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Tallahassee, FL 32399

Counting Airport Operations Using Aircraft Transponder Signals and/or Aircraft Automatic Dependent Surveillance-Broadcast (ADS-B) Data

Final Report
February 2024

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16. Abstract

Accurate estimation of daily and annual aircraft operations at airports is vital for various objectives, including airport planning, funding allocation, and aviation forecasts. However, obtaining precise operational data from airports without control towers has been challenging. In 2018, the Florida Department of Transportation (FDOT) published an assessment of aircraft operations counting technologies at non-towered airports, considering best practices from prior studies. After five years of the arrival of technologies available for object detection applications, it is time to update the assessment. To achieve this, a systematic approach was followed, starting with defining terminology and types of aircraft operations for consistent understanding. A ranking methodology based on critical selection criteria was established. Thorough research was conducted on technologies used in aviation and other relevant fields, and components and costs were obtained from vendors. Feedback from state airport authorities and Florida airports regarding their used technologies was also collected. Onsite evaluation showed that all aircraft operations counting technologies evaluated are prone to introducing both undercounting and overcounting errors.

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Executive summary

Accurate estimation of daily and annual aircraft operations at airports is vital for various objectives, including airport planning, funding allocation, and aviation forecasts. However, obtaining precise operational data from airports without control towers has been challenging. Florida has over 125 public-use airports, but only nine (9) have full-time control towers, 30 have part-time towers, and over 86 lack a control tower altogether, leading to inaccurate estimates. In 2018, the Florida Department of Transportation (FDOT) published an assessment of aircraft operations counting technologies at non-towered airports, considering best practices from prior studies. Five years later, with innovative technologies available for object detection applications, it is time to update the assessment. A systematic approach was followed to achieve this goal of accurately counting aircraft, starting with defining terminology and types of aircraft operations for consistent understanding. A ranking methodology was established, based on critical selection criteria consisting of (1) accuracy, (2) reliability, and, (3) costs associated with installation, operation, and maintenance was established. Thorough research was conducted on technologies used in aviation and other relevant fields, and components and costs were obtained from vendors. The ranking methodology was used to narrow down the technologies for further investigation. Feedback from state airport authorities and Florida airports regarding their used technologies was also collected. Onsite evaluations of highly ranked ADS-B-based technologies were conducted to assess the suitability of aircraft operations counting technology at non-towered airports. Our findings show that (1) ADS-B-only systems introduced both undercounting and overcounting errors and (2) no significant improvements were observed for the ADS-B system with a hybrid RADAR sensor in the configuration tested over the ADS-B-only system in terms of detecting aircraft operations. Further assessment of aircraft operation counting technologies through extensive onsite evaluation is needed to advance our findings.

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Tables

Acronyms

Acronym	Definition
ACRP	Airport Cooperative Research Program
ADS-B	Automatic Dependent Surveillance-Broadcast
AI	Artificial Intelligence
AIM	Airport Information Manual
ATC	Air Traffic Control
CFR	Code of Federal Regulations
CSV	Comma Separated Value
CTAF	Common Traffic Advisory Frequency
ERAU	Embry-Riddle Aeronautical University
FAA	Federal Aviation Administration
FDOT	Florida Department of Transportation
G.A.R.D.	General Audio Recording Device
GA	General Aviation
HD	High Definition
ICAO	International Civil Aviation Organization
iDAR	Intelligent Detection and Ranging
IR	Infrared
KDED	DeLand Municipal Airport
KOMN	Ormond Beach Municipal Airport
LiDAR	Light Detection and Ranging
MLAT	Multilateration
MSL	Mean Sea Level
NM	Nautical Miles
NEAR	Next Generation ERAU Applied Research Lab
RADAR	RAdio Detection And Ranging
TIS-B	Traffic Information System Broadcast
UAT	Universal Access Transceiver
UNICOM	Universal Communications

1. Introduction

Accurate estimates of daily and annual aircraft operations at airports (e.g., approaches, landings, takeoffs, departures, low approaches, touch-and-go landings, etc.), including the types of aircraft conducting the operations, provide critical information used by airports, the Florida Department of Transportation (FDOT) and the Federal Aviation Administration (FAA). Accurate and reliable operational data are used to develop aviation forecasts for airport master plans and statewide and national aviation forecasts developed by the FDOT and FAA, respectively. The availability of this information can vary widely, but the data is instrumental in airport planning, environmental analyses, funding allocations, project justifications, airport staffing, as well as other applications. For example, accurate data can serve as the basis for validating pavement evaluations at airports, justification for runway capacity improvements based on operational demand, and as a key metric for prioritizing state and federal funding for other airport development projects.

The aircraft operations are collected and reported by the tower controllers for airports with an air traffic control tower. Florida has over 125 public-use airports, of which only nine (9) have a full-time operating control tower, 30 have a part-time operating control tower, and over 86 do not have a control tower. Estimates of aircraft operations at the airports with part-time towers during the hours the tower is not operating and estimates of aircraft operations at all airports without a control tower can be inaccurate and unreliable. This issue has been the subject of several studies; however, an acceptable and cost-effective solution has yet to be identified.

In 2018, the FDOT published a report entitled *Operations Counting at Non-Towered Airports Assessment* (FDOT, 2018). This report assessed aircraft operations technologies based on the best practices of the *Airport Cooperative Research Program* (*ACRP) Report 129 – Evaluating Methods for Counting Aircraft Operations at Non-Towered Airports*, completed in 2015, and using a Florida-specific approach. The FDOT report also considered the estimating methods and counting technologies used in a nationwide survey and summarized in *ACRP Synthesis 4 – Counting Aircraft Operations at Non-Towered Airports* (Muia, 2007). The FDOT report evaluated four (4) separate audio-dependent and video-dependent technologies at Florida airports.

Five years have passed since the previous study of operations counting at non-towered airports, and new technologies became available for object detection applications. Hence, it is an appropriate time to update the assessment of the state-of-the-art aircraft counting technologies for non-towered airports. The research team has executed systematic steps to accomplish this goal: Researchers first defined the terminology necessary to conduct this study as well as distinct types of aircraft operations at an airport to ensure a consistent understanding of the performance of the systems. The team then defined a ranking methodology based on important criteria for selecting technologies.

After conducting thorough literature reviews on technologies used in aviation and other fields that could be applied to aviation, the team obtained components and costs required for enabling the systems to operate according to their specifications from vendors. We have also reached out to both state airport authorities as well as airports in Florida to learn what technologies are used by them. After initial rankings were made based on these findings, researchers have conducted onsite evaluations using the selected technologies. This study assessed the suitability of aircraft operations counting technology at non-towered airports based on the results of the onsite evaluation.

1.1. Objectives

New proprietary and non-proprietary systems were developed to count aircraft operations more reliably and accurately at airports without a staffed air traffic control tower. These systems include methods that utilize equipment that identifies aircraft transponder and/or ADS-B equipment signals.

This study will updates the 2018 FDOT *Operations Counting at Non-Towered Airports Assessment* report by exploring the feasibility, accuracy, and reliability of innovative technologies. These include receiving equipment combined with specialized computer programming that records aircraft operations. For example, a specific aircraft's location-altitude profile (as recorded using its transponder/ADS-B signals) in relation to a known airport's location, could be used to indicate a type of operation at that airport (e.g., landing, takeoff, etc.). Although several systems have been summarized in past research, innovative technologies continue to emerge, and this project identified and evaluated systems for counting aircraft operations using currently available technologies.

1.2. Statement of Problem

Accurate estimates of daily and annual aircraft operations at airports (i.e., approaches, landings, and takeoffs), including the types of aircraft conducting the operations, provide critical information used by airports, the Florida Department of Transportation (FDOT), and the Federal Aviation Administration (FAA). Accurate and reliable operational data are used in the development of aviation forecasts for airport master plans as well as statewide and national aviation forecasts developed by the FDOT and FAA, respectively. The availability of this information can vary widely, but the data are instrumental in airport planning, environmental analyses, funding allocations, project justifications, and airport staffing, as well as other applications. For example, accurate data can serve as the basis for validating pavement evaluations at airports, justification for runway capacity improvements based on operational demand, or a key metric for prioritizing state and federal funding for other airport development projects.

1.3. Purpose of Study

In the past few years, new proprietary and non-proprietary systems have been developed to count aircraft operations more reliably and accurately at airports without a full-time staffed Air Traffic Control (ATC) tower. These technologies/systems include methods that identify aircraft transponder and/or Automatic Dependent Surveillance-Broadcast (ADS-B) equipment signals, as well as systems that do not depend on the involvement of any aircraft systems, such as trail cameras or RAdio Detection And Ranging (RADAR). This project assessed different technologies/systems and provided an update to the findings of the FDOT 2018 Operation Counting at Non-Towered Airports Assessment report, with the addition of more innovative systems currently available.

1.4. Definitions and Terminologies

This section provides a list of terms utilized for this project, and their respective definitions, giving a more comprehensive understanding of the context in which the term is used. It also provides the various types of aircraft operations at an airport to ensure a consistent understanding of the performance of the systems.

- Accuracy: Defined by Merriam-Webster, as the freedom from mistake or error: correctness (Merriam-Webster, n.d.). For this project, accuracy is defined as the precision to which the System/Technology can precisely count (runway) aircraft operations
- ADS-B Out: The broadcasting of information about an aircraft's GPS location, altitude, ground speed, and other data to ground stations and other aircraft, at a rate of once per second.
- Aircraft operations: The airborne movement of aircraft in controlled or noncontrolled airport terminal areas, and counts at en route fixes or other points where counts can be made. There are two types of operations: local and itinerant. Local operations mean operations performed by aircraft which operate in the local traffic pattern or within sight of an airport. Itinerant operations mean all aircraft operations other than local operations. (Cornell Law School - Legal Information Institute, n.d.)
- Airport: An area of land or other hard surfaces, excluding water, that is used or intended to be used for the landing and takeoff of aircraft, including any buildings and facilities. (Code of Federal Regulations - A point in time eCFR system, n.d.)
- Classes of Airspace:
    - Class A includes airspace from 18,000 feet Mean Sea evel (MSL) up to and including FL 600, including the airspace overlying the waters within 12 Nautical Miles (NM) of the coast of the 48 contiguous states and Alaska; and designated international airspace beyond 12 NM of the coast of the 48 contiguous states and Alaska within areas of domestic radio navigational signal or ATC RADAR coverage, and within which domestic procedures are applied.
    - Class B includes airspace from the surface to 10,000 feet MSL surrounding the nation's busiest airports in terms of IFR operations or passenger numbers. The configuration of each Class B airspace is individually tailored and consists of a surface area and two or more layers, and is designed to contain all published instrument procedures once an aircraft enters the airspace. For all aircraft, an ATC clearance is required to operate in the area, and aircraft so cleared receive separation services within the airspace.
    - Class C includes airspace from the surface to 4,000 feet above the airport elevation (charted in MSL) surrounding those airports having an operational control tower, serviced by RADAR approach control, and having a certain number of IFR operations or passenger numbers. Although the configuration of each Class C airspace area is individually tailored, the airspace usually consists of a 5 NM radius core surface area that extends from the surface up to 4,000 feet above the airport elevation, and a 10 NM radius shelf area that extends from 1,200 feet to 4,000 feet above the airport elevation.
    - Class D includes airspace from the surface to 2,500 feet above the airport elevation (charted in MSL) surrounding those airports that have an operational control tower. The configuration of each Class D airspace area is individually tailored, and when instrument procedures are published, the airspace is normally designed to contain the procedures.

  - Class E includes airspace that is not Class A, Class B, Class C, or Class D, and is controlled airspace.
  - Class G includes airspace that is uncontrolled, except when associated with a temporary control tower, and has not been designated as Class A, Class B, Class C, Class D, or Class E airspace.
- Cooperative target: A target that automatically or interactively cooperates with a detection system by emitting information usable by available sensors to detect and track its movement. Examples include ADS-B Out, a transponder, or pilot voice transmissions.
- Non-cooperative target: A target that does not automatically or interactively cooperate with a detection system by emitting information usable by available sensors to detect and track its movement. The detection system's sensors must use technology that can independently detect and track the target. Examples include photographic or video cameras, acoustic microphones, RADAR, or Light Detection and Ranging (LiDAR).
- Departure: The flight path which begins after takeoff and continues straight ahead along the extended runway centerline. The departure climb continues until reaching a point at least 1/2 mile beyond the departure end of the runway and within 300 feet of the traffic pattern altitude (Aeronautical information Manual (AIM): Section 3, n.d.).
- Landing: From the beginning of the landing flare until aircraft exits the landing runway, comes to a stop on the runway, or when power is applied for takeoff in case of a touch-and-go landing (ICAO, 2013).
- Low approach: sometimes referred to as a low pass or go-around consisting of an approach at or below pattern altitude that passes over the approach and departure thresholds of a runway without touching down.
  - A low approach is counted as a landing and a take-off operation as per FAA Order JO 7210.3DD Section 13-2-1
- Reliability: The extent to which an experiment, test, or measuring procedure yields the same results on repeated trials (ICAO, 2013). For this project, reliability will be defined as the consistency of the system/equipment to perform as expected under different circumstances for extended periods.
- Takeoff: From the application of takeoff power, through rotation and to an altitude of 35 feet above runway elevation or until gear-up selection, whichever comes first (ICAO, 2013).
- Touch-and-go: A touch-and-go is a landing on a runway of any kind (grass or asphalt), which is then immediately followed by a taxi, applied power, and a subsequent takeoff.
  - A touch-and-go is counted as a Landing and a Take-off operation as per FAA Order JO 7210.3DD Section 13-3-1
- Scheduled Operation: Any common carriage passenger-carrying operation for compensation or hire conducted by an air carrier for which the air carrier or its representatives offers in advance the departure location, departure time, and arrival location. It does not include any operation conducted as a supplemental operation under 14 Code of Federal Regulations (CFR) Part 121 or public charter operations under 14 CFR Part 380.
- Unscheduled Operation: Any common carriage passenger-carrying operation for compensation or hire, using aircraft designed for at least 31 passenger seats, conducted by an air carrier for which the departure time, departure location, and arrival location are specifically negotiated with the customer or the customer's representative. This includes

any passenger-carrying supplemental operation conducted under 14 CFR Part 121 and any passenger-carrying public charter operation conducted under 14 CFR Part 380

- Undercount: Defined by the Oxford Languages dictionary as, enumerate (something, especially a sector of a population in a census) at a lower figure than the actual figure.
    - For this research, undercount refers to aircraft operations that occurred, but were not logged by a particular system or human observer. Undercounting of aircraft operations can occur for various reasons, including human error or distraction, sensor limitations or placement, or system configurations. Regardless, this results in inaccurate data and underestimation of aircraft activity.
- Overcount: Defined by Merriam-Webster as, to count more of (people or things) than is accurate.
    - For this research, overcount refers to aircraft operations logged by systems or observed by humans but did not occur in real life. This can lead to overestimation of aircraft activity. Overcounting can occur due to incorrect data input, algorithms, or calculations. It is important to identify and reduce overcounting to ensure accurate aircraft operation counts.

