Report for
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Unmanned Aerial System (UAS) Research for Public Safety Applications

Task 5: Detect and Avoid (DAA) Flight Testing
Final Report

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ADS-B............Automatic Dependent Surveillance-Broadcast
AESA ....Active Electronically Scanned Array
AGL ....Above Ground Level
AI ....Artificial Intelligence
API ....Application Programming Interface
ASTM ....American Society for Testing and Materials
BVLOS ....Beyond Visual Line of Sight
DAA...............Detect and Avoid
EO ....Electro-Optical
ESPRIT ....Estimation of Signal Parameters via Rotational Invariance Technique
ESA ....Electronically Scanned Array
FAA................Federal Aviation Administration
GPU................Graphics Processing Unit
IoT..................Internet of Things
IP ....Internet Protocol
ITAR ....International Traffic in Arms Regulations
MC ....Mission Commander
MESA ....Metamaterial Electronically Scanning Array
MUSIC...........Multiple Signal Classification
NAS................National Airspace System
PACAS...........Passive Acoustic Noncooperative Collision Avoidance System
PIC ....Pilot-in-Command
RPAS..............Remote Pilot Aircraft System
RTCA.............Radio Technical Commission for Aeronautics
SARA.............Scientific Applications and Research Associates, Inc.
SORA.............Specific Operational Risk Assessment
sUAS ....Small Unmanned Aircraft Systems
SWaP..............Size, Weight, and Power
TASA ....Terrestrial Acoustic Sensor Array
TCP ....Transmission Control Protocol
TDOA ....Time Difference of Arrival
TVA ....Tennessee Valley Authority
UAS................Unmanned Aircraft System
UAV ....Unmanned Aerial Vehicle
UI ....User Interface

EXECUTIVE SUMMARY

The safe and routine integration of small Uncrewed Aircraft Systems (sUAS) into the National Airspace System (NAS) requires proven Detect-and-Avoid (DAA) technologies capable of providing an equivalent level of safety to that achieved by human pilots in manned aviation. This report documents the evaluation and flight testing of radar-based, electro-optical, and acoustic sensing systems conducted under Task 5, with the objective of assessing their readiness for supporting Beyond Visual Line of Sight (BVLOS) operations in public safety and commercial contexts.

The assessment focused on three primary sensing modalities: radar, electro-optical, and acoustic systems. Each modality was tested for its ability to detect cooperative and non-cooperative aircraft, maintain well clear separation standards, and provide reliable situational awareness under realistic operational conditions. The findings highlight both the strengths and limitations of each technology and underscore the need for multi-sensor fusion approaches to achieve robust BVLOS capabilities.

Radar-based systems emerged as the most mature and operationally reliable class of DAA technology. Airborne radars such as Echodyne's EchoFlight and Fortem's TrueView R20 demonstrated compact form factors and low SWaP characteristics suitable for sUAS integration, with detection ranges extending up to several kilometers for small aircraft. Ground-based radars, including Echodyne's EchoGuard and Canadian UAVs' Sparrowhawk Marine Radar, provided wide-area surveillance and persistent coverage unconstrained by onboard power or payload limitations. Testing confirmed Sparrowhawk's ability to detect 1 m^2 radar cross-section targets out to 14 nautical miles with consistent performance across a variety of encounter geometries. These results reinforce the suitability of radar as a primary sensing modality, particularly where all-weather, day-night performance is required.

Electro-Optical (EO) systems demonstrated strong detection and tracking performance under favorable atmospheric conditions but showed sensitivity to visibility and weather conditions. Iris Automation's Casia G network provided scalable ground-based coverage, detecting general aviation aircraft within ranges of 1.3–2.8 km, depending on ceiling conditions. Multi-node network architectures successfully eliminated blind spots and ensured continuity of detection across the test area, although performance degradation was significant under low-ceiling or high-scatter conditions. These findings validate EO systems as effective supplements to radar, particularly in clear-weather operations, while highlighting their dependency on visual meteorological conditions.

Acoustic systems provided unique capabilities not available through electromagnetic sensing. Scientific Applications and Research Associates (SARA) Inc.'s Terrestrial Acoustic Sensor Array (TASA) demonstrated multi-mile detection ranges and the ability to detect aircraft obscured by terrain, vegetation, or structures. Unlike optical systems, performance was unaffected by lighting or weather conditions, but environmental noise proved to be a significant challenge. Reliable triangulation required multi-node deployments, as single nodes were limited in accuracy and vulnerable to false positives. Despite these limitations, acoustic sensing showed distinct promise for layered DAA architectures in environments where radar or EO sensors are restricted.

Taken together, these findings illustrate that no single modality can fully address the diverse operational requirements of BVLOS flight. Radar systems provide the most consistent baseline, EO systems offer cost-effective visual coverage where conditions permit, and acoustic systems fill critical detection gaps in non-line-of-sight environments. A hybrid, multi-sensor approach represents the most viable path forward for achieving regulatory compliance, ensuring public safety, and enhancing operational resilience.

This work directly supports the Federal Aviation Administration's (FAA) proposed Part 108 rule for BVLOS operations by providing empirical data on the performance of candidate DAA technologies. Continued maturation of these systems through expanded testing, standardized integration frameworks, and sensor fusion research will be essential for enabling scalable sUAS operations. By advancing the readiness of radar, EO, and acoustic systems, this research effort lays the foundation for achieving safe, routine BVLOS flights that expand the role of UAS in infrastructure inspection, emergency response, and other public safety applications.

1 INTRODUCTION & BACKGROUND

The safe and efficient integration of Unmanned Aircraft Systems (UAS) into the National Airspace System (NAS) requires technologies and procedures that achieve an equivalent level of safety to that of a human pilot in traditional aviation. The fundamental challenge of UAS operations is that, unlike conventional aircraft, they lack an onboard pilot who can visually scan for and avoid airborne hazards. This limitation creates a technical barrier to the wider adoption of UAS in shared airspace, particularly for beyond visual line of sight (BVLOS) missions, where reliance on ground-based observers or chase aircraft is impractical. Detect-and-Avoid (DAA) technologies address this challenge by providing UAS with the ability to sense surrounding cooperative and non-cooperative traffic, assess potential conflicts, and execute timely maneuvers to remain well clear and avoid collisions.

Research and development of DAA capabilities have accelerated in recent years, driven by regulatory needs and industry demand for expanded operational flexibility. The Federal Aviation Administration (FAA), through initiatives such as Radio Technical Commission for Aeronautics (RTCA) Special Committee 228, has outlined performance standards for DAA systems, emphasizing reliable detection, accurate tracking, and appropriate avoidance maneuvering (RTCA, 2020). Building on these foundations, the FAA's proposed Part 108 rule, published in August 2025, establishes a regulatory framework for routine BVLOS operations, emphasizing the critical need for validated DAA technologies that can reliably detect both cooperative and non-cooperative aircraft across diverse operational environments (FAA, 2025).

For small UAS weighing less than 55 pounds, achieving these performance standards is particularly challenging due to the strict size, weight, and power (SWaP) constraints. Unlike larger UAS, which can accommodate high-power radar or complex electro-optical payloads, sUAS platforms must employ compact, energy-efficient, and cost-effective solutions. As a result, research has explored multiple sensing modalities to strike a balance between capability and feasibility. Radar-based systems offer all-weather, long-range detection of non-cooperative targets, though SWaP constraints remain a key engineering challenge. Optical systems can achieve high resolution but are often limited by factors such as lighting, weather, and processing demands. Acoustic sensing provides a lightweight, low-power solution for detecting nearby aircraft, although its performance is sensitive to background noise and propagation conditions. A hybrid or layered approach that fuses data from radar, optical, and acoustic sensors is increasingly recognized as a promising pathway for sUAS DAA solutions, improving robustness across varied operational scenarios.

To address these challenges, this report examines the spectrum of DAA sensing modalities currently under investigation for small UAS applications, with a focus on their relative strengths, limitations, and integration considerations. Section 2 begins with radar-based systems, highlighting their maturity, active sensing advantages, and ongoing miniaturization efforts that make them increasingly viable within the strict SWaP limits of sUAS platforms. Section 3 examines optical sensing technologies that provide high-resolution situational awareness but are limited by environmental factors such as lighting and weather conditions. Section 4 turns to acoustic sensing, a lightweight and low-power modality with unique potential for detecting aircraft at close ranges, although it is challenged by noise, range, and directionality. Together, these discussions provide the technical foundation for understanding how DAA research and development can reduce barriers to NAS integration while enabling safe and routine BVLOS operations under emerging FAA regulatory frameworks such as the proposed Part 108 rule.

2 RADAR-BASED SYSTEMS

Radar technology is one of the most well-known and mature sensing modalities for DAA. Unlike passive sensors that rely on external signals or favorable lighting conditions, radar systems actively interrogate the environment using electromagnetic waves, enabling reliable detection and tracking of aircraft in all weather conditions, day or night (Khawaja, et al., 2022).

