be visible on the radar display.

⁶¹ For LSTAR User’s Guide contact <https://www.srcinc.com/forms/contact.aspx> or (315) 452-8000

7.3 TAURAS Initial Setup⁶²

The following instructions are for first-time setup of TAURAS and are tailored to NASA Langley users.

New users require access to a device with the TAURAS software installed (i.e., no user account setup required). TAURAS is packaged with the bare minimum files required for execution. No installation or administrative privileges are required. TAURAS requires an internet connection for the map display and a connection to CERTAINIOC for the sensor data feed.

- To launch TAURAS, navigate to the location TAURAS is stored and double click the launch_tauras_server.bat program.
- A terminal window with the title “TAURAS Server (DO NOT CLOSE)” should open minimized, and a web browser should open the TAURAS display shortly after.
 - Files should not be moved or deleted.
 - Do **not** close the terminal window that appears, or targets will stop appearing on TAURAS.
- To stop TAURAS, close its tab in the Web Browser and close the opened Terminal window with the title “TAURAS Server (DO NOT CLOSE).”

⁶² For more information about TAURAS, contact NASA Langley’s Simulation Development and Analysis Branch: https://flightsimulation.larc.nasa.gov/contact/?doing_wp_cron=1746218959.2258079051971435546875

8.0 Attachment 3: NASA Internet of Things Platform System Overview

The NASA IoT Platform (introduced in Section 1.4, Airspace Surveillance Sensor Data Sharing, with acronyms and terms in footnotes) is a cloud-based system designed to support scalable, secure, and efficient data streaming, capture, and analytics for IoT and IoT-like applications. The architecture is based on a widely used industry framework for the Industrial IoT, ensuring interoperability and scalability.

The core components include Mosquitto (MQTT broker) for message-based publish-subscribe communication, Telegraf (server agent) for data collection, InfluxDB (time-series database) for efficient storage and retrieval of IoT metrics, and Grafana (visualization and analytics platform) for real-time data monitoring and analysis. These components work in unison to create a resilient system capable of handling high-frequency data streams, ensuring robust security, and providing valuable data insights.

The NASA IoT Platform is multi-cloud capable, allowing deployment across all major cloud vendors' environments. It is currently deployed within the Google Cloud Platform (GCP) commercial cloud and managed using NASA's APPDAT Kubernetes environment⁶³.

While the system is currently considered a prototype, it operates with an active NASA Authority to Operate (ATO) and leverages the APPDAT System Security Plan (SSP) to ensure compliance with NASA security policies. The platform incorporates industry-leading authentication mechanisms, leveraging KeyCloak for zero-trust access control to web interfaces and X.509 certificates with TLS 1.2 encryption for securing MQTT communications.

8.1 APPDAT, NASA Managed Kubernetes Environment

The NASA IoT Platform is hosted within the NASA APPDAT-managed Kubernetes environment, which provides a scalable and secure container orchestration system. Kubernetes automates the deployment, scaling, and operation of containerized applications, ensuring high availability and fault tolerance. The APPDAT platform is used to host Docker images of the IoT Platform's core components, simplifying deployment and management. By leveraging Kubernetes, the platform ensures consistent and reliable operation of its containerized services while maintaining security and performance within NASA's cloud infrastructure.

8.2 KeyCloak, Zero-Trust Authentication

To maintain a secure and controlled access environment, the NASA IoT Platform integrates KeyCloak, an open-source identity and access management solution. KeyCloak enforces a zero-trust security model, ensuring that all users and services must authenticate before accessing platform resources. It supports Single Sign-On (SSO), multi-factor authentication (MFA), and fine-grained authorization policies, allowing administrators to define access levels for different users and services. In the context of the NASA IoT Platform, KeyCloak secures access to web

⁶³ AppDat is a software factory, application hosting framework, and set of core services to support integrated cloud-native systems for NASA and NASA partners. AppDat enables rapid systems development paired with an automation centric operational compute and data environments, all built within a security-first, Zero Trust Architecture. <https://appdat.jsc.nasa.gov/>

interfaces such as Grafana, ensuring that only authorized personnel can view and analyze IoT data. Additionally, it integrates with Kubernetes to enforce role-based access control (RBAC) policies, limiting access to system components based on predefined permissions. This approach minimizes the attack surface and enhances the security posture of the platform.