2. Findings from Initial Studies

2.1. Ranking Methodology

2.1.1. Technology Categorization

The existing literature regarding counting aircraft operations at non-towered airports contains an extensive list of attributes used to categorize systems. To simplify and standardize, a categorization system was selected based on whether the application or technology relied upon the actions of, or transmissions from, a pilot or aircraft in order to detect and count an airport operation.

The three (3) categories selected for use in this study are:

- Cooperative systems (e.g., ADS-B, voice communication) use sensors that rely on a cooperative target to provide information necessary to detect and track the target actively or passively.
- Non-cooperative systems (e.g., RADAR or LiDAR) use sensors that do not rely on a cooperative target to provide information and can actively detect and track a non-cooperative target.
- Hybrid systems (e.g., both ADS-B and RADAR) use a combination of sensors that can detect both cooperative and non-cooperative targets.

2.1.2. Ranking Criteria

Past studies in evaluating technologies for counting airport operations at non-towered airports are primarily based on a qualitative approach, gathering information through questionnaires and reviewing published studies on the subject. This project followed such a qualitative approach. The research team conducted literature reviews for technologies associated with counting airport operations at non-towered airports to identify the significant evaluation criteria used in this area of study. Accuracy is the most frequently evaluated criterion for this type of research. The system(s) must be able to perform under different conditions throughout the day and night; hence, the research team included reliability as part of the ranking criteria. Various costs associated with the installation and operation of the system(s) were included in order to determine the affordability by airports. Out of the attributes identified from the literature reviews, a final set of features for ranking criteria was approved by the FDOT. They are the following:

- Accuracy – Percentage of actual operations counted by the system
- Reliability – Ability of the technology to perform under all conditions for an extended period.
- Infrastructure requirement – Minimum infrastructure required to install a system to operate with the required accuracy.
- Installation costs – Total cost associated with the initial installation of the system, including equipment, installation fees, licenses, permits, etc.
- Operational costs – Recurring costs associated with the system's operation, such as an annual license fee.
- Maintenance costs – Any costs associated with all required maintenance to keep the system running within the original installation specifications.
- Additional features – Any notable features or properties considered as advantages compared to other systems being evaluated.

2.1.3. Ranking Methodology

Ranking of technologies can be accomplished by deriving an overall performance of technologies as a sum of individual rankings. It is not realistic to rank overall performance because the relative importance among parameters cannot be quantitatively defined accurately. Instead, it was proposed that a list of criteria of interest to the study be used, grouped into three levels of importance, which DOT approved. The levels were as follows:

- Highly important - Accuracy
- Important – Infrastructure requirement, reliability, and various costs
- Moderately important - Additional features

Each criterion of interest parameter (identified in section 2.1.2) was subjectively scored between 1 and 5 separately, with 5 being the highest ranking and a value of 0 indicating To Be Determined (TBD). **Error! Reference source not found.** demonstrates such an approach can be visually depicted by a radar chart. While infrastructure requirement, reliability, and various costs are all categorized as Important, neither infrastructure requirement nor reliability were considered during the ranking process for the following reasons:

1) The infrastructure requirements of all technologies in this study were essentially the same
2) The reliability of the candidate technologies could not yet be independently assessed

Consequently, only the accuracy, installation cost, operation cost, and maintenance cost variables were included in the ranking process.

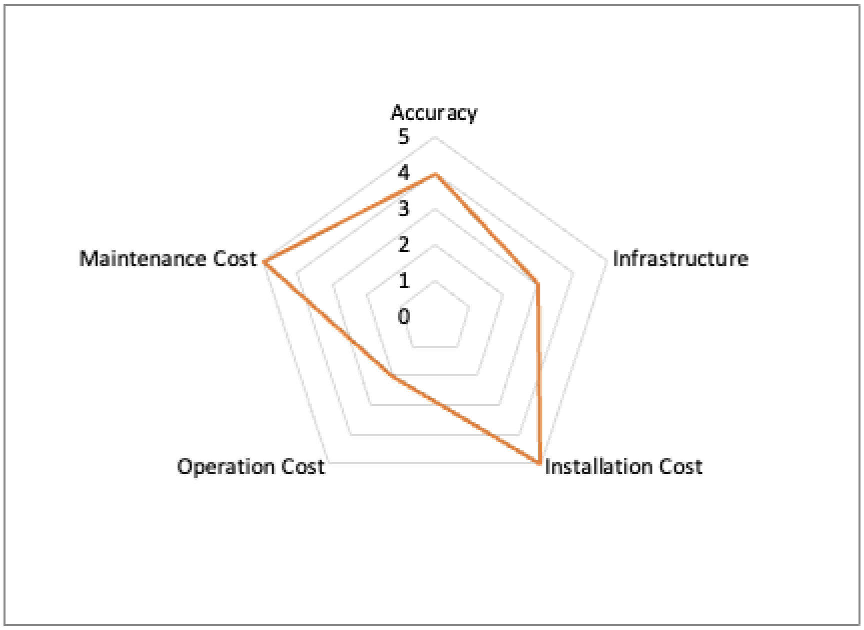


Figure 1. Visual Representation of the Ranking Methodology

The research team has explored various vendors already associated with the aviation/airspace industry, as well as vendors not currently conducting business associated with the aviation/airspace industry. This was conducted with the anticipation of finding innovative solutions that could be applied.

2.2. Cooperative Systems

Cooperative systems (e.g., ADS-B, voice communication) use sensors that rely on a cooperative target to provide information necessary to detect and track the target actively or passively.

2.2.1. General Audio Recording Device (G.A.R.D.)

Invisible Intelligence, LLC, has released a new upgrade to their General Audio Recording Device (G.A.R.D.) (Invisible intelligence, LLC, n.d.). The new system adds on an optional dual-band ADS-B (1090/978 MHz) receiver. Counting airport operations is based on monitoring an airport's Unicom frequency and using automated speech detection to identify and average the number of transmissions made by each aircraft to deduce a takeoff or landing operation. Figure 2 shows the G.A.R.D.

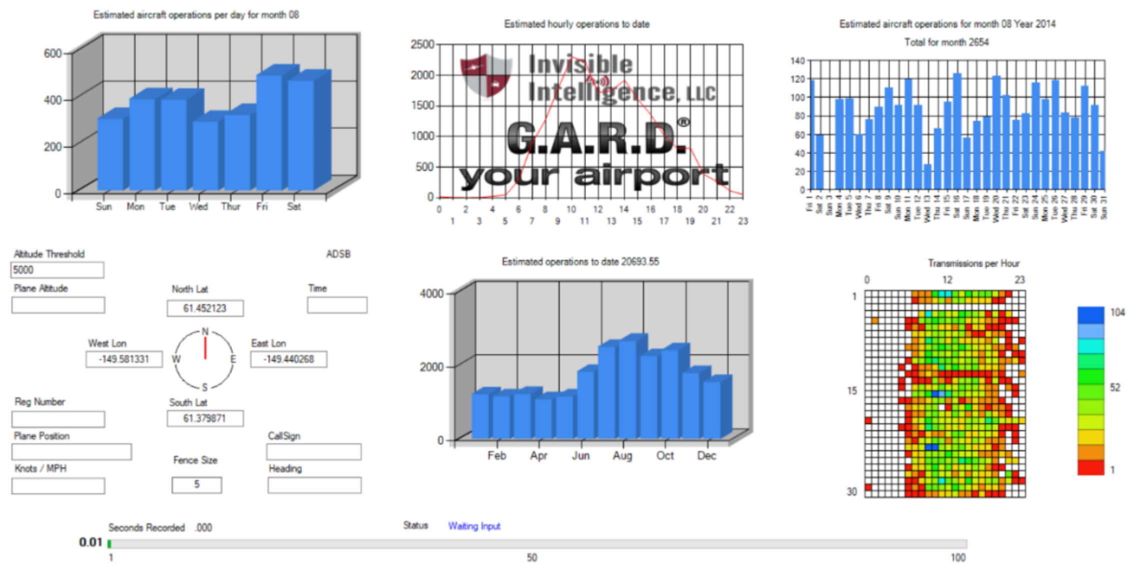


Figure 2. G.A.R.D. Reporting Screen of Operations by Month/Day of Month/Date/Hour

reporting screen with a breakdown of the operations by month, day of the month, date, and hour. The initial system configuration requires the user to input an estimated value for the number of audio transmissions per arriving and departing aircraft. The aircraft count method is based on the combination of the user inputs, and the speech detection functionality. The newly added ADS-B receiver option, and the FAA's aircraft registry integration, provides the end-user with complementary information regarding the aircraft type, landing speed, and owner. Figure 3 shows G.A.R.D. ADS-B Reporting Map interface.

The G.A.R.D. system is deployed pre-configured with the factory's airport Universal Communications (UNICOM) frequency set. The system must be placed near a window to avoid any potential signal interference and away from any source of white noise. The system can generate reports of aircraft operations counts by time and aircraft type.

According to a 2018 FDOT report, the accuracy of the G.A.R.D. system varied from 40% ~ 90% (FDOT, 2018). It was stated that this variation was due to either an incorrect estimation of the average for the number of transmissions per take-off and landing, an airport with a shared UNICOM frequency, or white noise (audio sound at all frequencies with equal measure). The current system with an ADS-B receiver costs around $7,000, at the time of this study, and the vendor reports accuracies above 70% approaching 85%-plus on audio.

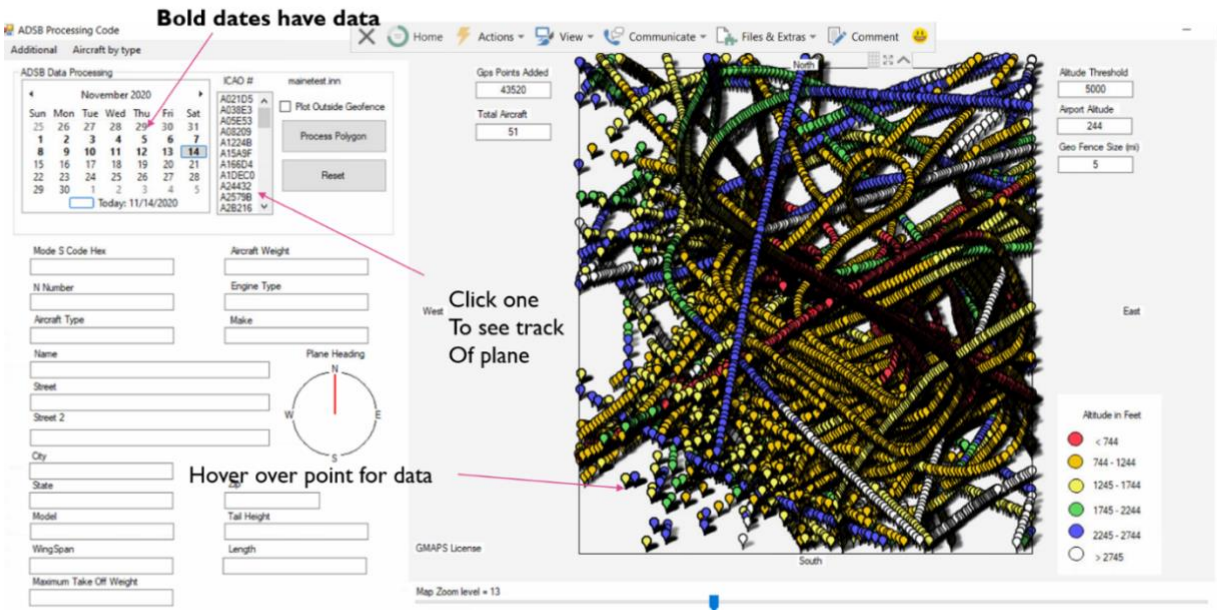


Figure 3. G.A.R.D. ADS-B Reporting Map

2.2.2. Virtower Airport Operations System

Developed by Virtower, LLC, the software monitors an airport's operations using a proprietary dual-band ADS-B (1090/978 MHz) receiver, and Mode S with multilateration (MLAT), to track aircraft with a range of up to 200 miles[1]. Multilateration tracking of a non-ADS-B Mode S transponder requires the aircraft to be in the range of at least (3) Virtower sensors, located at Virtower serviced airports, when landing or taking off. The system only requires the installation of one receiver per airport to monitor its operations. The system falls in the Cooperative Target category, relying on the aircraft's transmissions to receive its surveillance information. Additionally, the system collects Automatic Dependent Surveillance- Rebroadcast (ADS-R) and Traffic Information System Broadcast (TIS-B) received from L3Harris ground stations, although Virtower considers it too slow and inaccurate to use in the system reporting.
The software is able to record take-off, landing, and touch-and-go operations counts. Additionally, the system tracks ground movement on all areas of pavement at the airport for utilization, according to the rules set up by the airport management team. This includes individual aircraft movements on exits, taxiways, runway crossings, run-up areas, and fueling stations. The system provides a web-based user interface (Figure 4) that offers a set of pre-defined reports and surveillance data rendering on a map. Reports can be generated for any period and include a breakdown by aircraft type, activity type, and runway or helipad.