The fundamental appeal of radar for DAA applications lies in its ability to provide direct measurements of target range, bearing, and relative velocity through the physics of electromagnetic wave propagation. When radio waves encounter objects in the airspace, a portion of the energy is reflected back to the radar receiver, with the time delay between transmission and reception directly proportional to target distance (Khawaja, et al., 2022). This active sensing approach eliminates dependence on cooperative transponders or visual signatures, making radar particularly effective for detecting non-cooperative aircraft that may not broadcast position information or maintain visible lighting.

2.1 Overview

Contemporary radar architectures suitable for small UAS DAA applications have evolved significantly from traditional mechanically scanned systems to electronically steered arrays, offering superior flexibility and performance. Pulse-Doppler radar implementations dominate modern DAA systems, providing simultaneous range and velocity measurements through coherent processing of return signals. The Doppler effect, manifested as frequency shifts in returns from moving targets, enables critical discrimination between aircraft of interest and stationary environmental clutter while providing direct velocity measurements essential for collision prediction algorithms (Khawaja, et al., 2022).

The emergence of Active Electronically Scanned Array (AESA) and Metamaterial Electronically Scanned Array (MESA) technologies has revolutionized radar capabilities for airborne platforms. These solid-state architectures eliminate mechanical scanning limitations through electronic beam steering using phase shifters or metamaterial elements (Khawaja, et al., 2022). This technological advancement enables near-instantaneous beam positioning, simultaneous multi-beam operation, and adaptive waveform generation optimized for specific detection scenarios. For small UAS applications, these technologies offer the dual benefits of reduced mechanical complexity and enhanced reliability while maintaining detection performance in compact form factors.

For small UAS platforms operating under the 55-pound threshold, radar systems have some advantages and challenges. The primary benefit is operational reliability across diverse environmental conditions, enabling the system to maintain detection performance even in weather phenomena that would hinder other sensor types. Power consumption represents a primary constraint for onboard systems, as radar transmission and processing demands must be balanced against limited battery capacity and competing system requirements. Modern radar architectures try to address this challenge through duty cycle optimization, adaptive power management, and efficient solid-state amplifier designs that minimize energy consumption while maintaining detection performance (Fortem Technologies, 2025).

Ground-based DAA sensors can mitigate the SWaP limitations encountered by onboard sensors; however, they typically require a larger detection range, as the fixed detection volume must cover the entire operational area, which can increase costs. Regulatory considerations such as operating frequency allocations, power limitations, and interference mitigation requirements vary by jurisdiction and should be carefully considered.

The following sections examine specific radar systems that demonstrate these technological principles in practical implementations, ranging from compact airborne sensors designed for integration into small UAS platforms to ground-based systems that provide area surveillance capabilities for beyond visual line of sight operations.

2.2 Echodyne EchoFlight Airborne DAA Radar

EchoFlight is a compact, high-performance radar purpose-built for aerial DAA applications. Whether mounted on a tethered drone monitoring a crowded urban airspace or integrated into a UAS platform supporting autonomous flight operations, EchoFlight provides real-time situational awareness in an ultra-low SWaP package (Echodyne, 2025).

EchoFlight is an airborne DAA radar designed specifically to provide UAVs with advanced airspace deconfliction capabilities. Featuring Echodyne's cutting-edge active beam-steering technology, the ESA radar is highly configurable to provide an ideal solution for a wide range of unmanned aircraft platforms and missions. EchoFlight provides seamless and calibration-free integration, outputting rich and high-precision data that can be fed into autopilot and remote pilot systems, or combined with other sources, such as Automatic Dependent Surveillance-Broadcast (ADS-B). The compact and lightweight system has a relatively low power requirement. The EchoFlight also features Time Channel Mitigation, which allows multiple EchoFlight radars to operate on the same frequency in close proximity without compromising performance. The EchoFlight specifications are listed in Figure 1 below.

RADAR PERFORMANCE	SWaP & ENVIRONMENTAL	INTEGRATION & DATA
Frequency K-band 24.45 – 24.65 GHz	**Size** 18.7 cm x 12 cm x 4 cm	**Control I/O** Gigabit Ethernet
Field of View 120° Azimuth x 80° Elevation	**Weight** 817 g (Natural Convection)	**Power I/O** Snap Lock 12 Pin Connector
Track Accuracy < 1° Azimuth x < 1.5° Elevation	**Power** + 12 to + 28 VDC 45 W (Operating) ≤ 10 W (Hot standby)	**Data Output** R/Vmaps: 40 MBps Detections: 1 MBps Measurements: 1 MBps Tracks: 25 KBps
Track Update Rate 10 Hz	**Operating Temp** - 40° C to + 75° C	
Max Tracks Up to 20 Simultaneous Tracks	**Weather Protection** IP67	
Instrumented Range 6 km		
Range sUAV: > 750 m (Phantom 4) > 1 km (Matrice 600) Cessna: > 2 km		

Figure 1. EchoFlight Technical Specifications (Echodyne, 2025)

2.3 Fortem TrueView R20 Radar

The Fortem TrueView R20 Radar is among the smallest radar systems in its class, featuring true AESA technology (Fortem Tech, 2025). Engineered specifically for low-altitude airspace operations, the R20 provides three-dimensional detection and tracking of both cooperative and non-cooperative aircraft. Its configurable instrumented range extends from 1 km up to 8 km, with demonstrated detection capabilities of small multi-rotor UAS at approximately 0.75–1.0 km and larger multi-rotor platforms at around 1.3 km. For manned aircraft, Fortem reports detection ranges on the order of 3 km. The radar's field of view can be configured up to 120° in azimuth by 60° in elevation, with pointing accuracies of ±2° (Fortem Tech, 2025).

Table 1. TrueView R20 Radar Specifications (Fortem Tech, 2025)

Dimensions	8.11 in x 3.19 in x 3.37 in
Weight	2.9 lbs 2.4 lbs (without fan and shroud)
Input Power	18-36 VDC, 38 W draw
Power Transmitted	1.9 W (+32.8 dBm)
Radar Frequency Range	15.4-16.7 GHz
Max Radar Bandwidth	180 MHz (at 1 m range resolution)
Tx Antenna Gain	12 dBi
Tx EIRP	30.0 W (+44.8 dBm)
Maximum Field of View	Up to 120º azimuth x 60º elevation
Angular Accuracy	± 2º azimuth, ± 2º elevation
Tracking Range Small Multi-Rotor UAS (e.g. DJI Phantom 4)	0.75 km to 1.0 km
Tracking Range Multi-Rotor UAS (e.g. DJI Matrice 600)	1.3 km
Track Update Rate	Between 64 ms to 1.3 s, configurable
Minimum Target Radial Velocity	0.15 m/s or less, configurable
Instrumented Range	1-8 km, configurable

The system integrates Artificial Intelligence (AI) enabled micro-Doppler classification and convolutional neural network processing at the edge, which helps reduce false alarms commonly caused by birds or environmental clutter. This onboard processing capability enables real-time classification and prioritization of multiple simultaneous tracks, thereby enhancing situational awareness for informed collision avoidance decision-making.

2.4 Echodyne EchoGuard

The Electronically Scanned Array (ESA) radar, the gold standard, has been cost-prohibitive and operationally restrictive for all but Defense and National Security applications. Echodyne's patented MESA technology, along with advanced software, offers ESA performance in a compact, solid-state format. This system detects, tracks, and classifies objects on the ground or in the air, regardless of weather or lighting. The EchoGuard's ultra-low SWaP and software-defined capabilities, free from International Traffic in Arms Regulations (ITAR) rules, enable quick responses to user, site, and mission needs anywhere in the world. EchoGuard has a 120° azimuth x 80° elevation field of view. EchoGuard can detect and track up to 20 objects, delivering high-fidelity data in a proprietary format over a standard Transmission Control Protocol (TCP)/Internet Protocol (IP) gigabit Ethernet connection.

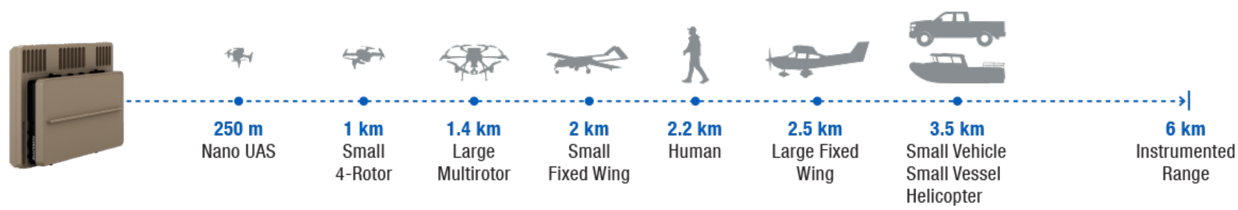


Figure 2. EchoGuard Typical Tracking Ranges (Echodyne, 2025)

The EchoGuard is designed to handle missions such as perimeter security for border or critical infrastructure applications, counter UAS detection and tracking of intruders, and ground-based DAA applications. It can provide the same level of safe operation for small UAS vehicles too small to carry their own radar system, by providing localized situational pilot awareness of both ownship position, along with cooperative and non-cooperative intruder air vehicles. Multiple EchoGuard units may be combined into flexible local networks for increased coverage.