8.3 System Components

8.3.1 *Mosquitto, Secure MQTT Publish/Subscribe Broker*

Mosquitto is a lightweight, open-source MQTT broker that facilitates real-time communication between IoT devices and backend systems. It implements the publish-subscribe messaging pattern, allowing devices to publish sensor data to specific topics while other components subscribe to these topics to receive relevant information. This architecture ensures efficient and decoupled communication, enabling scalable IoT data ingestion. Within the NASA IoT Platform, Mosquitto acts as the central messaging hub, managing the flow of IoT telemetry data from distributed sensors and devices. It supports Quality of Service (QoS) levels to ensure reliable message delivery, even in environments with intermittent connectivity. Secure communication is enforced through X.509 certificates and TLS 1.2 encryption, preventing unauthorized access and data tampering. The broker efficiently routes messages to Telegraf, which processes and forwards the data to InfluxDB for long-term storage and analysis.

Mosquitto supports a wide range of IoT devices, including microcontrollers (i.e., ESP32), wireless head-mounted displays (HoloLens 2, Apple Vision Pro), mobile devices (smartphones, tablets, wearables), and more complex applications running on traditional servers. This flexibility allows seamless integration with various IoT ecosystems, making it a powerful choice for industrial and enterprise applications.

Mosquitto includes robust topic-level security, enabling fine-grained access control for different MQTT topics. This feature allows administrators to define permissions for individual topics, ensuring that only authorized devices and users can publish or subscribe to specific data streams. By implementing topic-based security policies, the platform enhances data privacy and prevents unauthorized access to sensitive telemetry information.

The Mosquitto Management Console (MMC) is a web-based interface that provides real-time monitoring and administration of the MQTT broker. Through MMC, administrators can view connected clients, manage subscriptions, and troubleshoot communication issues. This tool enhances operational efficiency by offering a user-friendly way to oversee MQTT-based messaging within the NASA IoT Platform.

8.3.2 *Telegraf, Server Agent for Data Collection*

Telegraf is an open-source server agent used for collecting, processing, and forwarding metrics. It operates using a plugin-driven architecture, supporting a wide range of input and output sources. Within the NASA IoT Platform, Telegraf subscribes to MQTT topics managed by Mosquitto, retrieving real-time IoT data streams. It processes incoming messages, performs data transformation if needed, and forwards the structured data to InfluxDB.

Telegraf's modularity allows for easy integration with various data sources and destinations, ensuring flexibility in data handling. It also includes monitoring and alerting capabilities,

enabling proactive identification of anomalies within the IoT data streams. Additionally, Telegraf's extensibility allows users to install plugins that facilitate data routing to other cloud environments, ensuring seamless multi-cloud interoperability. This feature enables organizations to store and analyze IoT data across different cloud providers, increasing data redundancy and accessibility.

8.3.3 *InfluxDB, Time-Series Database for Data Storage*

InfluxDB is a high-performance, time-series database designed to handle large volumes of time-stamped data efficiently. In the NASA IoT Platform, InfluxDB serves as the primary storage solution for IoT telemetry, providing optimized data retention, indexing, and query capabilities. Its ability to handle high-frequency data-writes makes it ideal for IoT applications where sensor readings are generated at rapid intervals. InfluxDB supports powerful query languages, enabling users to extract trends, detect anomalies, and generate insights from historical data. It also integrates seamlessly with Grafana, allowing for real-time visualization of stored metrics. The database's retention policies and downsampling features help manage storage costs while ensuring critical data remains accessible for analysis. Through InfluxDB, the NASA IoT Platform provides a robust and scalable foundation for storing and analyzing time-series data collected from IoT devices.

8.3.4 *Grafana, Data Visualization and Analytics Platform*

Grafana is an open-source visualization and analytics tool that provides interactive dashboards and real-time monitoring capabilities. In the NASA IoT Platform, Grafana connects to InfluxDB to retrieve stored telemetry data, allowing users to explore trends, monitor system performance, and gain actionable insights from IoT-generated data. It supports customizable dashboards with a variety of visualization options, including graphs, heatmaps, and alerts. Grafana also integrates with KeyCloak for secure user authentication, ensuring that only authorized personnel can access the visualization platform. Through its alerting system, Grafana can notify users of critical conditions, enabling rapid response to anomalies detected in IoT data streams. By offering an intuitive and flexible interface, Grafana enhances the decision-making process, allowing engineers and analysts to derive valuable insights from the continuous flow of IoT data.