The service provided by the Virtower system offered two (2) service plans at the time of this study:

- General Aviation (GA) airports plan: fees advertised for $500/month
- Air carrier airport plan: fees advertised for a minimum of $1,000/month

[1] Based on data received from Virtower on 4/18/2022

- Equipment installation (1 receiver per airport) is included in both service plans

In terms of accuracy, Virtower claims a 100% degree of accuracy for aircraft actively transmitting ADS-B. This claim is with the caveat that the developer has seen 98% of aircraft equipped with at least a Mode S 1090ES transponder, Mode S transponder, or Universal Access Transceiver (UAT), operating at the airports where their service is currently provided. Additional features include:

- Generate Noise abatement maps by runway
- Extract all track data for Part 150 studies
- Display of METAR and TAF data for an airport
- Overlay FFA VFR and IFR charts on the track display map

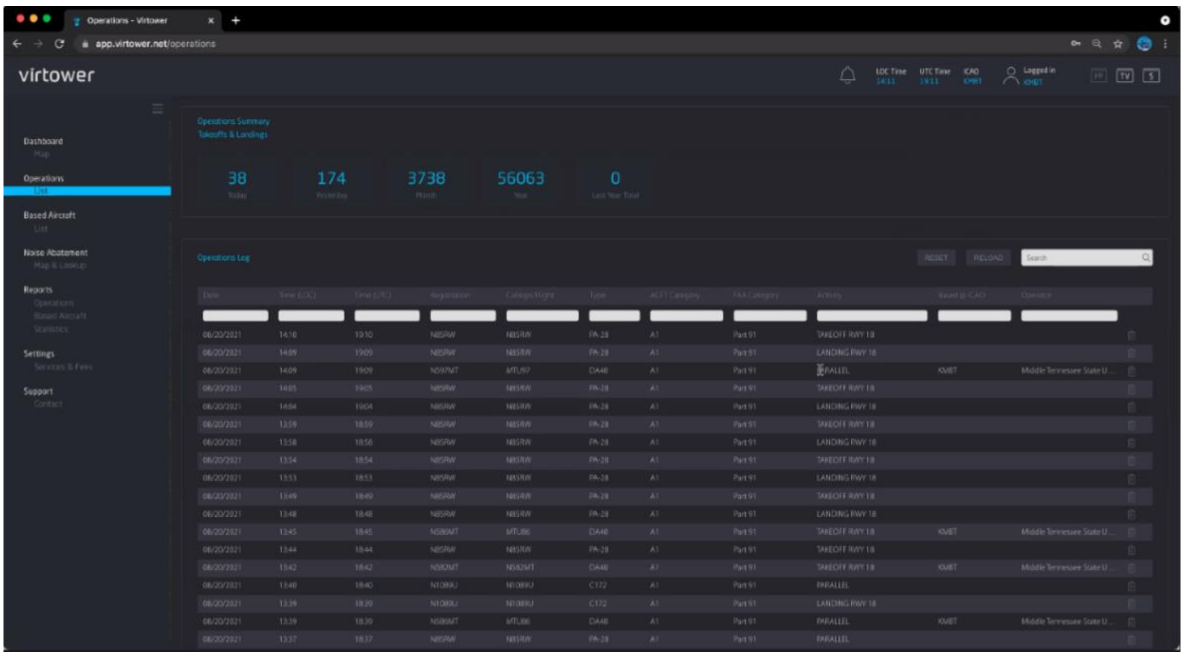


Figure 4. Virtower Web Interface

2.2.3. Airport Operations Counting and Analysis System

The Aircraft Operations Counting and Analysis System (AOCAS), was developed by Airport Monitoring Systems' (AMS) (Airport Monitoring system, n.d.). The system provides two (2) configurations: a base system with ADS-B, and an optional RADAR sensor for tracking non-ADS-B equipped aircraft.

The ADS-B system uses a proprietary dual-band ADS-B receiver (Mode S 1090ES/ UAT 978 Mhz) to capture the information from cooperative targets equipped with ADS-B OUT. The system is able to capture information regarding the following aircraft operations around the airport:

- Take-off (TO)
- Landing (LA)
- Flyover (FO)

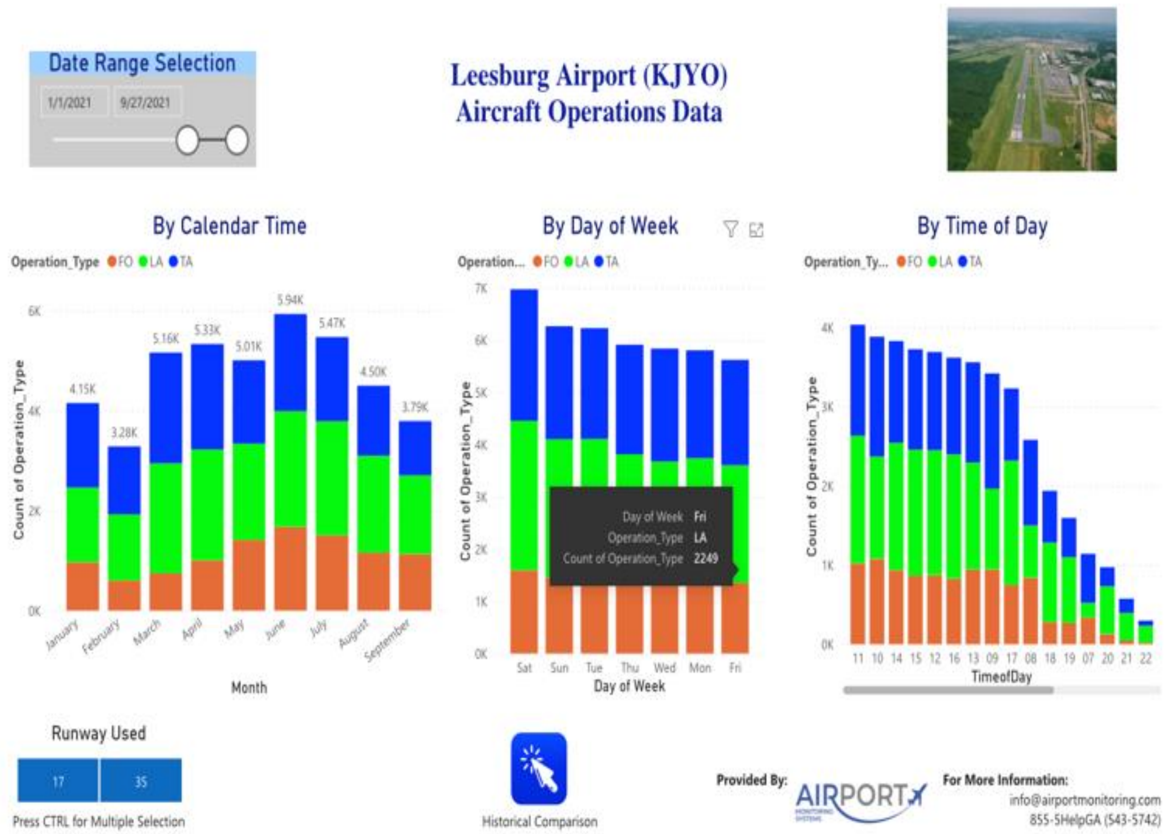


Figure 5. AOCAS Reporting Page of Operational Counts by Month/Day of the Week/Time

The system processes touch-and-go operations as separate take-off and landing operations, or optionally as distinct operations. Stop-and-go operations are also counted as separate take-off and landing operations based on criteria set by the airport. Helicopter operations are counted in alignment with FAA definitions, with optional filters. Figure 5, shows the web-based interface for the Airport Operations Counting Analysis System where take-off, landing, and flyover operations are denoted as TA, LA, and FO. Reports can be generated for aircraft operations by type, month, day of the week, and time of day.

Flight tracks, and origin/destination information, for a particular aircraft, are available with FlightAware integration. AOCAS includes a proactive event notification feature to alert stakeholders of real-time aircraft noise compliance events associated with a particular aircraft penetrating a certain geofence volume at a specific time, or the arrival of an aircraft after hours. The system can queue data for more than 30 days in the event of disrupted Internet connectivity and will forward the data when connectivity is restored or pulled via the cellular modem.

At the time of this study, the system's annual cost was $1,495, including all hardware, maintenance, installation, and training costs, with an optional five-year bundle of $6,952.

The user interface provided is based on Microsoft Power BI business analytics service.

Additional features include:

- An open architecture for integration with external systems, such as FBO and airport management software, fuel services, and aircraft owner datasets

- Export of Operations and Aircraft Position databases for use in modeling software, GIS software, and data visualization tools
- Optional integration with on-premises wildlife cameras and broad-spectrum imaging technology to generate notifications to pilots and airport staff

2.3. Non-cooperative Systems

Non-cooperative systems (e.g. RADAR or LIDAR) use sensors that do not rely on a cooperative target to provide information, and are able to actively detect and track a non-cooperative target.

2.3.1. 4SIGHT M

Developed by AEye, 4SIGHT M, is a Light Detection and Ranging (LiDAR) based technology (4sight M, n.d.). The system is built on a unique proprietary artificial intelligence (AI) technology, Intelligent Detection And Ranging, (iDAR), algorithms. This intelligence is enabled by patented bistatic architecture, which separates the transmit and receive channels, allowing iDAR to optimize both operations. As each laser pulse is transmitted, the receiver is informed where and when to seek its return – enabling deterministic AI to be introduced into the sensing process at the acquisition point. Ultimately, this establishes the iDAR platform as adaptive – allowing it to focus on what matters most in its surroundings. The result mimics how the human visual cortex conceptually focuses on and evaluates the environment around the vehicle, driving conditions, and road hazards, enabling more intelligent, more accurate decision-making – radically improving the probability of detection and the accuracy of classification.

The system combines solid-state LiDAR and optionally fused low-light High Definition (HD) cameras and integrated deterministic AI to capture more intelligent information with less data, enabling faster, more accurate, and more reliable perception. It collects 4 to 8 times the information of conventional, fixed pattern LiDAR while reducing power consumption 5 to 10 times. It does this by decreasing how much irrelevant data are conveyed to the motion-planning system – in many cases, by more than 90 percent.

Adapting the 4SIGHT system to the context of counting aircraft operation will require updating its model/object to allow it to efficiently detect aircraft on a runway with an expected accuracy of 95%. The system will be capable of detecting non-cooperative target take-offs, landings, and touch-and-go operations. The estimated cost of the new system, at the time of this study, was around $20,000.

2.3.2. EchoGuard 3D Surveillance RADAR

The EchoDyne EchoGuard 3D surveillance RADAR, Figure 6, is an Electronically Scanned Array (ESA) RADAR technology used in fighter jets, reduced to the size of a book with COTS pricing (EchoDyne, n.d.). Innovative software defined RADAR technology allows the RADAR to operate standalone or as part of a larger system. The sensor has a 120 degrees azimuth and 80 degrees elevation field of view, with an angular resolution of just 2 degrees in azimuth and 6 degrees in elevation. It can detect and track 20 targets per panel, with a range of 2.5 km with an update rate of 10 times per second. It weighs just 2.75 lbs, consuming 50 W of power, with a Manufacturer's Suggested Retail Price (MSRP) of $40k per unit at the time of this study. A lower cost version of the EchoGuard CR RADAR was also available.

The manufacturer believes that most airport configurations could be covered with one or two units, and the unit can track targets on the surface and in the air. The sensor outputs non-cooperative target track data and is heavily used today to track UAV by commercial companies and researchers (Figure 7). It is expected that some software development would be required to apply the geofencing feature and count aircraft operations.

Figure 6. EchoGuard3D RADAR Sensor

Figure 7. EchoGuard RADAR Deployed for Ground-Based Airspace Management by the University of Alaska

2.4. Hybrid System

Hybrid systems (e.g., both ADS-B and RADAR) use a combination of sensors that can detect both cooperative and non-cooperative targets.

2.4.1. Airport Operations Counting and Analysis System (ADS-B & RADAR)

The Aircraft Operations Counting and Analysis System (AOCAS), was developed by Airport Monitoring Systems' (AMS). The system provides a base configuration with ADS-B (described in section 2.2.3), and an optional RADAR sensor for tracking non-ADS-B equipped aircraft.
The ADS-B plus RADAR option includes all the base system features described in section 2.2.3 plus RADAR sensors to track and count non-ADS-B equipped aircraft.
The ADS-B system uses a proprietary dual-band ADS-B receiver (Mode S 1090ES/ UAT 978 Mhz) to capture the information from cooperative targets equipped with ADS-B OUT. The RADAR is based on similar RADAR technology used by police department RADAR guns and is deployed to capture non-cooperative targets. The annual cost of the base system at the time of this study was $1,495, and includes all hardware, maintenance, installation, and training costs.
The RADAR Sensors' additional one-time cost, at the time of this study, is based on runway length.

- RADAR sensors for a runway length < 4000 ft will cost an additional $3000.
- RADAR sensors for a runway length > 4000 ft and <7000f t will cost additional $6000.

If the RADAR location does not allow for power cabling, there is a Solar Power option for the RADAR sensors at an additional one-time cost at the time of this study.

- Solar power for a runway length < 4000 ft will cost an additional $3000.
- Solar power for a runway length > 4000 ft and <7000 ft will cost additional $6000.

2.4.2. Airport Operations Counting and Analysis System (ADS-B & Camera)

The Aircraft Operations Counting and Analysis System (AOCAS), was developed by Airport Monitoring Systems' (AMS). The system provides a base configuration with ADS-B (described in section 2.2.3), and optional camera sensors for tracking non-ADS-B equipped aircraft.
The ADS-B plus camera option includes all the base system features described in section 2.2.3 plus camera sensors to track and count non-ADS-B equipped aircraft. The ADS-B system uses a proprietary dual-band ADS-B receiver (Mode S 1090ES/ UAT 978 Mhz) to capture the information from cooperative targets equipped with ADS-B OUT. The Camera configuration is customized for each airport and is deployed to capture non-cooperative targets.
Below are representative costs to provide ADS-B sourced, and camera (non-ADS-B) sourced operations information, for a typical one-runway airport with four runway ingress/egress taxiways. The cost will vary based on airport geometry as configuration, data, and cost tradeoffs are made collaboratively with each airport. For example, most non-ADS-B operations at many airports are related to aerial applicators that have minimal, if any, night operations. Therefore, the higher cost of cameras and possibly Infrared (IR) illuminators to collect non-ADS-B operations at night is not justified for these airports.
The annual cost of the base system's ADS-B source data at the time of this study was $1,495, and includes all hardware, maintenance, installation, and training costs.
The annual cost for the camera source data at the time of this study, up to 3,000 operations/month, was an additional $2995.00
There was one charge for the camera design/implementation of $1000 at the time of this study.
The one-time cost for each taxiway/runway intersection camera was typically around $995.00 at the time of this study.

For the single runway example with four runway ingress/egress taxiways, there would be an initial one-time cost of $3980.00 at the time of this study.