Figure 3. Echodyne EchoGuard ground-based radar.

RADAR PERFORMANCE

Frequency
K-band 24.45 – 24.65 GHz (USA)
K-band 24.05 – 24.25 GHz (INTL)

Field of View
120° Azimuth x 80° Elevation

Track Accuracy
< 1° Azimuth x < 1.5° Elevation

Track Update Rate
10 Hz

Max Tracks
Up to 20 Simultaneous Tracks

Instrumented Range
6 km

Range
sUAV: > 1 km (Phantom 4)
> 1.4 km (Matrice 600)
Vehicle: > 3.5 km
Human: > 2.2 km

SWaP & ENVIRONMENTAL

Size
20.3 cm x 16.3 cm x 4 cm

Weight
1.25 kg

Power (USA)
+ 15 to + 28 VDC
50 W (Operating)
≤ 10 W (Hot Standby)

Power (INTL)
+ 15 to + 24 VDC
50 W (Operating)
≤ 7 W (Hot Standby)

Operating Temp
- 40° C to + 75° C

Weather Protection
IP67

INTEGRATION & DATA

Control I/O
Gigabit Ethernet

Power I/O
Snap Lock 12 Pin Connector

Data Output
R/V Maps: 40 MBps
Detections: 1 MBps
Measurements: 1 MBps
Tracks: 25 KBps

Mounting
VESA 75 & 100 mm

Figure 4. EchoGuard Technical Specifications (Echodyne, 2025)

2.5 Fortem R30

The R30 is a high-performance, ground-based AESA radar with 256 receive elements, 16 digital channels, multi-channel digital beamforming, and simultaneous analog beam steering. TrueView radars have an advantage over alternatives, with onboard graphics processing, the R30 analyzes contacts in real-time to deliver intelligence to operators and other end-users of tracked information.

Figure 5. Fortem Technologies TrueView R30 in a four-radar installation.

Table 2. Fortem Technologies TrueView R30 Radar System Specifications

Specification	Value
Field of View	120° azimuth x 120° elevation
Resolution	Configurable
Detection Range	Small UAS: 1800m Manned Aircraft: 4.5km
Operating Conditions	"All Weather Conditions"

2.6 MatrixSpace 360 Radar

MatrixSpace 360 Radar is a sensor system that is designed to enhance situational awareness. The system uses cutting-edge radar technology, combined with artificial intelligence, to detect and classify intruding aircraft. The radar system is small and is designed specifically for small UAS DAA applications. The system can be supplied in a number of configurations, from single-panel up to quad-panel configurations, with each panel offering a 120° x 120° field of view. This flexibility allows operators to tailor the radar coverage to meet specific mission requirements and environmental conditions (MatrixSpace, 2025).

Table 3. MatrixSpace 360 Radar System Specifications (MatrixSpace, 2025)

Specification	Value
Dimensions (Single Unit)	8.7cm x 14.1cm x 4.2cm
Weight	<1 lb per unit
Power Consumption	25W
Detection Range (Cessna 172)	2.5km typical, >3km maximum
Detection Range (Small UAS)	750m typical, >1km maximum
Field of View (Single Panel)	120° x 120°
Environmental Operation	All weather conditions
Power Options	Battery, solar, 120VAC, 240VAC, 48VDC

The system features onboard AI processing, enabling object classification and tracking without needing external computing infrastructure. The system can continue to operate and maintain full functionality across all weather conditions, day and night, that typically compromise optical sensor performance. The system features dynamic clutter filtering to reduce false alarms from environmental returns while maintaining sensitivity to targets of interest.

The system has gained significant recognition through high-profile implementations and strategic partnerships. MatrixSpace was recently selected to provide airspace detection capabilities for the Department of Homeland Security's U.S. Customs and Border Protection BVLOS drone operations. This government validation demonstrates the system's operational readiness and regulatory compliance for critical security applications (MatrixSpace, 2025). MatrixSpace has also partnered with Sagetech Avionics to integrate the radar with certified DAA computers, demonstrating the system's compatibility with existing aviation safety systems (Sagetech Avionics, 2025). The Campbell Police Department has implemented the system in their drone first responder program, enabling single-operator BVLOS flights at extended altitudes during day and night operations (Axon, 2024)

The modular architecture supports scalable deployment across operational areas without requiring infrastructure modifications. Multiple radar nodes can be networked to extend coverage areas while maintaining centralized monitoring and control. The system's compact form factor enables integration with both fixed installations and mobile platforms for tactical deployment scenarios.

2.7 Canadian UAVs: Sparrowhawk Marine Radar

The Sparrowhawk Marine Radar is a ground-based DAA solution specifically engineered for BVLOS operations. Developed by Canadian Unmanned Aerial Vehicles (UAVs), the system combines X-band pulse radar (9410 MHz, 25 kW) with Software-Defined Radio for ADS-B data fusion, creating comprehensive airspace surveillance for the detection of small aircraft.

The system detects 1 m^2 radar cross-section targets (Cessna-172 equivalent) at ranges up to 14 nautical miles with 360° azimuth coverage and ±11° elevation. Operating through the Sparrowhawk Airspace Management Software, raw radar data undergoes real-time processing with 3-of-5 scan confirmation logic, integrating with Lockheed Martin's VCSi interface for operator visualization. Figure 6 shows how the Sparrowhawk Marine Radar is used for field testing and operations.

Figure 6. Sparrowhawk Mobile Setup on GCS Trailer

Unlike airborne systems, Sparrowhawk's ground-based architecture eliminates size, weight, and power constraints while providing unlimited operational endurance.

2.7.1 System Specifications

General System Characteristics (Canadian UAVs, 2025)

- Radar Type: Pulse
- Radiator Length: 8 ft
- Antenna Gain: 31.5 dBi
- ERP: 106 dBm (74dBW / 24 MW)
- Emission Designator: 60M0P0N
- Weight: 42 kg / 93 lbs
- Operational Mode: Airspace Surveillance
- Mobility: Fixed-Site, Vehicle-Mounted, Transportable
- Intended Use Case: DAA for BVLOS Remote Pilot Aircraft System (RPAS) Operations, Air Traffic Monitoring

Performance Specifications (Canadian UAVs, 2025)

- Output Power: 25 KW
- Operating Frequency Band: 9410 MHz ±30 MHz (X-band)
- Radar Cross Section (RCS) Detection: 1 m^2 (assumed size for Cessna-172)
- Detection Range: Up to 14 NM
- Altitude Coverage: Up to 6,000 ft Above Ground Level (AGL)
- Azimuth Coverage: 360°
- Elevation Coverage: ±11°
- Scan Rate / Update Rate: 2.4 seconds
- Range Resolution: 1% of range
- Angular Resolution: 0.9° beamwidth
- Multi-Target Tracking (>100 targets with no observed performance degradation)

Processing Capabilities (Canadian UAVs, 2025)

- Automatic Track Initiation: Automatically detects and tracks aircraft
- Sensor Data Fusion: Integrates ADS-B track with radar tracks
- Clutter Filtering: Adaptive filtering to extract ground clutter
- Weather Filtering: Adaptive filtering to extract weather patterns
- Data Latency: <200ms for User Interface (UI) presentation (after scan processing)

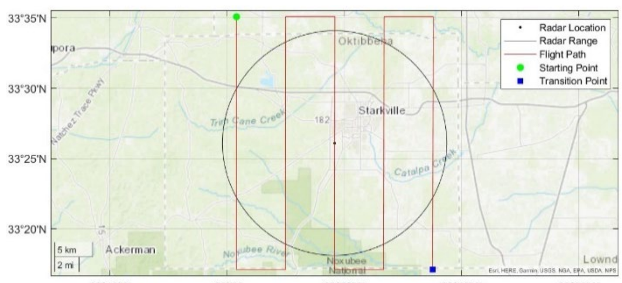
Environmental & Operational Capabilities (Canadian UAVs, 2025)

- Power Requirements: 110-240V AC, 12-24V DC
- Operating Temperature Range: -25°C to +55°C
- Weather Resistance: IP56, all-weather operation
- Communications Interface: Ethernet, Wi-Fi, 4G/5G, radio link
- RPAS Integration Capabilities: Application Programming Interface (API) availability for RPAS operators
- Software Integration Capabilities: API availability for third-party applications

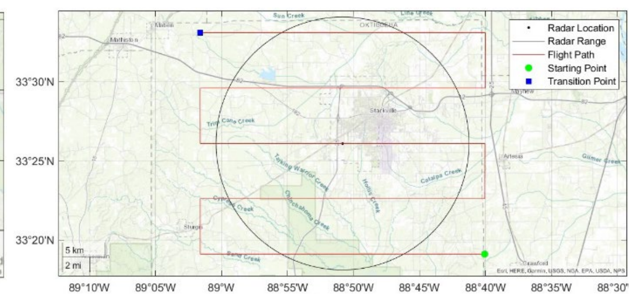
2.7.2 Test Methodology

As one of the selected DAA technologies acquired for testing, a comprehensive test methodology was developed to evaluate the system's performance in the operational environment. The primary objective of this test campaign was to validate system functionality and performance against manufacturer specifications, with particular emphasis on detection probability at various ranges and altitudes. This systematic approach ensures that operational deployment meets both regulatory requirements and safety standards for BVLOS operations. Additionally, this testing approach directly supports the Specific Operational Risk Assessment (SORA) documentation (used under USRA Task 4) by providing empirical data on detection capabilities across the operational envelope.