8.4 Capabilities and Features

Publish/Subscribe Architecture

- Supports decoupled, asynchronous communication between devices and services.
- Enables scalable and dynamic message flow in distributed systems.
- Optimized for real-time telemetry delivery and minimal bandwidth overhead.

Commercial Cloud Deployment

- Deployable on GCP, Amazon Web Services (AWS), Azure, or hybrid environments.
- Facilitates high availability, redundancy, and compliance with organizational standards.

- Containerized architecture supports automated deployment and scaling via Kubernetes.

Data Encryption and Secure Communication

- TLS 1.2 ensures secure, encrypted transport for all MQTT messages.
- Integrated certificate-based authentication guards against spoofing and data tampering.

Certificate-Based Authentication

- Devices and clients authenticate using industry-standard X.509 certificates.
- Fine-grained access control down to the topic level using access control lists (ACLs).

Zero-Trust Authorization Model

- All resource access requires continuous authentication and authorization.
- RBAC policies ensure that users only access the data they are explicitly allowed to see.
- Integration with federated identity services supports organizational access policies.

Edge Computing Compatibility

- Integrates with edge devices for low-latency processing and local decision-making.
- Reduces bandwidth and supports disconnected or low-connectivity environments.
- Buffers and forwards data when networks become available.

Modular and Extensible Architecture

- Built with open-source components and plugin ecosystems.
- Easily expandable with new services or protocols.
- Supports mission-specific customization and rapid prototyping.

Real-Time Alerting and Anomaly Detection

- Time-series data streams trigger alerts in real-time via Grafana.
- Supports rule-based monitoring for proactive incident response.

Federated Identity and Multi-Tenant Support

- KeyCloak enables secure user federation across organizations.
- Supports isolated data access and dashboard views by mission or role.

Auditing and Observability

- Full audit trails of authentication, data access, and system performance.

- Compatible with Prometheus for system monitoring.

Developer and Application Programming Interface (API)-Friendly Design

- All services offer well-documented APIs.
- Enables automation, integration with external pipelines, and Continuous Integration/Continuous Deployment (CI/CD) workflows.

Offline and Disconnected Operation Support

- Caches or buffers telemetry in environments with limited connectivity.
- Supports deployment in field sites or remote research facilities.

Automated Deployment and Infrastructure as Code

- Supports Terraform, Helm, and other tools for repeatable, automated infrastructure provisioning.
- Ensures consistency across environments and simplifies lifecycle management.

Interoperability with Industry Standards

- Adheres to open protocols including MQTT, HTTP(S), REST, and WebSockets.
- Facilitates easy integration with third-party platforms and tools.
- Compatible with many industrial systems

Policy-Driven Data Governance

- Tagging and classification for mission-specific data management.
- Enforces compliance and supports audit readiness with minimal overhead.

Built-In High Availability and Failover

- Kubernetes-based orchestration ensures fault tolerance and rapid recovery.
- Supports geo-distributed deployment strategies.

Integration with Digital Twins and Simulation Environments

- Enables closed-loop telemetry exchange with digital twin models.
- Supports real and synthetic data workflows.

Data Lifecycle Management

- Retention policies, tiered storage, and automated rollups reduce data costs.
- Supports long-term storage planning and archiving.

8.5 Potential Use Cases and Applications

The NASA IoT Platform supports a diverse set of mission-driven applications that span Earth, space, and interplanetary operations:

Environmental Monitoring and Life Support Systems

- Collects real-time data from spacecraft and habitat sensors (e.g., temperature, CO₂, humidity).
- Supports alerts, dashboards, and trend analytics for crew safety and system optimization.

Autonomous Robotics and Rovers

- Aggregates telemetry from mobile platforms such as Mars rovers or drones.
- Enables secure command-and-control and performance monitoring via MQTT.

Augmented Reality (AR) for Maintenance and Training

- Streams contextual telemetry to AR headsets for real-time procedural guidance.
- Supports hands-free operations using devices like HoloLens 2 or Apple Vision Pro.

Ground Station Telemetry Aggregation

- Consolidates signals from distributed antennas and uplink/downlink systems.
- Offers a unified view of satellite health, tracking status, and telemetry logs.

Scientific Instrumentation and Field Research

- Provides sensor data ingestion from portable labs, observatories, and remote sites.
- Ensures data reliability and continuity through edge buffering and cross-cloud syncing.