2.4.3. Vantage

The Vantage system is developed by Vector Airport Systems. The system uses a combination of camera and data feeds from L3Harris to count aircraft operations. It utilizes three (3) distinct types of cameras, which are defined by their utilizations at the airport as follows:

- Runway camera: These cameras are pointed at the runway and are equipped with large IR lights for low-speed aircraft up to 1,000 ft away.
- Taxiway camera: These cameras are pointed at taxiway entry/exit points and are equipped with small IR lights for low-speed aircraft up to 400 ft away.
- Touch-and-go Camera: The Touch-and-go cameras do not use IR lighting and are suitable for daylight pictures in high-speed flights.

Cameras using IR lights, are stand-alone, solar-powered, and motion-activated to conserve battery power. Pictures are stored on the camera and periodically transferred to a central server to preserve the battery used by Wi-Fi, typically within 3 hours. Images are post-processed on the server. The height of the cameras varies depending on weather and terrain, with around 3 ft high in Florida to 6 feet high in snow areas to avoid obstructions. The number of cameras varies based on airport complexity, airport requirements, and budget (i.e., some airports may not count all operations, types of departures, arrivals, and touch & goes)

A typical small airport with two taxiway cameras will cost about $60k for installation and $12.5K per year for Out-of-Pocket (OOP) Man-and-Materials (M+M) services (Including equipment tech refresh every five -5- years) at the time of this study. The Installation cost includes travel and site surveys, which can vary depending on the equipment used. Other airports nearby could share costs with overlapping installations. Installation and OOP M+M costs include base cost-plus incremental charges based on the number of cameras.

Locations that do not have aircraft coverage with the L3Harris data feed, can be equipped with an augmentation sensor (~$10k at the time of this study) that feeds track data into the L3Harris service feed. L3Harris service fees are included within OOP M+M service cost, and vary depending on location, update rate, and use.

According to Vantage, some small remote airports have seen as much as 50-60% of aircraft not ADS-B equipped, relying on cameras to detect operations. The System is used at airports and heliports. No water-based airports are currently served, but it represents a possible alternative for this type of operation. Figure 8 shows the Vector user interface display.

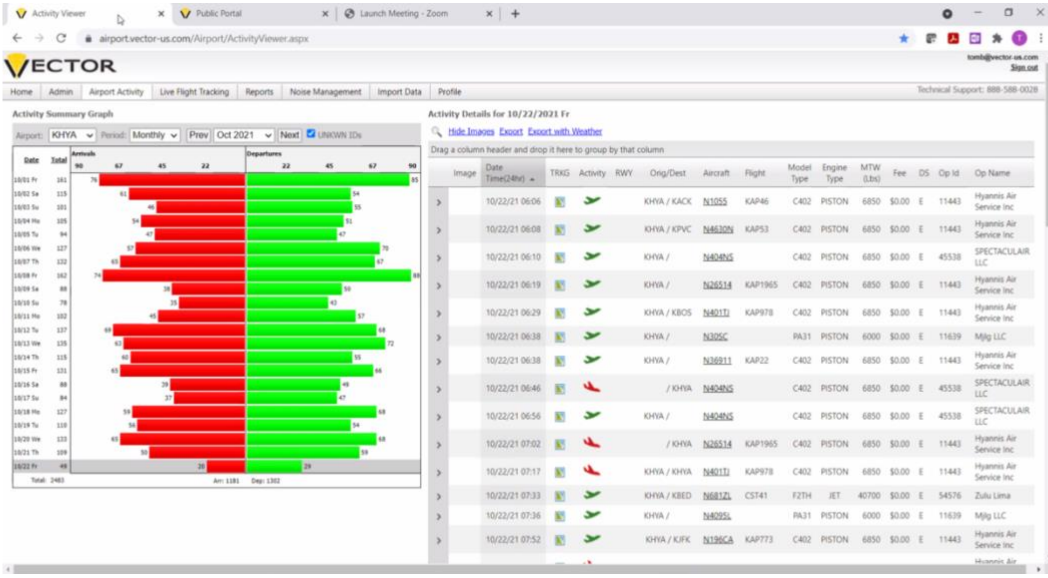


Figure 8. Vantage User Interface Display

2.5. Findings From State's Airport Authority Questionnaire

A questionnaire about practices in airport operation counting at non-towered airports (47)was sent out to the majority of state airport authorities (whose contact information was available) within the United States. The questions aimed to collect information regarding the counting technologies and methods airports used (if any), any future plans to do so, the purpose of counting, etc. As shown in Table 1, only ten (10) states completed the questionnaire, and due to the small number of responses, no statistically significant information was gained, but it may imply that airport operation counting at non-towered airports is of significant interest only to a limited number of states.

Table 1. State Airport Authority Questionnaire Feedback For Operations Counting

State	Reported known systems	Comments
Idaho	G.A.R.D.	The state no longer manages or monitors the counting process Each airport chooses its own method of counting operations
Illinois	G.A.R.D.	One time pilot project study at 20 airports 80-90% estimated accuracy, not validated
Louisiana	Unknown	A consultant contract for a system plan study Counts are calculated based on a methodology A snapshot in time Less than 80% estimated accuracy
	G.A.R.D.	ADS-B record of tracks. Greater than 95% reported accuracy

Table 2. Table 1 Continued. State Airport Authority Questionnaire Feedback For Operations Counting

State	Reported known systems	Comments
Idaho	G.A.R.D.	The state no longer manages or monitors the counting process Each airport chooses its own method of counting operations
Illinois	G.A.R.D.	One time pilot project study at 20 airports 80-90% estimated accuracy, not validated
Louisiana	Unknown	A consultant contract for a system plan study Counts are calculated based on a methodology A snapshot in time Less than 80% estimated accuracy
	G.A.R.D.	ADS-B record of tracks Greater than 95% reported accuracy
Maine	G.A.R.D.	Each NPIAS airport has a G.A.R.D. system Well over 90% accuracy compared to airport data
Minnesota	G.A.R.D.	System purchased as a test to see if airports found it useful Some airports purchased a system Unknown reported accuracy
Montana	Unknown	Estimated counts provided by airport managers Unknown reported accuracy
New Jersey	ADS 4000 Phenix	Operations count estimated by Delaware Valley Regional Planning Commission Estimated seasonal averages Acoustic counting device The vendor reported accuracy greater than 90%
Texas	G.A.R.D.	Airports use a combination of seasonally adjusted estimates and ADS-B Less than 80% reported accuracy for anything less than human counting
Virginia	N/A	Uses a based aircraft formula to estimate counts
Wyoming	N/A	Have not collected statewide counts Airports report using a variety of sample methods, including acoustical counters, visual counts, and cameras.

2.6. Findings From Sampled Airports in Florida

Opinions about airport operations counting technologies and requirements were also solicited from a pseudo-random sampling of airports in Florida by asking a set of questions (Appendix 51). The selection was based on whether they had a control tower and/or an existing counting system in place, which could be used for historical comparison of counts to quantify the accuracy of a current system, and proximity to Daytona Beach as a potential location for onsite evaluation with human spotters. Table 3 summarizes the comments received from responding airport managers regarding their use of operations counting technology. Due to the small number of responses, no statistically significant information was gained. However, the feedback did indicate that historical track data are important to some airports for noise abatement calls and asset utilization. Additionally, comparing system counts to tower counts for airports with at least a partially operating control tower could be helpful for deducing aircraft Mode S / ADS-B equipage data for aircraft operating within Florida.

Table 3. Sampled Florida Airport Feedback for Operations Counting

Identifier	**Name**	**Comments**
F15	Halifax River Sea Plane Base	Generally has no revenue No benefit to having counts with small numbers
KFIN	Flagler Executive	Uses tower for operations counts Using Virtower for six months Provides track history for noise abatement and researching nuisance calls Provides geofencing for fuel farm
OMN	Ormond Beach	Using Virtower for 17 months Operations counts are supplementary to tower counts Track history used to research noise complaints Runway usage information Throughout 2021, there is a 25-30% undercount of operations with Virtower operating 24 hours per day, compared to tower counts operating 12 hours per day Lack of ADS-B equipage suspected for undercounts
X04	Orlando Apopka	Only GA aircraft No interest in operations counts as the airport does not apply for funding
X36	Englewood (Buchan Airport)	Mostly light-sport aircraft Using Virtower Airport is VFR only and closes at sunset Reports run weekly

2.7. Ranked Technologies

This section summarizes the findings of aircraft operation counting technologies investigated. As previously stated, each of the technologies received a score between 1 and 5 for each criteria of interest parameter, with a value of 0 indicating TBD (to be determined). Each criterion was based on a subjective and relative comparison among the technologies evaluated, and the number in the parenthesis at the end of each entry in the table indicates their scores. While 4SIGHT M (LiDAR) and EchoGuard 3D Surveillance RADAR were explored as promising technology solutions for airport operations counting purposes, a complete counting system using each technology was not available at the time of the investigation. Hence, their scores for available criteria were listed in the table solely for reference, and excluded from the ranking process. Since information either provided by vendors or found on their websites is based on different standards and was not validated in the same experimental setting, scoring (and thus ranking) should be taken with this context in mind.

- Accuracy: All vendors claimed at least 85% of accuracy. However, this claim assumes that systems dependent on cooperative targets are installed at airports with at least this percentage of aircraft with the required equipment. All systems that utilize ADS-B from cooperative targets should have similar detected counts, therefore:
    - Virtower, and Airport Operations Counting and Analysis (ADS-B only option) have a score of 3.
    - Airport Operations Counting and Analysis ADS-B & RADAR option and ADS-B & Camera options have a score of 4 because the RADAR and cameras can count non-cooperative targets that are not ADS-B equipped.
    - Vector Airport Systems' Vantage with ADS-B and multiple specialized camera options provides additional coverage of non-cooperative targets and has a score of 5.
    - G.A.R.D. relies on cooperative voice transmission but is based on observed average counts of radio transmission, so it was assigned a score of 2.
    - Reliability: All vendors claim high reliability without any statistical information. Hence, they are left out as TBD for this report.
    - Infrastructure: All technologies require at least one power supply. Virtower and Vector Airport Systems further need Internet access. Hence, they received scores of 3 while the rest of the technologies received scores of 4.
    - Installation cost: Vector Airport Systems and G.A.R.D. required installation costs of approximately $60,000 and $7,000, respectively, at the time of this study. Hence, their scores were 1 and 3, respectively. Systems without any installation cost received a score of 5. The research team was unable to find the installation cost of the EchoGuard and 4SIGHT M system; hence, these are left out as TBD with a score of 0.
    - Operational cost: Vector Airport Systems has the highest operational cost of $12,500 per year for their minimal configuration at the time of this study, and hence it received a score of 1. The operational cost of Virtower ($6,000-$12,000/year) at the time of this study, is the second highest and received 2. Airport Operations Counting & Analysis systems with RADAR ($1,495/year + RADAR subscription at the time of this study) and camera options (about $4,500/year at the time of this study) received a score of 3, with ADS-B only option ($1,495/year at the time of this study) received a score of 4. G.A.R.D. got a

score of 5 for not requiring operational costs. Neither 4SIGHT M (LiDAR) nor EchoGuard 3D Surveillance RADAR have complete systems. Hence, these are left out as N/A with a score of 0.

- Maintenance cost: Virtower, Vector Airport Systems, and Airport Operations Counting & Analysis systems (ADS-B only) received a score of 5 as they do not require additional maintenance costs. It is unclear if Airport Operations Counting & Analysis systems with RADAR or camera options have maintenance cost, hence they are left out as TBD with a score of 0. Neither 4SIGHT M (LiDAR) nor EchoGuard 3D Surveillance RADAR have complete systems, hence they are left out as N/A with a score of 0.
- Additional features – None of the vendors' additional features were quantifiable and were disregarded. Hence, this criterion will not be used for ranking systems until additional information is obtained.

Based on the scores shown in Table 4, a radar chart was created for each system. **Error! Reference source not found.** shows a set of radar charts to visually assist each component of the overall score for each system.

Table 4. Summary of Findings of Aircraft Operation Counting Technologies

Item	**G.A.R.D. (Radio + ADS-B)**	**Virtower (ADS-B + Mode S)**	**4SIGHT M (LiDAR)**	**EchoGuard 3D Surveillance RADAR**	**Airport Operations Counting & Analysis (ADS-B only)**	**Airport Operations Counting & Analysis (ADS-B + RADAR)**	**Airport Operations Counting & Analysis (ADS-B + Camera)**	**Vector Airport Systems Vantage (ADS-B + Cameras)**
Accuracy	40%~90% [Ref FDOT 2018 Assessment Report] 70~85% (Vendor stipulation) (2)	100% (Vendor assumption of 98% ADS-B equipage) (3)	~95% (Vendor stipulation of target detection (2)	~95% (Vendor stipulation of target detection) (2)	~95% (Vendor stipulation) (3)	~95% (Vendor stipulation) (4)	~95% (Vendor stipulation) (4)	~100% (Vendor noted as low as 50% with low aircraft equipage and no camera) (5)
Reliability	TBD	TBD	TBD	TBD	TBD	TBD	TBD	TBD
Infrastructure requirement	Power (4)	Power Internet (3)	TBD	TBD	Power (4)	Power (4)	Power (4)	Power Internet (3)

Table 5. Table 4 Continued, Summary of Findings of Aircraft Operation Counting Technologies

Item	**G.A.R.D. (Radio + ADS-B)**	**Virtower (ADS-B + Mode S)**	**4SIGHT M (LiDAR)**	**EchoGuard 3D Surveillance RADAR**	**Airport Operations Counting & Analysis (ADS-B only)**	**Airport Operations Counting & Analysis (ADS-B + RADAR)**	**Airport Operations Counting & Analysis (ADS-B + Camera)**	**Vector Airport Systems Vantage (ADS-B + Cameras)**
Installation Cost	$6,995 base system (optional $5,200 ADS-B add on) (3)	None (5)	TBD	TBD ($40k per sensor, and complete system cost not available)	None (5)	An additional $3,000 for RADAR for runways for less than 4000 ft, $5,000 for RADAR for runways for greater than 4,000 ft and less than 7,000 ft (3)	$1,000 for design + $995 per camera(e.g., $ 3,980 for one runway and 4 taxi intersections) (3)	$60,000 (for a typical 2 camera system), to $100,000 with 3-5 year lease option until paid for (for a 4 taxiway camera system) (1)
Operational Cost	None (5)	$6,000-$12,000/year (2)	N/A	N/A	$1,495/year (4)	$1,495/year for ADS-B data + RADAR subscription (3)	$1,495/year for ADS-B data + $2,995/year for camera data (assuming one runway and 4 taxi intersections) (3)	$12,500 per year (with 2 cameras) $18-20k per year (with 4 cameras) (1)
Maintenance Cost	TBD	Hardware replacement cost included in the operational cost (5)	N/A	N/A	No additional cost (5)	TBD	TBD	Hardware replacement cost included in the operational cost (5)
Additional Features						Solar power option available ($4,000 for a runway less than 4,000 ft, and $6,000 for a runway greater than 4,000 ft and less than 7,000 ft)		

Figure 9. Radar Charts Comparing Overall Score among Evaluated Systems

2.8. Recommended Technologies for Field Test

All systems (except G.A.R.D) are based on ADS-B technology, and they include options to augment their accuracy with additional sensor types to count non-cooperative aircraft. They are ranked overall in terms of accuracy and cost based on the ability to include counts for non-cooperative targets. Airports would weigh the cost and the benefit of additional sensors, based on their budget and the mix of aircraft equipage of their users.