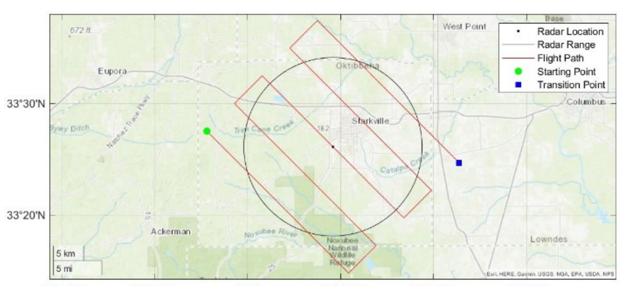
Encounter tests were conducted using the Grumman AA-5B Tiger, a crewed aircraft that flew structured patterns at varying altitudes. The flight paths for each of the test cards are illustrated below in Figure 7 and Figure 8. The test cards are divided into two distinct encounter trajectories, primarily linear and non-linear.



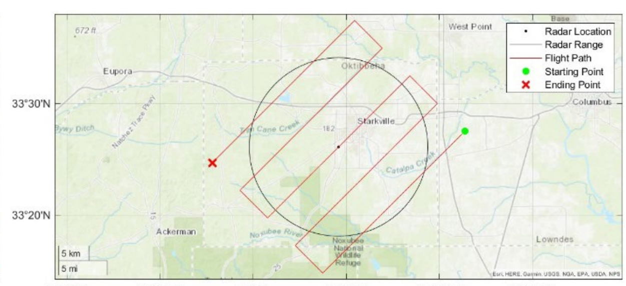
(A): North-South TC



(B): East-West TC



(C): Northwest-Southeast TC



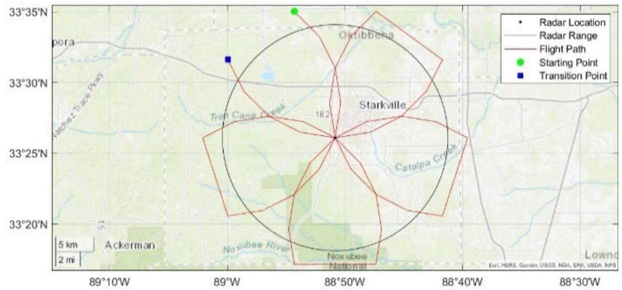
(D): Northeast-Southwest TC

Figure 7. Linear Encounter Test Cards

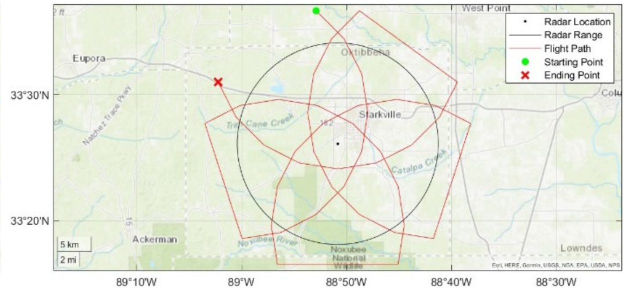
These linear flight patterns were specifically designed to provide systematic coverage of the radar's detection volume at multiple approach angles. Each pattern was executed at varying altitudes (1,500 ft, 3,000 ft, & 6,000 ft) AGL to evaluate altitude-dependent performance characteristics. The survey-style approach ensures comprehensive spatial coverage while maintaining consistent test conditions for statistical analysis.

The linear encounter set comprises 40 individual encounters covering 428 miles of flight distance over approximately 3.08 hours of flight time. Each flight leg was designed so that aircraft would exit the detection volume before beginning the next segment, ensuring each encounter constituted an independent detection event for statistical purposes.

The non-linear flight patterns were designed to assess radar performance under dynamic encounter scenarios. The clover-leaf patterns, shown in Figure 8, provide evaluation of the system's tracking capabilities during maneuvering flight profiles.



(A)



(A)

Figure 8. Non-linear Flight Path Test Cards.

These non-linear patterns covered 294.7 miles over 2.12 hours of flight time, offering a focused assessment of the effectiveness in handling unconventional flight scenarios typical of general aviation operations. The curved flight paths test the system's ability to maintain track continuity during aircraft maneuvering, a critical capability for operational DAA systems.

2.7.3 Sparrowhawk Flight Testing Results

The comprehensive field testing campaign successfully validated the Sparrowhawk radar's ability to detect 1 m² radar cross-section targets at distances up to 14.26 NM, meeting manufacturer specifications (Canadian UAVs, 2025). The overall radar coverage and detection patterns are illustrated in Figure 9, which presents the complete dataset from the Starkville testing campaign.

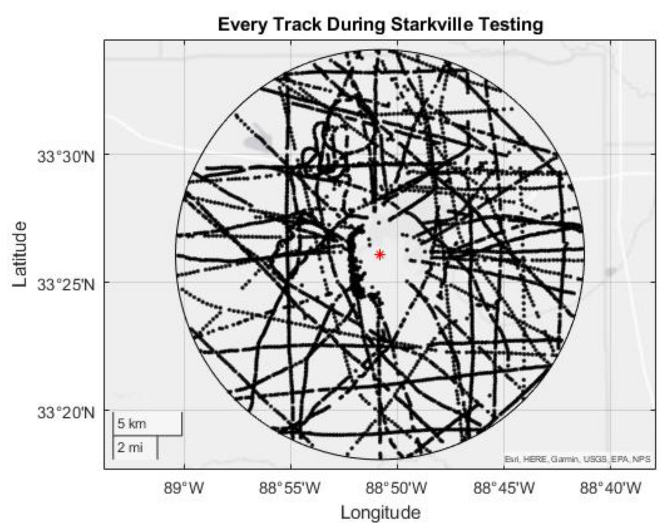


Figure 9. Sparrowhawk Operational Coverage.

This visualization demonstrates the system's 360° coverage capability and reveals the spatial distribution of successful detections across the test volume. The density of track data confirms consistent detection performance across multiple approach angles and ranges, validating the radar's omnidirectional surveillance capabilities.

Detailed performance analysis of individual test scenarios reveals the system's detection accuracy and consistency. Figure 10 presents a representative test card showing the correlation between planned flight paths and actual radar detections.

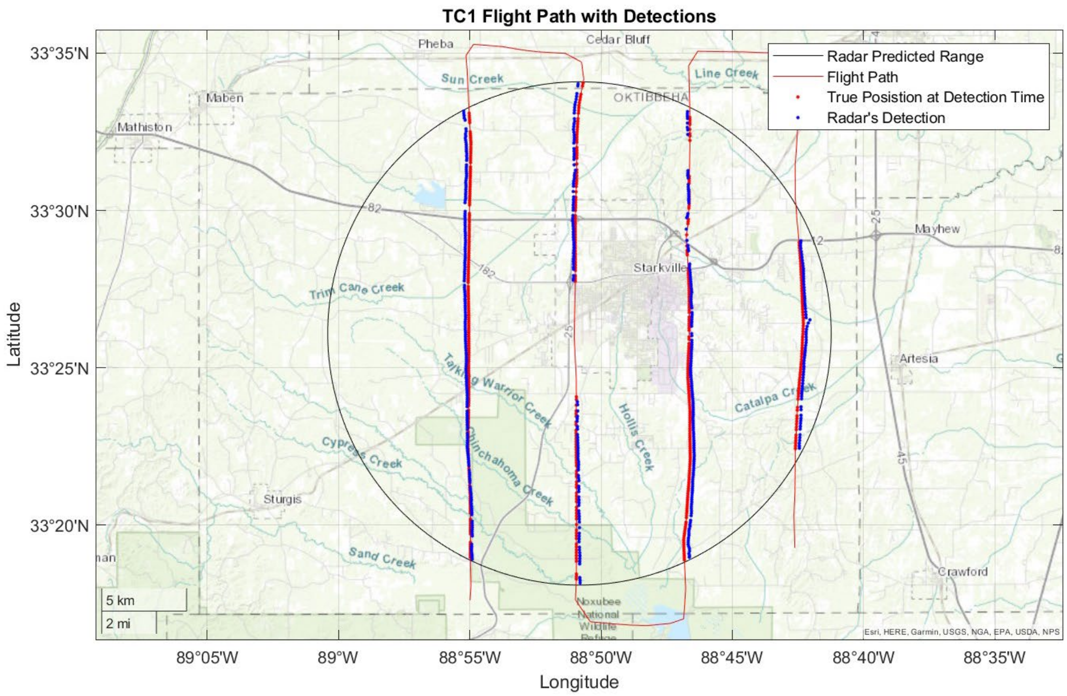


Figure 10. Sparrowhawk Detection Accuracy vs True Location.