Smart Facilities and Infrastructure

- Enables predictive maintenance, occupancy analysis, and energy optimization in NASA buildings.
- Centralizes control of lighting, HVAC, and structural health monitoring systems.

8.6 Additional Resources

- Mosquitto - <https://mosquitto.org/>
- Telegraf - <https://docs.influxdata.com/telegraf/>
- InfluxDB - <https://docs.influxdata.com/influxdb/>
- Grafana - <https://grafana.com/docs/>

- KeyCloak - <https://www.keycloak.org/>
- NASA APPDAT Handbook - <https://handbook.appdat.jsc.nasa.gov/docs/about/kubernetes/>

9.0 Attachment 4: Acronym List

AADS	Airspace Awareness and Detection System
AAM	Advanced Air Mobility
ACL	Access Control List
ADS-B	Automatic Dependent Surveillance Broadcast
AGL	Above Ground Level
AM	Airspace Monitor
ANRA SS CTR	NRA Smart Skies Control
API	Application Programming Interface
AR	Augmented Reality
ARC	Ames Research Center
ARMD	Aeronautics Research Mission Directorate
ATC	Air Traffic Control
ATO	Authority to Operate
AWS	Amazon Web Services
BUI	Browser User Interface
BVLOS	Beyond Visual Line of Sight
C2	Command and Control
CERTAIN	City Environment for Range Testing of Autonomous Integrated Navigation
CERTAINIOC	CERTAIN Input/Output Concentrator
CI/CD	Continuous Integration/Continuous Deployment
COA	Certificate of Authorization
COTS	Commercial Off-The-Shelf
FAA	Federal Aviation Administration
FLARM	Flight Alarm
FOV	Field-of-View
FTL	Flight Test Lead
GA	General Aviation
GBDAA	Ground-Based Detect and Avoid
GCP	Google Cloud Platform
GCS	Ground Control Station

GFCI	Ground Fault Circuit Interrupter
GPS	Global Positioning System
GUI	Graphical User Interface
HDV	High Density Vertiplex
HPE	Hewlett Packard Enterprise
IAD	Integrated Airspace (surveillance) Display
IAM	Identity and Access Management
INS	Inertial Navigation System
IoT	Internet of Things
JRE	Java Runtime Environment
KSC	Kennedy Space Center
KML	Keyhole Markup Language
KVM	Keyboard, Video, Mouse
LAFB	Langley Air Force Base
LaRC	Langley Research Center
LaRCNet	Langley Research Center Network
LMV	LaRC Monitoring Volume
LOP	Letter of Procedure
LSTAR	Lightweight Surveillance and Target Acquisition Radar
MAAP	Mid-Atlantic Aviation Partnership
MC	Mission Commander
MFA	Multi-Factor Authentication
MMC	Mosquito Management Console
MO	MOSAIC Operator
MOSAIC	Mission Operations & Autonomous Integration Center
NASA	National Aeronautics and Space Administration
NEMA	National Electrical Manufacturers Association
NM	Nautical Mile
NOVO	No Visual Observer
NTIA	National Telecommunications and Information Administration
NTRS	NASA Technical Reports Server
NTP	Network Time Protocol

O.W.L. TM	Observation Without Limits
PoE	Power-Over Ethernet
PPI	Plan Position Indicator
QoS	Quality of Service
RBAC	Role-Based Access Control
RF	Radio Frequency
RFA	Radio Frequency Authorization
RO	Radar Operator
ROAM	Remote Operations for Autonomous Missions
R-PIC	Remote Pilot in Command
RSO	Range Safety Officer
SAN	Storage Area Network
SAO	Scalable Autonomous Operations
SCM	System Control Module
SDA	Software-Defined Access
SDAB	Simulation Development and Analysis Branch
SRC	Syracuse Research Corporation
SSO	Single Sign-On
SSP	System Security Plan
STI	Scientific and Technical Information
sUAS	Small Uncrewed Aircraft System
TAURAS	Traffic Awareness and Ubiquitous Real-Time Airspace
TLS	Transport Layer Security
UAM	Urban Air Mobility
UAS	Uncrewed Aircraft System
UMAT	UAS Mission Analysis Tool
VAC	Volts of Alternating Current
VA-FIX	Virginia Flight Information eXchange
VDC	Volts of Direct Current