Evaluated technologies and configurations were ranked from first to last in the following order:

- ADS-B only, lowest cost
  - Virtower (ADS-B + Mode S)
  - Airport Operations Counting & Analysis (ADS-B only)
- ADS-B plus + camera/RADAR, higher cost
  - Airport Operations Counting & Analysis (ADS-B + Camera)
  - Airport Operations Counting & Analysis (ADS-B + RADAR)
- L3Harris feed (RADAR, multilat, ASDE-X, ADS-B) plus multiple camera types, highest cost
  - Vector Airport Systems Vantage (L3Harris feed + Cameras)
- Acoustic counting, plus ADS+B position data (not used for counting)
  - G.A.R.D.

3. Field Tests

From the recommendations provided in Phase 1 Task 3, the following technologies and configurations were selected for the onsite testing:

- ADS-B only, lowest cost
  - Virtower (ADS-B + Mode S)
  - Airport Airport Monitoring Systems (ADS-B only)
- (ADS-B + RADAR), evaluated to capture non-cooperative aircraft
  - Airport Airport Monitoring Systems (ADS-B +RADAR)

Evaluations of the selected technologies were conducted by implementing the same performance indicators and variable samples (i.e., the same sets of aircraft operations at the same airport on the same day). This methodology ensured the evaluation condition was identical to all technologies assessed.

3.1. Onsite Evaluation Location

Based on several factors that included 1) availability of systems installed at airports, 2) proximity of airports from ERAU Daytona Campus, and 3) willingness of airport managers and staff to support the onsite testing, the DeLand Municipal Airport (KDED) and Ormond Beach Municipal Airport (KOMN) were selected for the onsite evaluation activities.

3.1.1. Deland Municipal Airport (KDED)

The ADS-B sensors by Virtower and Airport Monitoring Systems were both collocated within the KDED airport. An aerial view of the Deland Municipal Airport highlighting runway numbers is shown in Figure 10. KDED Airport Runway Configuration Airport Aerial View. The runways characteristics are the following:

- Runway 05/23 Length (feet): 4,301
- Runway 05/23 Width (feet): 75
- Runway 05/23 Surface: Asphalt
- Runway 12/30 Length (feet): 6,001
- Runway 12/30 Width (feet): 100
- Runway 12/30 Surface: Asphalt
- Type: Public General Aviation

Figure 10. KDED Airport Runway Configuration Airport Aerial View

As of the time of this research, Virtower had an existing installation at KDED. However, Airport Monitoring Systems(AMS) installed a temporary instance of their product to comply with the requirements of this on field testing. The location of ADS-B sensors by Virtower and Airport Monitoring Systems are shown in Figure 11 and **Error! Reference source not found.**, respectively.

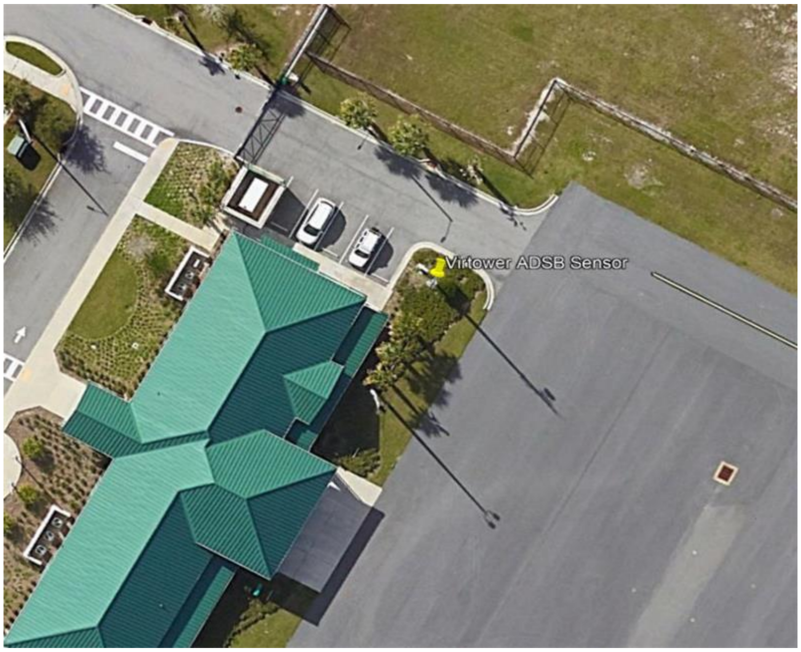


Figure 11. KDED Location of Virtower ADS-B Sensor

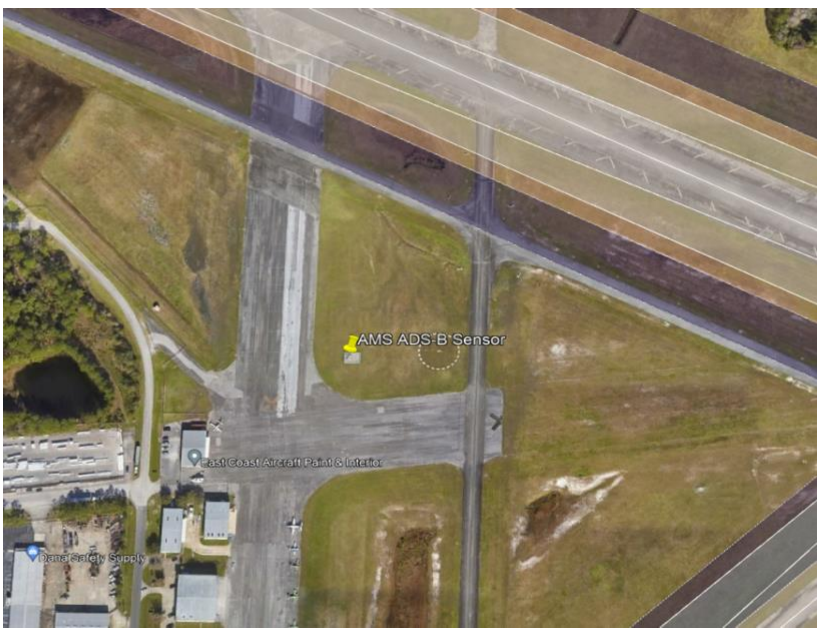


Figure 12.KDED Location of AMS ADS-B Sensor

The RADAR sensor equipment was temporarily installed only to detect aircraft operations for Runway 05 and Runway 23. The original installation locations, planned by AMS to be ideal for detecting aircraft operations, were not approved by the FAA. Therefore, new locations of the RADAR sensors and solar panels for Runway 05 and Runway 23 were identified, and these are shown in Figure 13 and Figure 14, respectively.

Figure 13. KDED Location of AMS RADAR Equipment at Runway 5

Figure 14. KDED Location of AMS RADAR Equipment at Runway 23

The human spotters were located within, and moved about, the ramp area during the data collection periods in order to observe the aircraft operations (Figure 15).

Figure 15. KDED Human Spotter Observation Area

3.1.2. Ormond Beach Municipal Airport (KOMN)

The ADS-B sensors by Virtower and Airport Monitoring Systems were both collocated within the KOMN air traffic control tower.

KOMN (Figure 16) has the following characteristics:

- Runway 09/27 Length (feet): 4,005
- Runway 09/27 Width (feet): 75
- Runway 09/27 Surface: Asphalt
- Runway 17/35 Length (feet): 3,704
- Runway 17/35 Width (feet): 100
- Runway 17/35 Surface: Asphalt
- Type: Public General Aviation

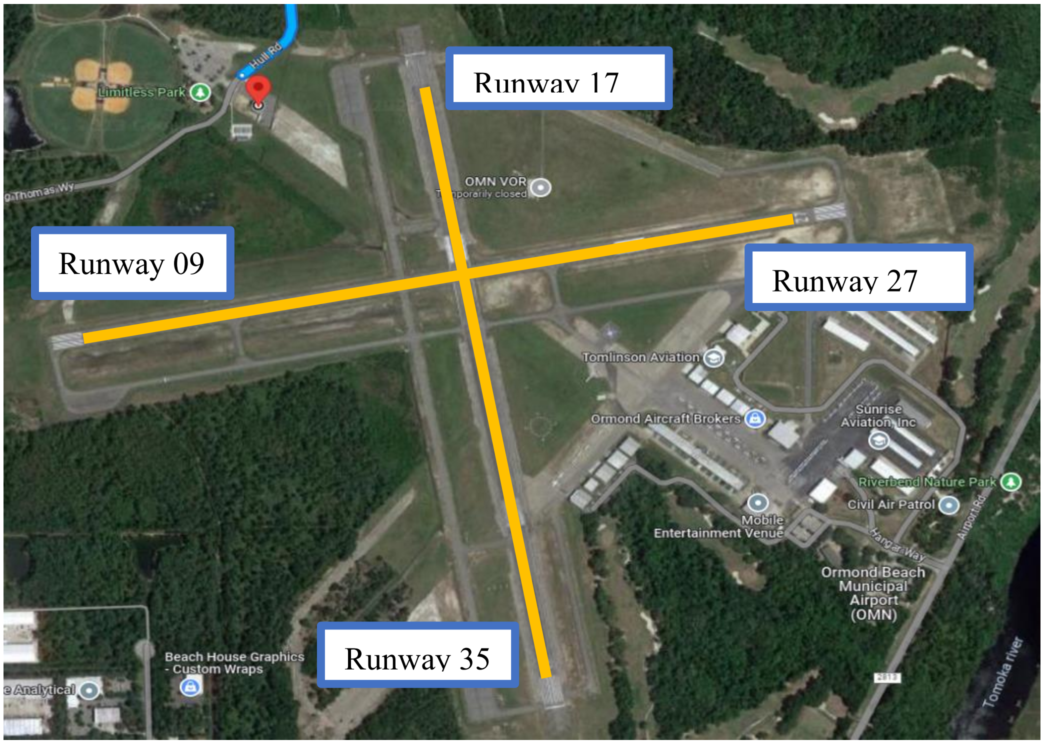


Figure 16. KOMN Airport Runway Configuration

The human spotters parked within the air traffic control tower fenced area during the data collection periods in order to observe the aircraft operations (Figure 17).

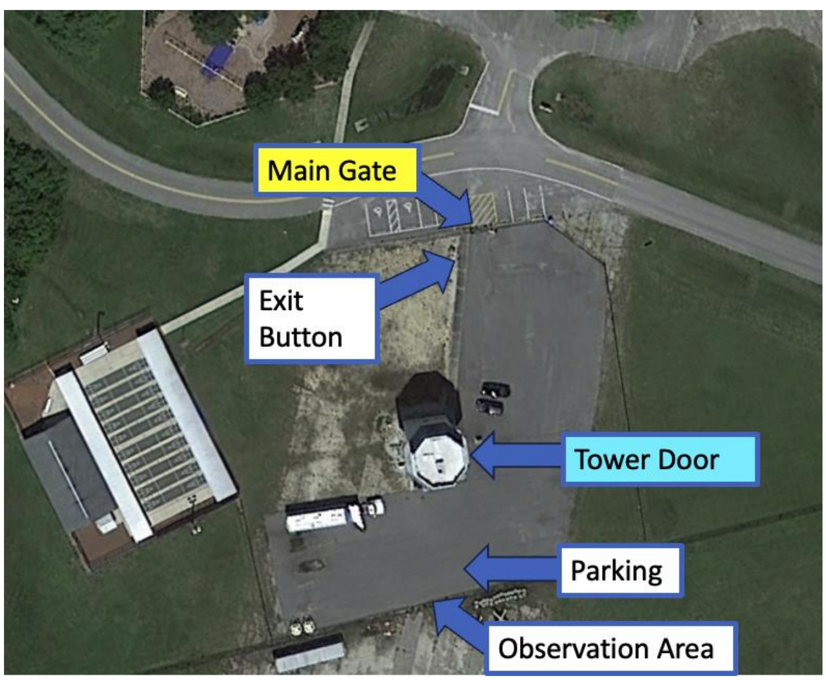


Figure 17. KOMN Human Spotter Observation Area

3.2. Selected Technologies for Onsite Evaluation Location

We have evaluated the following configurations of the selected technologies:

- ADS-B only, lowest cost
  - Virtower (ADS-B + Mode S)
  - Airport Operations Counting & Analysis (ADS-B only)
- Airport Operations Counting & Analysis (ADS-B + RADAR) – This configuration was selected for evaluation at field test due to its affordability. On the other hand, Airport Operations Counting & Analysis (ADS-B + Camera) was not selected for its high price.

3.2.1. Technology Utilization for Aircraft Operation Counts

The following section will provide a detailed description of the methodology applied for the commercial systems.

Airport Monitoring Systems (AMS) LLC

The Aircraft Operations Counting and Analysis System provided two (2) different alternatives regarding sensor configurations, and these are the following:

- ADS-B
- RADAR

The system uses a dual-band ADS-B receiver (1090/978 Mhz) to capture the information broadcast from cooperative targets equipped with ADS-B Out. The system is able to capture information regarding the following aircraft operations around the airport:

- Take-off
- Landing
- Low approach
- Touch-and-go

The system processed the low approach and Touch-and-go operations as separate take-off and landing operations.

The RADAR option utilizes sensors similar to those used by police department RADAR guns and is deployed to capture non-cooperative targets, see Figure 18. In this configuration, the system detects take-off and landing operations using RADAR detected position and speed measurements. The system requires one RADAR sensor for runways 3,000-4,000 ft in length and two sensors for runways over 4,000 ft. RADAR sensor placement is customized for each airport based on airport configuration.