This detailed analysis demonstrates the radar's ability to detect and track aircraft throughout the planned flight profile accurately. The close correlation between predicted detection zones and actual detection events validates the system's performance modeling and confirms operational reliability within the specified detection envelope. The characteristics of the marine radar’s detection performance will influence the system deployment and operational procedures.

Performance analysis shows optimal radar effectiveness in the 3-10 NM range band, where detection probabilities consistently exceed 75%. Field testing identified some environmental variables that impacted detection reliability. For instance, ground clutter effects such as terrain features, buildings, and vegetation create radar returns that can block and mask aircraft signatures, particularly at longer ranges and lower altitudes. The system's adaptive clutter filtering provides mitigation; however, performance degradation is observable in areas with high ground clutter density.

3 OPTICAL DAA SYSTEMS

Optical detection systems represent a rapidly advancing DAA technology category that leverages computer vision and machine learning algorithms to identify and track aircraft through passive imaging sensors. Drawing on extensive development in autonomous vehicle and surveillance applications, optical DAA systems can offer compelling advantages in terms of size, weight, power, and cost compared to other DAA sensor solutions. Companies like Iris Automation have pioneered the commercial deployment of vision-based DAA, demonstrating operational viability through numerous regulatory approvals and thousands of flight hours across diverse operational environments.

3.1 Overview

Optical DAA systems utilize cameras operating across multiple electromagnetic spectrum bands to detect aircraft against sky backgrounds. Detection algorithms use computer vision techniques to identify potential collision threats within captured imagery.

Iris Automation is known for creating state-of-the-art ground/air collision detection and avoidance systems used in both manned and unmanned aircraft. Based in San Francisco, California, the company operates flight tests under a BVLOS authorization in Reno-Tahoe, Nevada. Iris offers a comprehensive family of EO DAA sensors for both airborne and ground-based applications. The original camera system's range was improved in 2020 to meet developing requirements of Well Clear and now averages around 4,400 feet in horizontal range for general aviation aircraft.

3.2 Casia I

The Casia I is a single-camera unit with an integrated Graphics Processing Unit (GPU) for data processing and storage. This system represents the most cost-effective entry point into the Casia family while maintaining the core detection and avoidance capabilities. The system is designed for applications where directional coverage is sufficient and weight/power constraints are critical factors.

Figure 11. Iris Automation Casia I DAA Sensor.

Table 4. Casia I Specifications

Specification	Value
Field of View	80° Horizontal; 50° Vertical
Detection Range	1338m (4390ft) average
Power Consumption	10W Nominal, 15W Peak
Total Weight	482g
Camera Dimensions	60mm (W) x 60mm (L) x 105mm (D)
Processing Module Dimensions	77mm (W) x 110mm (L) x 36mm (D)

Figure 12. Casia I Integration on small UAS

3.3 Casia G

The Iris Automation Casia G represents a ground-based electro-optical DAA solution specifically designed for airspace surveillance and UAS traffic management. Developed by Iris Automation, a San Francisco-based company specializing in computer vision-based collision avoidance systems, the Casia G extends the proven Casia family technology to ground-based operations. Unlike airborne systems that are constrained by size, weight, and power limitations, the ground-based architecture allows for enhanced detection capabilities and continuous operational endurance.

The Casia G system functions as nodes in a mesh network configuration, enabling comprehensive area coverage for BVLOS operations. This distributed approach provides multiple UAS operators with centralized surveillance capabilities while offering redundancy and extended detection ranges through strategic sensor placement. The system integrates seamlessly with existing situational awareness tools, providing Pilot-in-Command/Mission Commander (PIC/MC) access to real-time airspace information from a centralized interface.

Figure 13. Iris Automation Casia G

3.3.1 System Specifications

General System Characteristics (Iris Automation, 2022)

- **Sensor Type:** EO
- **Detection Method:** Computer Vision with Machine Learning
- **Weight:** 4.2 kg per node
- **Physical Footprint:** 0.81 m^2 per node
- **Mobility:** Fixed-Site, Transportable

Performance Specifications (Iris Automation, 2022)

- **Field of View:** 360° Azimuth; 50° Elevation
- **Detection Range:** 2km average for single node (Network scalable)
- **Range Estimation Accuracy:** ±15% (Casia G Training Documentation)
- **Average Detection Range:** 2011m
- **Maximum Detection Range:** 2866m
- **Power Consumption:** 45W Nominal, 60W Peak
- **Operating Temperature:** 0 to 60°C
- **Operating Conditions:** Visual Meteorological Conditions (Day and Night capable)
- **Data Storage:** Internal 1TB SSD (8 hours continuous capture)

3.3.2 Test Methodology

The Casia G was selected as one of the systems to be acquired for evaluating its performance in an operational environment. The primary objective was to validate system functionality and performance against manufacturer specifications, with particular emphasis on detection probability, latency, accuracy, and precision across varying atmospheric conditions. The test approach focused on assessing the unique characteristics of electro-optical detection systems, including their sensitivity to atmospheric conditions and visual meteorological conditions.

Encounter tests were conducted using the Grumman AA-5B Tiger and Cessna aircraft flying structured flight patterns at varying altitudes over Mississippi State's Ag Research North Farm. A network of four Casia G systems was strategically positioned to provide comprehensive coverage of the test area while minimizing detection blind spots. Each unit was mounted on tripods and equipped with dedicated Wi-Fi hotspots for data connectivity. The network was controlled remotely through an Intel NUC running the Iris Casia visualization software. As shown in Figure 14, Casia G node was positioned at the following coordinates:

1. 33.473333, -88.785297
2. 33.478814, -88.783678
3. 33.469379, -88.778340
4. 33.472250, -88.772143

Figure 14. Casia G Mesh Network Setup Locations

provided overlapping coverage zones within the approximately 0.625 mi² test area. This configuration enabled evaluation of both individual sensor performance and networked detection capabilities, simulating operational scenarios where multiple sensors provide redundant coverage.

3.3.3 Casia G Flight Testing Results

The flight test campaign successfully demonstrated the Casia G system's electro-optical detection capabilities while revealing important operational characteristics related to atmospheric conditions and system precision. Testing conducted on two separate days revealed the significant impact of atmospheric conditions on electro-optical system performance. May 22, 2023, had "ideal weather conditions" with the key factor being the high ceiling conditions (12,000 ft ceiling): The high cloud ceiling provided optimal visual meteorological conditions for electro-optical detection. Under these conditions, the four-node Casia G network demonstrated comprehensive coverage with minimal atmospheric interference. On the other hand, the weather conditions for the second day of testing were more challenging. A low ceiling of 2,000 ft created challenging conditions for optical detection, with increased atmospheric scatter and reduced visibility affecting system performance.

The strategic deployment of four Casia G nodes (designated as Sensors 20, 21, 23, and 24) successfully eliminated coverage blind spots and provided overlapping detection zones throughout the test area. Figure 15 illustrates the comprehensive detection coverage achieved during optimal atmospheric conditions on May 22, 2023.