Both sensors (ADS-B and RADAR) were installed by AMS at the KDED airport. However, only ADS-B sensors were installed at KOMN. The installation at both airports were completed under the approval of the FAA and airport authorities following the submission of FAA Form 7460-1 in accordance with guidelines and regulations to avoid any safety issues or disruption of the aircraft operations. However, the FAA mandated locations of the RADAR sensors for this temporary installation were far from the vendor's recommended locations for normal operations. AMS provided direct access to its system's database, and data were retrieved by the research team the morning after each day of data collection. The system is able to log the type of sensor that detected the operation (ADS-B or RADAR). Logged aircraft operations detected by

RADAR may also include the aircraft identification if correlated with ADS-B reports, or anonymous if detected by RADAR only.

Figure 18. AMS RADAR Sensor

Virtower

Developed by Virtower, LLC, the software monitors an airport's operation using proprietary dual-band ADS-B (1090/978 MHz), and Mode S (a secondary surveillance and communication system supporting ATC) with multilateration (MLAT) capabilities and a range of up to 75 miles. The system only requires the installation of one receiver per airport to monitor its operation. The system falls in the Cooperative Target category and, therefore relies on the aircraft to receive its surveillance information.

The system is able to capture information regarding the following aircraft operations around the airport:

- Take off
- Landing
- Low approach
- Touch-and-go
- Movement in the airport based on the rules set up by the airport management team

The system processed the low approach and Touch-and-go operations as separate take-off and landing operations.

Among the variables considered for airport selection, the research team contemplated the fact that this system (Virtower) was already installed and running at both facilities. Therefore, the only action (method) expected from the company was access to the system's reports. The reports for KDED were received by the research team via email from Virtower the day following each of the data collection activity days. The research team received the reports for KOMN via email from the airport manager following the data collection activity period.

3.3. Human-in-the-Loop Aircraft Count

Manual Count: for the data collection process, the research team assigned a group of "aircraft spotters" to be at the airport's facilities to observe and collect information about aircraft operations. The observations were classified as take-off, landing, low approach, and touch-and-go.The human spotters recorded their observations in journals. At the end of each shift, the spotters photographed their journal pages and emailed them to the research team for backup.

3.3.1. Rules and Guidelines

The research team established a set of rules and guidelines to be followed by the spotters. The main objective was to ensure that the collected data aligned with the project's purpose. Training and general information regarding points of contact, facility access, and logistics were provided ahead of the activity. However, the spotters were directed to follow these general guidelines:

- Record your own observations in the notebook
- Do not rely on information given by others
- Do not be distracted by others – If someone starts chatting with you, politely tell them that you are busy and you need to concentrate on your task
- Do not be distracted by other applications or activities
- Your sole objective is to visually detect all take-off, landing, low approach, and touch-and-go events for runways
- Not all aircraft may be making radio calls or be ADS-B equipped
- Focus on runway operations. Do not include helicopter operations such as hovering or approaches/departures that only cross runways

At each airport, scanner radios were tuned to the Common Traffic Advisory Frequency (CTAF) or Universal Communications (UNICOM) frequency during data collection periods. An audio recording device was attached to the radio to record all audio transmissions for later review should there be any ambiguity regarding an aircraft callsign or reported pilot radio calls and controller instructions.

3.4. Aircraft Operations Classification Criteria

As mentioned above, the aircraft operations were classified as:

- Take-off: From the application of take-off power, through rotation and to an altitude of 35 feet above runway elevation or until gear-up selection, whichever comes first
- Landing: From the beginning of the landing flare until aircraft exits the landing runway, comes to a stop on the runway, or when power is applied for take-off in case of a touch-and-go landing
- Low approach: sometimes referred to as a low pass or go-around consisting of an approach at or below pattern altitude that passes over the approach and departure thresholds of a runway without touching down.
- Touch-and-Go: A touch-and-go is a landing on a runway of any kind (grass or asphalt), which is then immediately followed by a taxi, applied power, and a subsequent take-off. From the spotter's point of view, the touch-and-go operations were registered as one landing immediately followed by a departure (take-off).
-

3.5. Data Analysis Methodology

Aircraft operations were counted by each technology and human spotters during the evaluation period. While the capabilities of data collection may vary, depending on vendor and technology, at least the following attributes needed to be collected by each technology to evaluate the accuracy of counting airport operations activities:

- Time of event
- Event type: (i.e., Landing, Take-Off, Low Approach, or Touch-and-Go)
- Runway used

The spotters were instructed to log the confidence level of their observation for each event. In particular, they were instructed to log a high level of confidence when they captured all three of these attributes. Additionally, the following attributes were desired to aid the airports with additional operations information and assist in correlating operations counts between vendors and human manual counts by researchers:

- Aircraft type
- Aircraft identification
- Weather conditions during evaluation

This research project compared the output of each system with that of human spotters in order to determine the effectiveness and error of each vendor system using the available sensor technology. In order to perform the data analysis on the operation counts output by each vendor system, a few steps were needed to first normalize the data prior to correlating individual operations. This correlation was necessary as each system produced aggregate take-off and landing counts while also exhibiting undercounts and overcounts. While the aggregate counts may be close to actual counts, the combined under and over counts partially washout and hide missed counts and/or inflate actual counts. Each system relies heavily on ADS-B to detect aircraft positions, which are not broadcast from non-cooperative aircraft not equipped with ADS-B OUT. While multilateration can help, the research team noticed that not all non-cooperative aircraft were detected. Additionally, even with ADS-B OUT, multiple cases were observed where multiple take-offs were counted for an aircraft without the corresponding landings in between.

3.5.1. Data Preprocessing

The raw data from each vendor system was received and stored in a Comma Separated Value (CSV) file containing a number of parameters describing each aircraft operation and details of the aircraft involved. A list of parameters provided by each vendor can be found in Appendix 52. Only a select few of these parameters were used in the data correlation phase of this study (see Table 6).

Table 6. Data Parameters

Parameter	Description
Operation Date/Time	The date and time the operation occurred in Zulu
Operation Type	The type of operation: Landing (LA) or Takeoff (TO)
Runway Used	i.e., 30, 05, etc.
Aircraft N-Number	Provided within ADS-B message or on airframe (i.e., N123ER)
Aircraft Callsign	Provided within ADS-B message or via radio call (i.e., ERU123)

The CSV files were first imported into a spreadsheet application, and the parameters not used in the data correlation were removed to simplify the comparison. Any operations reported by the vendor systems during periods when human spotters were not available were also removed, as these could not be correlated with the spotters' observations. Additional events involving the utilization of designated airport areas not associated with runway utilization were also removed.
The human spotters' journal pages were transcribed into a spreadsheet application, and each touch-and-go and low approach entry was converted into corresponding landing and take-off entry pairs.

3.5.2. Data Correlation

Once daily files of operations were produced for each vendor system and the human spotters, each operation was manually correlated between the three (3) files line-by-line in order to determine if a reported operation was corroborated, an overcount, or an undercount.

- A reported operation was flagged as an overcount if the operation was not seen by at least one other system or spotter.
- A reported operation was flagged as an undercount if the operation was not seen by a system or spotter, but was seen by at least two (2) other systems or a spotter.

In the case of non-cooperative aircraft not broadcasting ADS-B, that were not detected by either system but were observed by a human spotter, undercounts were recorded for both systems.

At times, there were instances of intermittent detection, for example, a touch-and-go operation was missed by one or more systems or a spotter, or there was an illogical entry by one system, such as two (2) sequential take-offs on intersecting runways without a landing. In these cases, third-party archived ADS-B position report data sources were used to visually playback the path taken by the aircraft in order to determine if an operation could have logically taken place in space and time. The analysis of the replay informed whether the operations were undercounts or overcounts for the respective system or spotter. Sources of undercounts and overcounts for a system can include such things as unreceived or corrupted ADS-B reports, or errors with bounding boxes or algorithms. Sources of undercounts and overcounts for human spotters can include such things as visual obstruction by buildings or trees, faint or unintelligible radio calls, distractions, or bio breaks.

For each system and the spotters, the raw number of takeoffs and landings reported were tabulated for each collection day, as shown in Table 7.

Table 7. Sample Raw Reported Operation Counts

		7/5/2023		
Airport	Operation/Rwy	Spotter	Virtower	AMS
DED	TO 05	4	2	4
	TO 23	24	20	24
	TO 12	21	12	11
	TO 30	7	7	7
	Counted TO	56	41	47
	LA 05	4	4	4
	LA 23	25	24	25
	LA 12	23	17	22
	LA 30	10	8	9
	Counted LA	62	53	60

After each operation was manually correlated for each system and the spotters, the flagged over and under counts were tabulated and used to compute final adjusted takeoff and landing counts, as shown in Table 8, using the following formulas.

Adjusted LA = Raw Counted LA – Overcounted LA + Undercounted LA
Adjusted TO = Raw Counted TO – Overcounted TO + Undercounted TO

Table 8. Sample Computed Adjusted Operation Counts

		7/5/2023		
Airport	Operation/Rwy	Spotter	Virtower	AMS
DED	Under LA	0	10	2
	Under TO	1	16	10
	Over LA	0	1	0
	Over TO	0	0	0
	Adjusted LA	62	62	62
	Adjusted TO	57	57	57
	% Under LA	0.00%	16.13%	3.23%
	% Under TO	1.75%	28.07%	17.54%
	% Over LA	0.00%	1.61%	0.00%
	% Over TO	0.00%	0.00%	0.00%

3.6. Results

3.6.1. KDED Tabulated Results

The KDED raw numbers of takeoffs and landings reported and correlated by the spotter, Virtower, and AMS systems are presented in this section for the week of 7/5/2023 to 7/12/2023.

Table 9. KDED Tabulated Results 7/5/2023

Operation/Rwy	Spotter	Virtower	AMS		Operation/Rwy	Spotter	Virtower	AMS
TO 05	4	2	4		Under LA	0	10	2
TO 23	24	20	24		Under TO	1	16	10
TO 12	21	12	11		Over LA	0	1	0
TO 30	7	7	7		Over TO	0	0	0
Counted TO	56	41	47		Adjusted LA	62	62	62
LA 05	4	4	4		Adjusted TO	57	57	57
LA 23	25	24	25		% Under LA	0.00%	16.13%	3.23%
LA 12	23	17	22		% Under TO	1.75%	28.07%	17.54%
LA 30	10	8	9		% Over LA	0.00%	1.61%	0.00%
Counted LA	62	53	60		% Over TO	0.00%	0.00%	0.00%

Table 10. KDED Tabulated Results 7/6/2023

Operation/Rwy	Spotter	Virtower	AMS		Operation/Rwy	Spotter	Virtower	AMS
TO 05	23	19	19		Under LA	22	18	13
TO 23	80	76	82		Under TO	20	25	15
TO 12	10	11	10		Over LA	1	10	5
TO 30	34	40	40		Over TO	2	4	3
Counted TO	149	146	155		Adjusted LA	164	164	164
LA 05	26	23	25		Adjusted TO	167	167	167
LA 23	74	73	80		% Under LA	13.41%	10.98%	7.93%
LA 12	13	19	14		% Under TO	11.98%	14.97%	8.98%
LA 30	27	41	36		% Over LA	0.61%	6.10%	3.05%
Counted LA	143	156	156		% Over TO	1.20%	2.40%	1.80%

Table 11. KDED Tabulated Results 7/7/2023

Operation/Rwy	Spotter	Virtower	AMS		Operation/Rwy	Spotter	Virtower	AMS
TO 05	3	9	4		Under LA	10	11	13
TO 23	130	122	137		Under TO	10	26	12
TO 12	3	3	4		Over LA	0	0	4
TO 30	15	7	7		Over TO	0	5	3
Counted TO	152	141	153		Adjusted LA	163	163	163
LA 05	8	7	8		Adjusted TO	162	162	162
LA 23	124	133	130		% Under LA	6.13%	6.75%	7.98%
LA 12	7	7	7		% Under TO	6.17%	16.05%	7.41%
LA 30	13	5	5		% Over LA	0.00%	0.00%	2.45%
Counted LA	153	152	154		% Over TO	0.00%	3.09%	1.85%

Table 12. KDED Tabulated Results 7/8/2023

Operation/Rwy	Spotter	Virtower	AMS		Operation/Rwy	Spotter	Virtower	AMS
TO 05	0	3	0		Under LA	4	5	1
TO 23	66	55	64		Under TO	2	13	5
TO 12	0	0	0		Over LA	0	3	1
TO 30	3	3	3		Over TO	0	3	1
Counted TO	69	61	67		Adjusted LA	61	61	61
LA 05	0	2	0		Adjusted TO	71	71	71
LA 23	54	52	58		% Under LA	6.56%	8.20%	1.64%
LA 12	1	2	1		% Under TO	2.82%	18.31%	7.04%
LA 30	2	3	2		% Over LA	0.00%	4.92%	1.64%
Counted LA	57	59	61		% Over TO	0.00%	4.23%	1.41%

Table 13. KDED Tabulated Results 7/9/2023

Operation/Rwy	Spotter	Virtower	AMS		Operation/Rwy	Spotter	Virtower	AMS
TO 05	0	0	0		Under LA	7	3	9
TO 23	99	93	98		Under TO	8	12	5
TO 12	0	2	0		Over LA	0	1	1
TO 30	23	27	27		Over TO	0	3	0
Counted TO	123	122	126		Adjusted LA	133	133	133
LA 05	0	1	0		Adjusted TO	131	131	131
LA 23	99	100	96		% Under LA	5.26%	2.26%	6.77%
LA 12	7	8	7		% Under TO	6.11%	9.16%	3.82%
LA 30	20	22	20		% Over LA	0.00%	0.75%	0.75%
Counted LA	126	131	125		% Over TO	0.00%	2.29%	0.00%

Table 14. KDED Tabulated Results 7/10/2023

Operation/Rwy	Spotter	Virtower	AMS		Operation/Rwy	Spotter	Virtower	AMS
TO 05	1	0	1		Under LA	7	14	24
TO 23	138	115	119		Under TO	2	26	24
TO 12	0	1	0		Over LA	4	0	1
TO 30	15	14	14		Over TO	0	0	3
Counted TO	154	130	135		Adjusted LA	152	152	152
LA 05	2	2	3		Adjusted TO	156	156	156
LA 23	142	130	121		% Under LA	4.61%	9.21%	15.79%
LA 12	0	0	0		% Under TO	1.28%	16.67%	15.38%
LA 30	5	6	5		% Over LA	2.63%	0.00%	0.66%
Counted LA	149	138	129		% Over TO	0.00%	0.00%	1.92%