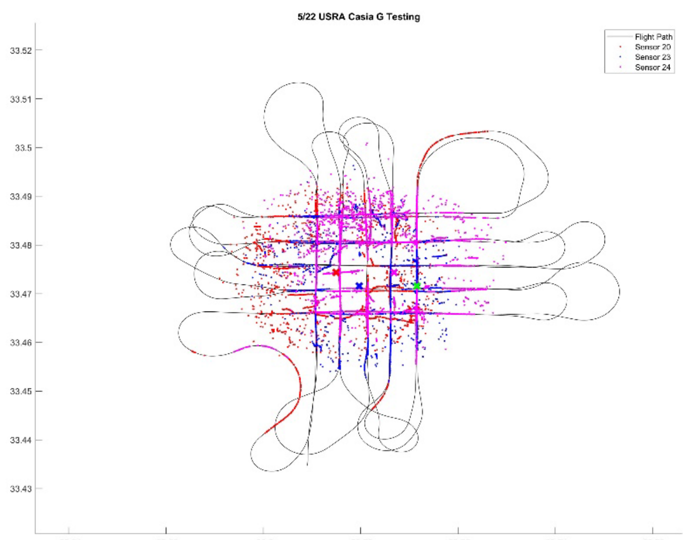


Figure 15. Casia G Network Detection Coverage - May 22, 2023 (12,000 ft ceiling).

Figure 15 presents the complete detection dataset from the May 22nd testing with high cloud ceiling conditions. The visualization demonstrates the comprehensive coverage capability of the sensor network, with each sensor's detections plotted in different colors to illustrate the distributed detection architecture. The dense concentration of detection points in the central test area confirms consistent sensor performance throughout the structured flight patterns, while the flight path overlay validates the correlation between planned trajectories and actual detection events.

Detailed analysis of individual test scenarios reveals the system's detection precision characteristics. Figure 16 presents the North-South Pass Test Card results from May 22, 2023, showing aircraft flight path correlation with sensor detections at 1,000 ft AGL.

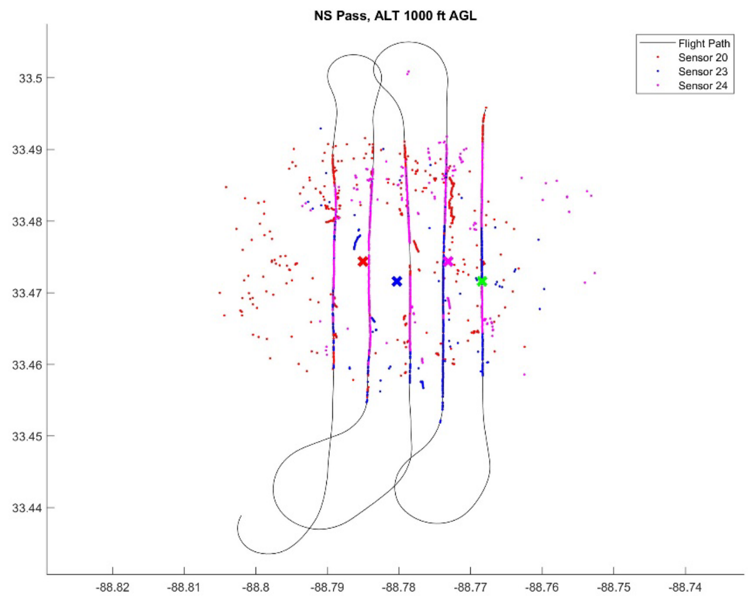


Figure 16. North-South Pass Test Card - May 22, 2023 (1,000 ft AGL)

The correlation between the aircraft's true flight path (represented by the continuous line) and the actual sensor detections (colored points) illustrates the system's tracking accuracy. The detection points closely follow the aircraft's actual trajectory, with minimal lateral deviation, indicating good precision within the system's operational envelope.

The impact of reduced visibility conditions is clearly illustrated in the May 24, 2023 testing results. Figure 17 shows the overall detection performance under low ceiling conditions (2,000 ft ceiling).

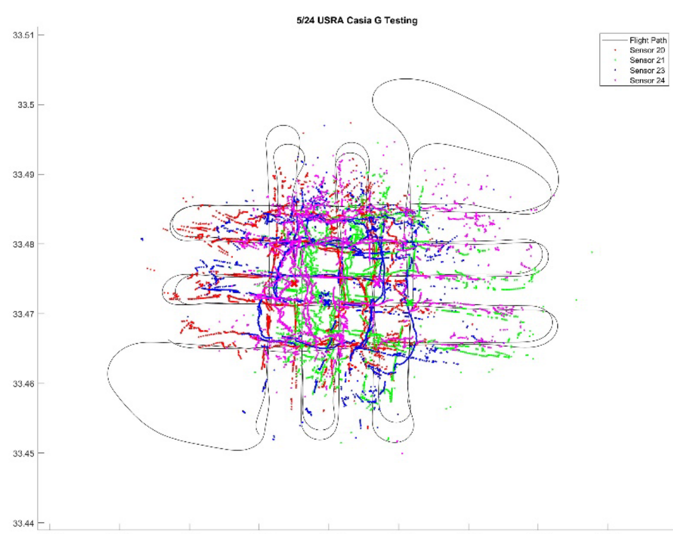


Figure 17. Casia G Network Detection Performance - May 24, 2023 (2,000 ft ceiling)

The reduced cloud ceiling significantly affected detection density and distribution compared to the optimal conditions observed on May 22. The detection pattern shows increased scatter and reduced consistency, highlighting the sensitivity of electro-optical systems to atmospheric conditions. Despite these challenging conditions, the multi-node network maintained detection capability across the test area, though with notably reduced precision.

Figure 18 presents the corresponding North-South test card analysis from May 24th testing at 1000 ft AGL.

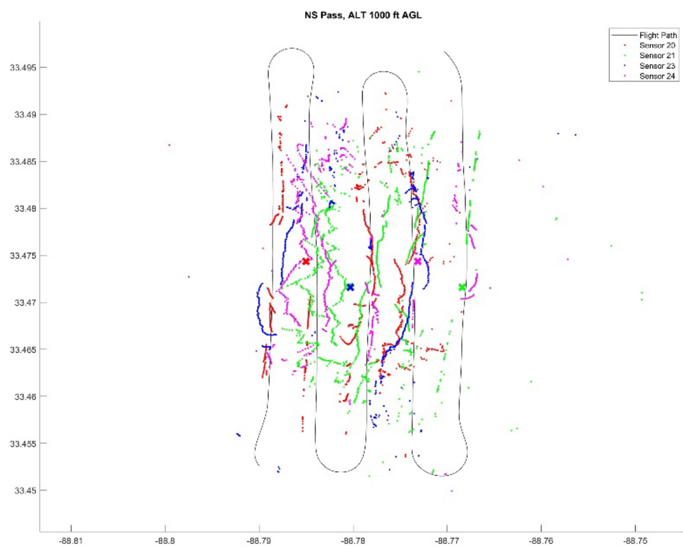


Figure 18. North-South Pass Test Card - May 24, 2023 (1,000 ft AGL, 2,000 ft ceiling)

The comparison between optimal and degraded atmospheric conditions identifies a system's operational envelope limitations and provides critical data for establishing operational weather minimums.

The multi-sensor network approach proved effective in providing redundant coverage and eliminating potential blind spots in the detection volume. Color-coded detection points clearly show how different sensors contributed to overall airspace awareness, with sensor handoffs occurring seamlessly as aircraft moved between coverage zones. This distributed architecture provides operational resilience and enhanced detection probability compared to single-sensor configurations.

Detection performance analysis reveals several operational characteristics critical for BVLOS deployment. The system demonstrated consistent performance in optimal conditions (12,000 ft ceiling) with dense, accurate detection patterns throughout the test envelope. Performance degradation under lower ceiling conditions (2,000 ft) illustrates the inherent limitations of electro-optical systems and emphasizes the importance of weather minimums for operational safety.

The encounter detection and tracking analysis demonstrates the system's ability to detect and maintain accurate tracking assessments across various flight profiles. Detection continuity appears consistent within the specified range envelope, although some variability is evident during changes in atmospheric conditions. The multi-sensor approach provides enhanced tracking reliability through sensor redundancy and overlapping coverage zones.

The Casia G offers particular value for area operations where multiple UAS may operate, providing centralized surveillance with lower per-aircraft costs. Key operational findings include the importance of strategic sensor placement for optimal coverage, the effectiveness of the mesh network architecture for area surveillance, and the critical dependency on visual meteorological conditions for reliable performance. The testing validated the manufacturer's specified detection ranges while highlighting environmental factors that impact operational reliability.

4 ACOUSTIC DAA

Acoustic detection represents a unique approach to DAA that exploits the distinctive sound signatures generated by aircraft noise. SARA Inc. has pioneered the development of acoustic DAA systems through decades of military acoustic surveillance experience, culminating in the Passive Acoustic Noncooperative Collision Avoidance System (PANCAS) and TASA systems specifically designed for UAS collision avoidance. This passive sensing modality offers compelling advantages for certain operational scenarios while presenting distinct challenges compared to electromagnetic and optical approaches.

4.1 Overview

Acoustic DAA systems utilize arrays of microphones to detect and localize aircraft through their acoustic emissions. Aircraft generate characteristic sound signatures through multiple mechanisms, such as engine noise and propeller harmonics. Direction-of-arrival estimation utilizes beamforming algorithms that coherently combine signals from distributed microphones to enhance sensitivity in specific directions while suppressing noise from off-axis directions. Time Difference of Arrival (TDOA) techniques correlate signals between microphone pairs to triangulate source position, while advanced algorithms like MUSIC (Multiple Signal Classification) and ESPRIT (Estimation of Signal Parameters via Rotational Invariance Technique) provide super-resolution bearing estimation. Acoustic intensity vector measurements using closely-spaced microphone pairs enable three-dimensional localization without large aperture arrays.

Modern acoustic DAA systems incorporate sophisticated signal processing to extract aircraft signatures from environmental noise. Adaptive filtering algorithms suppress wind noise, precipitation, and ground vehicle sounds that could mask aircraft detection. Machine learning classifiers trained on extensive acoustic signature databases distinguish aircraft from false alarms while estimating target type and threat level. Kalman filtering and multiple hypothesis tracking maintain persistent tracks through temporary signal occlusions or interference.

Low-frequency sound propagation enables detection at ranges exceeding 10 kilometers under favorable conditions, with minimal atmospheric attenuation below 100 Hz. Acoustic waves diffract around obstacles, enabling the detection of aircraft obscured from line-of-sight sensors by terrain or structures.

Acoustic detection faces fundamental limitations that constrain its effectiveness as a primary DAA sensor. Environmental noise from wind, precipitation, traffic, and industrial sources can mask aircraft signatures, reducing detection range and reliability. The detection range exhibits high variability, depending on the aircraft type, with quiet aircraft or gliders potentially undetectable. Range estimation from passive acoustic measurements remains inherently ambiguous without multiple nodes. Urban environments present particularly challenging conditions, characterized by high ambient noise levels and multiple reflection paths that can lead to frequent false detections.

4.2 SARA Inc. TASA

SARA TASA represents a ground-based acoustic DAA solution specifically designed for passive airspace surveillance and UAS traffic management. Developed by SARA Inc., a Virginia-based company with over 35 years of experience in acoustic sensor technology, the TASA system extends proven acoustic detection capabilities to ground-based BVLOS operations. Unlike electro-optical systems that require line-of-sight and are constrained by atmospheric conditions, the acoustic-based architecture allows for detection capabilities that can penetrate through trees, buildings, darkness, fog, and terrain features.

The TASA system functions as an Internet of Things (IoT) based network of acoustic phased array systems, enabling comprehensive area coverage for BVLOS operations. This distributed approach provides multiple UAS operators with centralized surveillance capabilities while offering detection redundancy and extended coverage through strategic sensor placement. The system integrates seamlessly with existing UAS flight control systems, providing PIC/MC access to real-time airspace information and automated collision avoidance capabilities.

Figure 19. TASA node during encounter flight test

4.2.1 System Specifications

General System Characteristics (SARA Inc., 2024)

- Sensor Type: Passive Acoustic Phased Array
- Network Architecture: IoT-based mesh network capability

Performance Specifications (SARA Inc., 2024)

- Field of View: 360° azimuth coverage
- Detection Range: Multi-mile detection capability (exact range varies by aircraft type and environmental conditions)
- Power Consumption: Low power operation with solar capability for indefinite operation
- Operating Temperature: All-weather operational capability
- Operating Conditions: All-weather collision avoidance (day/night, fog, precipitation)
- Regulatory Compliance: Meets American Society for Testing and Materials (ASTM) Detect and Avoid Performance Standards

4.2.2 Test Methodology

The SARA TASA was selected as one of the ground-based DAA systems for evaluation. The primary objective was to validate system functionality and performance in environments representative of BVLOS operations, with particular emphasis on detection probability, latency, and accuracy across varying acoustic environments. The test approach focused on assessing the unique characteristics of passive acoustic detection systems.

Encounter tests were conducted using a Grumman AA-5B Tiger and Bell 429 flying structured flight patterns at varying altitudes over the operational site. Two TASA nodes were positioned to provide overlapping coverage areas, enabling the evaluation of both individual sensor performance and networked detection capabilities. Each unit was mounted on a stabilized mast system with twelve support wires, as shown in Figure 20 and equipped with dedicated power supplies and internet connectivity for real-time data transmission.

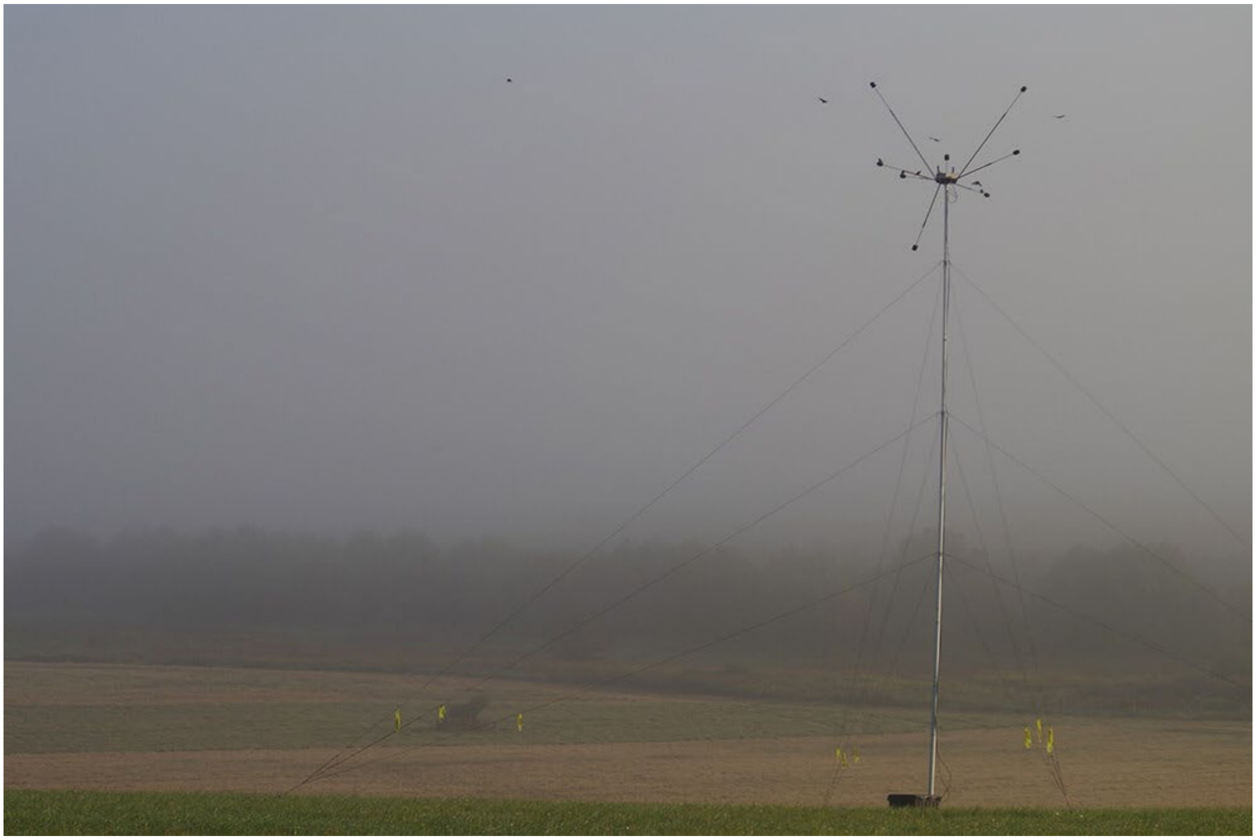


Figure 20. TASA node field deployment

Figure 20 shows the field deployment for a joint flight test with Tennessee Valley Authority (TVA) that took place over the Colbert Combustion Turbine Plant. Two TASA nodes deployed in a networked configuration

This configuration enabled the evaluation of the acoustic detection system's performance in realistic operational environments, providing a direct comparison with electro-optical DAA technologies operating in the same airspace.

Table 5: DAA Encounter Flight Test Card from TASA testing

Test Card:	1	**Description:**	Wagon Wheel (W to E)
Altitude:	2,000 ft MSL	**Airspeed:**	115 ± 5 Kts
Setup:	1) **PIC** maneuvers to a due East heading toward the ground-based sensor at a distance of 2 miles away. 2) **Test Director/Engineer** records initial ADS-B and intruder detection time, alert time, and classification accuracy. Also note any false detection and alert times if observed. 3) **PIC** continues due East away from the ground-based sensor until a distance of 2 miles is reached. 4) **PIC** transitions to SW heading to prepare for next TC.		
Notes:			
ADS-B Detection Time: ADS-B Alert Time: Acoustic/Visual Detection Time: Acoustic/Visual Alert Time: Classification Accuracy:			
Weather Limitations:	VFR conditions required Adequate ceiling required	**Abort Criteria:**	PIC Discretion

4.2.3 SARA TASA Flight Testing Results

The flight test campaign demonstrated the TASA system's passive acoustic detection capabilities and revealed important operational characteristics related to environmental noise and system precision. Testing conducted across multiple TVA sites provided valuable insights into the performance of acoustic sensors in industrial environments with varying background noise levels.