Table 15. KDED Tabulated Results 7/11/2023

Operation/Rwy	Spotter	Virtower	AMS		Operation/Rwy	Spotter	Virtower	AMS
TO 05	0	1	2		Under LA	9	7	4
TO 23	127	120	129		Under TO	4	12	3
TO 12	1	1	1		Over LA	1	1	4
TO 30	6	5	5		Over TO	0	1	4
Counted TO	134	127	139		Adjusted LA	139	139	139
LA 05	0	1	1		Adjusted TO	138	138	138
LA 23	126	126	131		% Under LA	6.47%	5.04%	2.88%
LA 12	2	4	3		% Under TO	2.90%	8.70%	2.17%
LA 30	3	2	2		% Over LA	0.72%	0.72%	2.88%
Counted LA	131	133	139		% Over TO	0.00%	0.72%	2.90%

Table 16. KDED Tabulated Results 7/12/2023

Operation/Rwy	Spotter	Virtower	AMS		Operation/Rwy	Spotter	Virtower	AMS
TO 05	52	52	53		Under LA	18	11	11
TO 23	60	63	60		Under TO	16	16	16
TO 12	0	1	0		Over LA	0	8	2
TO 30	33	34	31		Over TO	0	5	2
Counted TO	145	150	147		Adjusted LA	156	156	156
LA 05	55	53	57		Adjusted TO	161	161	161
LA 23	55	68	61		% Under LA	11.54%	7.05%	7.05%
LA 12	3	6	4		% Under TO	9.94%	9.94%	9.94%
LA 30	25	26	24		% Over LA	0.00%	5.13%	1.28%
Counted LA	138	153	147		% Over TO	0.00%	3.11%	1.24%

3.6.2. KOMN Tabulated Results

KOMN raw numbers of takeoffs and landings reported and correlated by the spotter, Virtower, and AMS systems are presented in this section for the week of 7/12/2023 to 7/19/2023.

Table 17. KOMN Tabulated Results 7/12/2023

Operation/Rwy	Spotter	Virtower	AMS		Operation/Rwy	Spotter	Virtower	AMS
TO 09	24	0	19		Under LA	5	7	10
TO 27	1	1	0		Under TO	2	3	5
TO 17	0	1	1		Over LA	0	0	0
TO 35	0	0	0		Over TO	0	1	0
Counted TO	25	25	22		Adjusted LA	31	31	31
LA 09	25	0	19		Adjusted TO	27	27	27
LA 27	1	1	1		% Under LA	16.13%	22.58%	32.26%
LA 17	0	1	0		% Under TO	7.41%	11.11%	18.52%
LA 35	0	0	0		% Over LA	0.00%	0.00%	0.00%
Counted LA	26	24	21		% Over TO	0.00%	3.70%	0.00%

Table 18. KOMN Tabulated Results 7/13/2023

Operation/Rwy	Spotter	Virtower	AMS		Operation/Rwy	Spotter	Virtower	AMS
TO 09	17	0	19		Under LA	3	4	1
TO 27	53	49	51		Under TO	4	2	1
TO 17	6	6	6		Over LA	4	0	0
TO 35	0	0	0		Over TO	5	0	4
Counted TO	77	74	79		Adjusted LA	78	78	78
LA 09	18	0	20		Adjusted TO	76	76	76
LA 27	54	48	50		% Under LA	3.85%	5.13%	1.28%
LA 17	6	6	6		% Under TO	5.26%	2.63%	1.32%
LA 35	0	0	0		% Over LA	5.13%	0.00%	0.00%
Counted LA	79	74	77		% Over TO	6.58%	0.00%	5.26%

Table 19. KOMN Tabulated Results 7/14/2023

Operation/Rwy	Spotter	Virtower	AMS		Operation/Rwy	Spotter	Virtower	AMS
TO 09	40	44	39		Under LA	10	14	11
TO 27	127	125	124		Under TO	8	6	11
TO 17	0	0	0		Over LA	0	0	0
TO 35	0	0	0		Over TO	1	1	0
Counted TO	167	169	163		Adjusted LA	175	175	175
LA 09	40	44	40		Adjusted TO	174	174	174
LA 27	124	117	124		% Under LA	5.71%	8.00%	6.29%
LA 17	0	0	0		% Under TO	4.60%	3.45%	6.32%
LA 35	0	0	0		% Over LA	0.00%	0.00%	0.00%
Counted LA	165	161	164		% Over TO	0.57%	0.57%	0.00%

Table 20. KOMN Tabulated Results 7/15/2023

Operation/Rwy	Spotter	Virtower	AMS		Operation/Rwy	Spotter	Virtower	AMS
TO 09	1	2	0		Under LA	9	12	21
TO 27	171	173	163		Under TO	11	12	16
TO 17	17	10	10		Over LA	4	0	0
TO 35	0	0	0		Over TO	4	1	0
Counted TO	189	185	180		Adjusted LA	195	195	195
LA 09	1	1	0		Adjusted TO	196	196	196
LA 27	172	172	164		% Under LA	4.62%	6.15%	10.77 %
LA 17	17	10	8		% Under TO	5.61%	6.12%	8.16%
LA 35	0	0	0		% Over LA	2.05%	0.00%	0.00%
Counted LA	190	183	174		% Over TO	2.04%	0.51%	0.00%

Table 21. KOMN Tabulated Results 7/16/2023

Operation/Rwy	Spotter	Virtower	AMS		Operation/Rwy	Spotter	Virtower	AMS
TO 09	0	0	0		Under LA	0	8	6
TO 27	57	51	50		Under TO	0	6	6
TO 17	0	0	0		Over LA	0	0	0
TO 35	0	0	0		Over TO	0	0	0
Counted TO	57	51	51		Adjusted LA	58	58	58
LA 09	0	0	0		Adjusted TO	57	57	57
LA 27	58	50	51		% Under LA	0.00%	13.79%	10.34%
LA 17	0	0	0		% Under TO	0.00%	10.53%	10.53%
LA 35	0	0	0		% Over LA	0.00%	0.00%	0.00%
Counted LA	58	50	52		% Over TO	0.00%	0.00%	0.00%

Table 22. KOMN Tabulated Results 7/17/2023

Operation/Rwy	Spotter	Virtower	AMS		Operation/Rwy	Spotter	Virtower	AMS
TO 09	0	1	0		Under LA	1	3	4
TO 27	84	80	81		Under TO	1	5	4
TO 17	0	0	0		Over LA	0	1	0
TO 35	0	0	0		Over TO	0	1	0
Counted TO	84	81	81		Adjusted LA	83	83	83
LA 09	0	1	0		Adjusted TO	85	85	85
LA 27	82	80	79		% Under LA	1.20%	3.61%	4.82%
LA 17	0	0	0		% Under TO	1.18%	5.88%	4.71%
LA 35	0	0	0		% Over LA	0.00%	1.20%	0.00%
Counted LA	82	81	79		% Over TO	0.00%	1.18%	0.00%

Table 23. KOMN Tabulated Results 7/18/2023

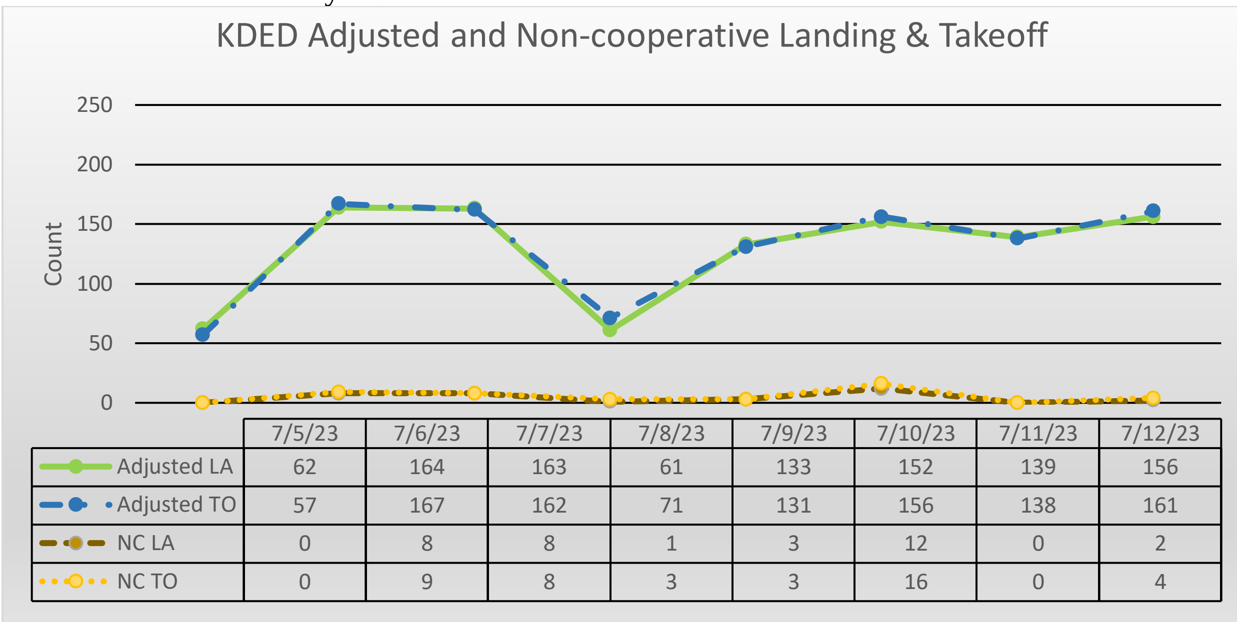
Operation/Rwy	Spotter	Virtower	AMS		Operation/Rwy	Spotter	Virtower	AMS
TO 09	30	0	29		Under LA	3	13	15
TO 27	114	105	100		Under TO	1	11	13
TO 17	0	0	0		Over LA	0	1	0
TO 35	0	0	0		Over TO	0	2	0
Counted TO	144	136	132		Adjusted LA	145	145	145
LA 09	31	0	32		Adjusted TO	145	145	145
LA 27	111	102	98		% Under LA	2.07%	8.97%	10.34 %
LA 17	0	0	0		% Under TO	0.69%	7.59%	8.97%
LA 35	0	0	0		% Over LA	0.00%	0.69%	0.00%
Counted LA	142	133	130		% Over TO	0.00%	1.38%	0.00%

Table 24. KOMN Tabulated Results 7/19/2023

Operation/Rwy	Spotter	Virtower	AMS		Operation/Rwy	Spotter	Virtower	AMS
TO 09	9	8	8		Under LA	2	8	6
TO 27	0	16	15		Under TO	1	4	6
TO 17	87	69	68		Over LA	0	1	0
TO 35	0	3	0		Over TO	0	3	0
Counted TO	96	96	91		Adjusted LA	95	95	95
LA 09	11	10	10		Adjusted TO	97	97	97
LA 27	0	17	17		% Under LA	2.11%	8.42%	6.32%
LA 17	82	61	62		% Under TO	1.03%	4.12%	6.19%
LA 35	0	0	0		% Over LA	0.00%	1.05%	0.00%
Counted LA	93	88	89		% Over TO	0.00%	3.09%	0.00%

3.6.3. Data Visualization

The collected data were visualized as shown in Figure 19 to **Error! Reference source not found.** for KDED and Figure 22 to Figure 24 for KOMN, so that patterns and trends could be studied for extended analysis.



	7/5/23	7/6/23	7/7/23	7/8/23	7/9/23	7/10/23	7/11/23	7/12/23
Adjusted LA	62	164	163	61	133	152	139	156
Adjusted TO	57	167	162	71	131	156	138	161
NC LA	0	8	8	1	3	12	0	2
NC TO	0	9	8	3	3	16	0	4