The strategic deployment of two TASA nodes at Colbert Combustion Turbines demonstrated the system's ability to provide overlapping acoustic coverage while enabling triangulation capabilities for enhanced target localization. Figure 21 illustrates the acoustic detection coverage achieved during the wagon wheel flight pattern testing.

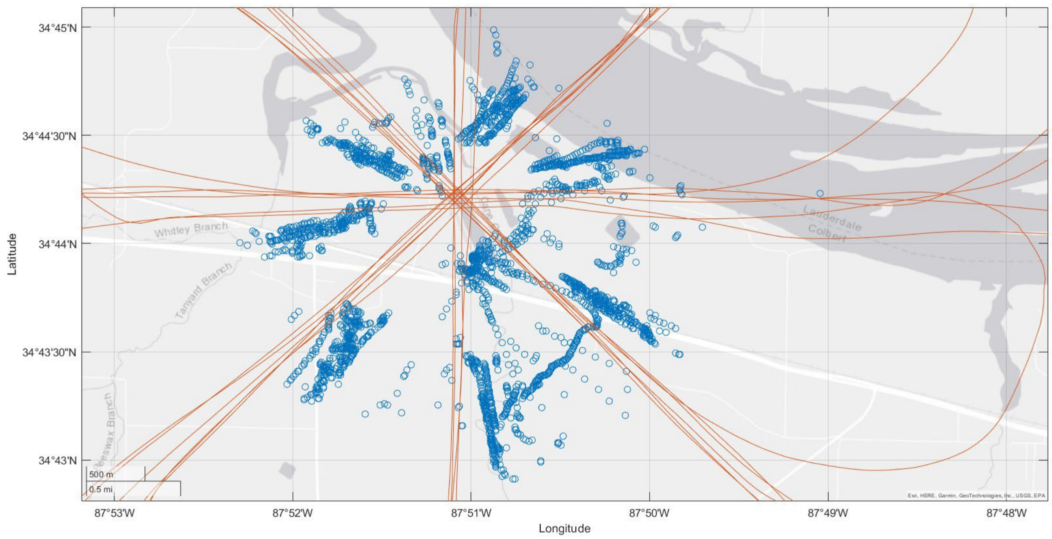


Figure 21. TASA Detections vs True Flight Path

The TASA system demonstrated nominal detection ranges during flight testing, successfully identifying both fixed-wing and rotorcraft targets throughout the planned encounter scenarios. However, some operational challenges were identified that impact system reliability and precision.

The acoustic detection system was highly susceptible to environmental noise sources, resulting in false positive detections despite the implementation of noise-masking capabilities. Industrial noise from the TVA facilities, construction noise, road traffic, and other environmental sounds created challenging conditions for target discrimination. The system consistently and reliably detected aircraft across all encounter scenarios. One node on its own would only be able to detect and give a relative bearing, and it would be hard to distinguish traffic from noise. Having two or more nodes tracking the same encounter allows for triangulation. Figure 21 shows the intersecting points of each node's detected bearing. The data has been filtered only to show confident tracks for the duration of the test card.

The TASA system's passive acoustic detection approach provides both operational advantages and some environmental considerations. Unlike electro-optical systems, the TASA demonstrated consistent detection capabilities regardless of visual meteorological conditions, providing reliable performance during periods of reduced visibility, precipitation, and darkness. The acoustic detection method's ability to detect aircraft despite visual obstructions (trees, buildings, terrain features) proved valuable for operational scenarios where line-of-sight limitations restrict other DAA technologies. Testing in the TVA industrial environment revealed the impact of background noise on system performance, highlighting the importance of noise characterization and masking for deployment in similar operational areas.

5 CONCLUSION

The safe integration of small UAS into the National Airspace System depends on the availability of Detect-and-Avoid technologies that can deliver reliable performance within the SWaP constraints of small platforms. This report has presented a detailed evaluation of radar-based, electro-optical, and acoustic sensing systems, each of which offers unique contributions to the problem of providing an equivalent level of safety to manned aviation. Taken together, these findings provide both a technical foundation for DAA research and a practical basis for guiding technology selection, system integration, and deployment planning in support of routine BVLOS operations.

Radar-based systems demonstrated the most robust and operationally reliable performance across diverse environmental conditions. Ground-based solutions, such as the Sparrowhawk Marine Radar, eliminated SWaP constraints by moving sensing hardware off the aircraft while providing persistent 360° surveillance. Testing revealed detection ranges up to 14 nautical miles for 1 m^2 targets, with consistent performance regardless of lighting, visibility, or precipitation. This all-weather, day-and-night reliability highlights the value of radar as a primary detection modality, particularly for applications requiring continuous monitoring of defined operational volumes. Airborne radar implementations remain challenged by SWaP limitations but are steadily advancing through miniaturization and low-power processing techniques, reinforcing radar's position as the most mature DAA technology pathway for sUAS.

Optical systems offer strong performance under favorable atmospheric conditions; however, the performance is significantly influenced by lighting, atmospheric, and computational factors. Iris Automation's Casia G demonstrated detection ranges between 1.3 and 2.8 km depending on environmental conditions. During testing, low cloud ceilings (2,000 ft) markedly reduced system performance compared to operations under higher ceilings (12,000 ft).

Acoustic systems provided unique capabilities that were not replicated by radar or EO sensors. The SARA TASA platform demonstrated the ability to detect aircraft at multi-mile ranges with full 360° coverage. This made acoustic detection especially effective in environments where line-of-sight systems were degraded. However, acoustic systems were highly susceptible to environmental noise, requiring advanced filtering and multiple sensor nodes for reliable triangulation. Range estimation accuracy was limited in single-node configurations, making multi-node deployments a practical necessity. While acoustic technology is less mature than radar or EO, its ability to detect aircraft in non-line-of-sight conditions underscores its potential as a valuable component in layered DAA architectures.

Environmental factors influenced system performance across all modalities. Radar was the least sensitive, maintaining detection capability through precipitation, reduced visibility, and variable atmospheric conditions. EO systems, by contrast, experienced significant degradation under low ceilings, haze, and poor lighting, reducing both range and detection density. Acoustic systems were resilient to weather but highly vulnerable to competing noise sources, such as urban or industrial environments, which reduced detection reliability. Ground clutter, terrain masking, and atmospheric effects add additional complexities, highlighting the importance of carefully matching sensor architecture to operational environments.

Radar-based solutions emerged as the most technologically mature, with multiple commercially available systems already demonstrating regulatory approvals and deployment in operational contexts. EO systems displayed moderate maturity, with proven operational deployments but greater susceptibility to environmental variability. Acoustic systems showed promise but remain at earlier stages of maturity, with limited fielded deployments and ongoing research required to address accuracy and noise susceptibility challenges.

System integration readiness varied significantly across vendors. Some platforms supported standardized interfaces and APIs, enabling streamlined integration into broader UAS command-and-control systems, while others required custom solutions. Real-time processing capability was also uneven, with differences in track filtering, conflict detection, and automated threat assessment. These disparities highlight the importance of evaluating not only sensing performance but also system-level integration, scalability, and operational usability. As such, hybrid or fused architectures that integrate multiple modalities are likely to represent the most viable path forward. Multi-sensor approaches can leverage the strengths of each technology while compensating for the individual weaknesses, providing the resilience required for regulatory approval and public trust.

These findings carry direct relevance to the FAA's proposed Part 108 rule on BVLOS operations, which emphasizes the need for validated DAA technologies capable of detecting cooperative and non-cooperative aircraft in diverse environments. Continued flight testing, data collection, and performance validation are essential to maturing these systems and informing regulatory decision-making. Furthermore, the development of standardized integration frameworks, common performance metrics, and scalable deployment strategies will be critical to accelerating industry adoption.

DAA development for small UAS represents both a technical challenge and a strategic opportunity. The technical data presented in this report demonstrate that radar, EO, and acoustic systems each bring unique capabilities that, when integrated, can provide the robust detection and avoidance performance necessary for routine BVLOS operations. These technologies not only reduce the technical barriers to NAS integration but also enable the safe expansion of sUAS applications across industries such as infrastructure inspection, agriculture, logistics, and emergency response.

By addressing the safety imperative while unlocking significant operational and economic benefits, DAA research and flight testing lay the groundwork for the next phase of UAS integration. As the FAA advances its regulatory framework through Part 108 and related initiatives, the continued maturation of multi-sensor DAA solutions will play a pivotal role in building public confidence, enabling scalable operations, and realizing the full potential of unmanned aviation in the national airspace.

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