Figure 19. KDED Daily Adjusted and Non-cooperative Operations Counts

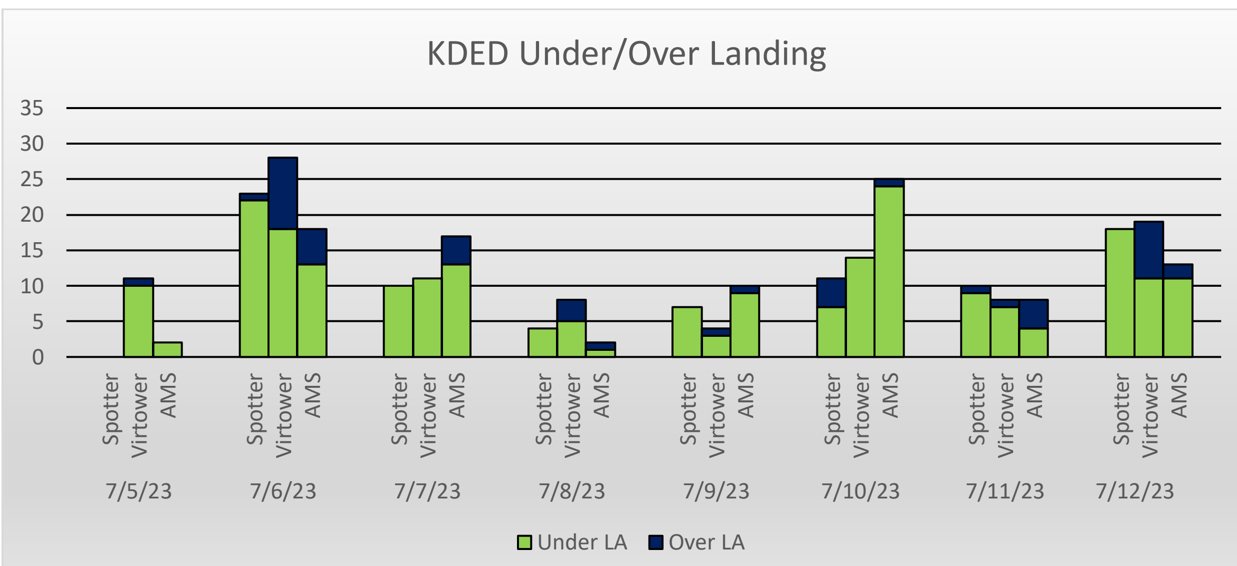


Figure 20. KDED Derived Operations over/under Landing Counts

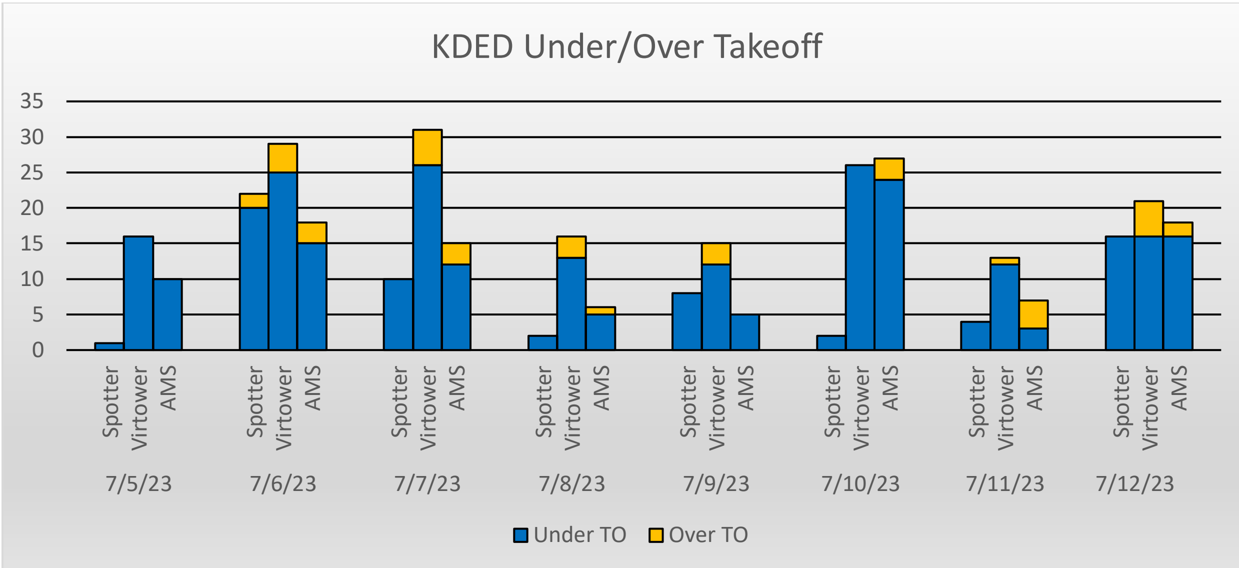
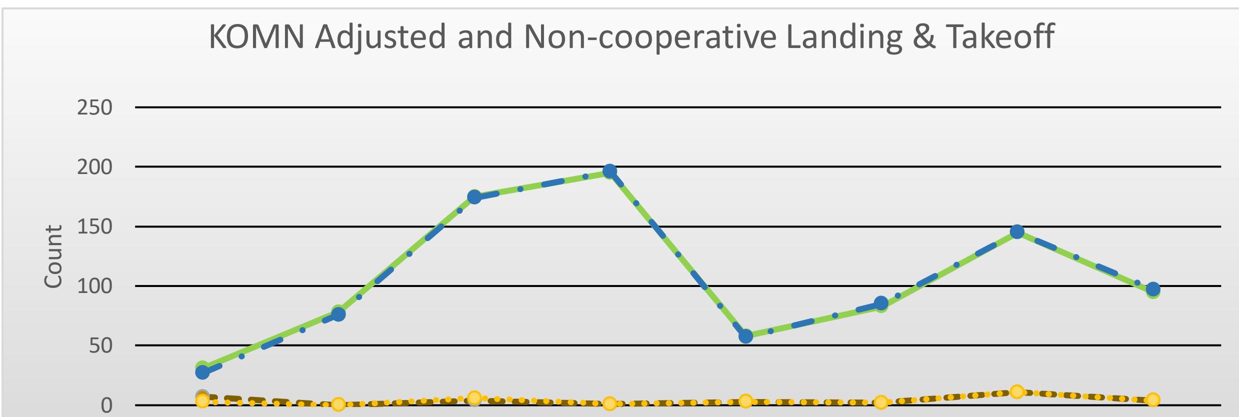


Figure 21. KDED Derived Operations over/under Takeoff Counts



	7/12/23	7/13/23	7/14/23	7/15/23	7/16/23	7/17/23	7/18/23	7/19/23
Adjusted LA	31	78	175	195	58	83	145	95
Adjusted TO	27	76	174	196	57	85	145	97
NC LA	7	0	4	1	3	2	11	4
NC TO	3	0	6	1	3	2	11	4

Figure 22. KOMN Daily Adjusted and Non-cooperative Operations Counts

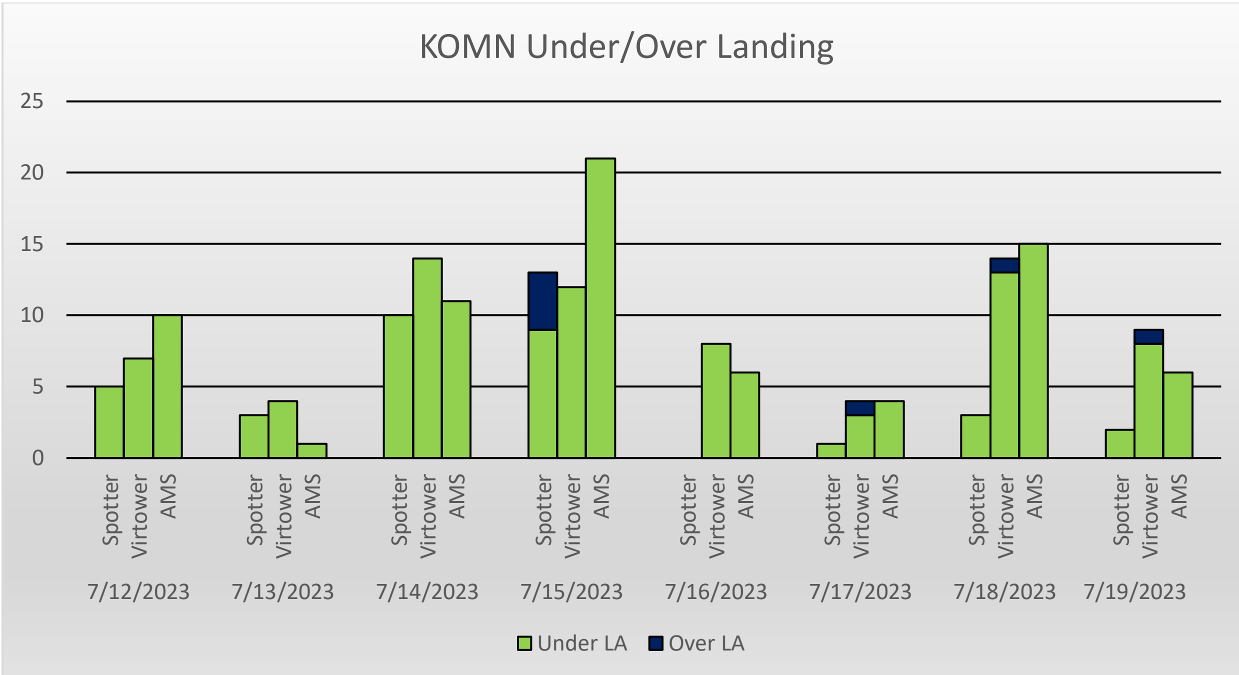


Figure 23. KOMN Derived Operations over/under Landing Counts

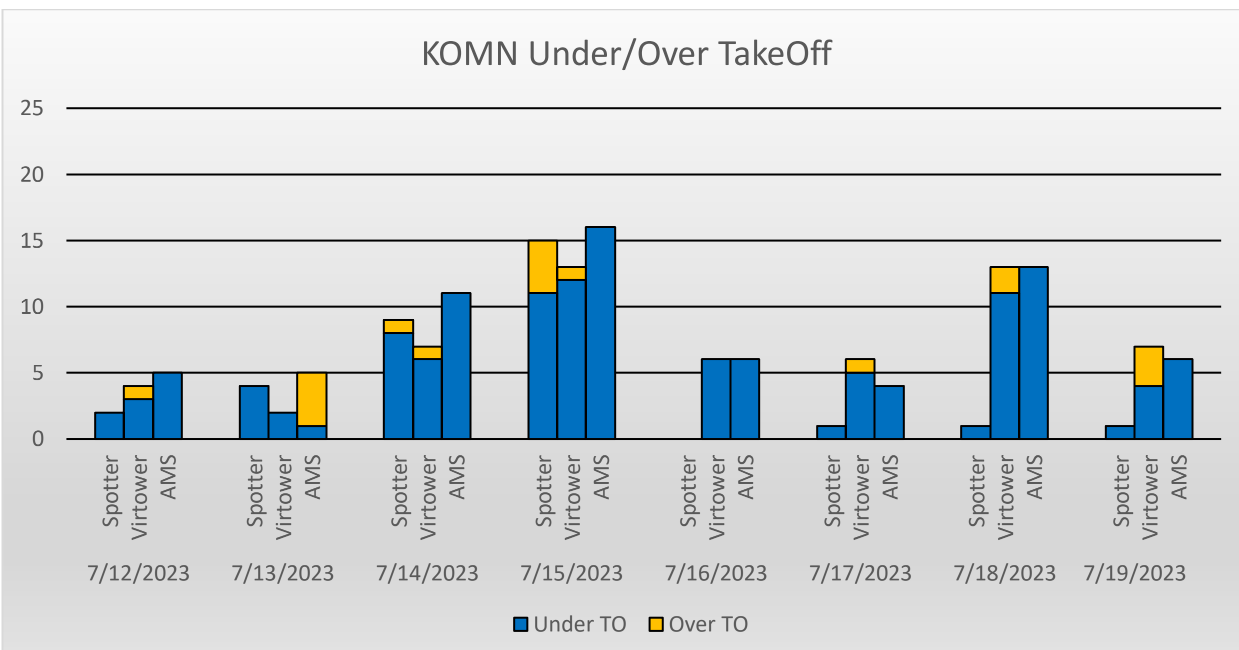


Figure 24. KOMN Derived Operations over/under Takeoff Counts

3.6.4. Findings

The research team utilized (in addition to the manual counts) two (2) Commercial-off-the-Shelf systems. These systems were installed at the airport facilities and provided reports as requested by the team. These reports were then compared with the manual counts (spotters) to analyze their efficiency in detecting aircraft operations and any related information.

- The counts by Virtower and AMS did not always match the spotter. Hence, the systems are either overcounted, undercounted, or both. The spotters were more likely to undercount than overcount aircraft operations throughout the observation period. This was expected because they did not log aircraft operations they missed (contributing to undercounts). However, they did, at times, incorrectly log events that did happen, such as a Touch-and-Go rather than a landing (contributing to overcounts). Spotter counts are also higher than the ADS-B and RADAR sensor-derived counts, due to their capability of detecting aircraft that were not ADS-B equipped and not detected by the RADAR sensors or multilateration.
- Virtower reported that their system's multilateration capability was impacted due to interference with the low-power AMS RADAR units installed on one of the runways at KDED. However, this could not be corroborated with the available data. On the other hand, Virtower produced similar over and under counts at KOMN where no RADAR units were installed. Both systems should have received the same ADS-B reported aircraft positions from their onsite sensors.
- The data collected by the RADAR sensors was sub-optimal partly due to the required placement location mandated by the FAA guidelines and regulations and the inability to relocate them after initial testing and calibration. For each of the AMS RADAR detected operations, there was a corresponding ADS-B correlated target. While there were several cases of aircraft operations only seen by the human spotters, which was indicative of a non-ADS-B equipped non-cooperative aircraft, the AMS dataset did not include a RADAR detection of any of these aircraft.

4. Lessons Learned

We have encountered multitudes of challenges throughout this project. Ones noteworthy are listed here so that appropriate precautions can be taken for those who may conduct projects with similar tasks:

- Anticipate regulations and guidelines for temporary installation of equipment for testing: This project consumed a significant amount of time to complete the FAA Form 7460 approval process for the temporary installation/placement of equipment at the airport.
- Assess potential implications for temporary installation of equipment for testing in advance: Virtower reported that their system's multilateration capability was impacted due to interference with the low-power AMS RADAR units installed on one of the runways at KDED. Potential interference among types of equipment should be carefully investigated prior to proceeding with the installation of new equipment.
- Minimize the interaction with the vendors during the data collection process to avoid distractions and bias.

- Minimize the risk of incomplete data collection by establishing a direct relationship with the airport to acquire the data from their instance of the vendor system under test or acquire an independent instance of the system for the test.

5. Conclusions

New systems such as Virtower, Airport Operations Counting and Analysis System, and Vector Airport Systems Vantage have been developed to count airport operations at non-towered airports for the past few years. The core technology of some of these systems depends on aircraft transmitting surveillance information (cooperative targets) such as ADS-B or Mode S transponder. The FAA mandated the use of (at least) ADS-B OUT by 2020, but it is only required for use in Class A, B, and C airspace. This regulation (as is) leaves an unknown number of aircraft with the option of not equipping or enabling ADS-B OUT in other airspaces. That, in turn, may reduce the accuracy of such systems that depend on cooperative targets, resulting in undercounting aircraft that are not equipped or not actively transmitting. However, this could also be compensated by utilizing additional sensor devices such as cameras or RADAR as optional features.

After thoroughly updating the study of airport counting technologies, the research team reached the following conclusions:

- Airports with a low percentage of ADS-B equipment can still take advantage of the G.A.R.D. system, which relies on radio communications.
- With the advent of lower-cost innovative technologies such as LiDAR and adaptive RADAR, non-cooperative targets that would otherwise result in undercounts can be counted. Such technologies are already put into practice in various applications, yet none are deployed for airport operations counting.
- Our onsite evaluation showed that an ADS-B system could introduce both undercounting (missed detection of actual aircraft operations) and overcounting (counted as aircraft operations when such events did not occur) errors.
- A hybrid system including sensors able to detect cooperative and non-cooperative targets could result in a higher accuracy value. However, based on our onsite evaluation of ADS-B with RADAR, the addition of such sensors was not significant in improving the detection of operations of non-cooperative aircraft. The deployment of sensors needs to be precisely selected before it can show its effectiveness.

Further assessment of aircraft operation counting technologies through extensive onsite evaluation is needed to advance our findings.

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Questionnaire for Counting and Estimating Aircraft Operations at Non-towered Airports

The following questionnaire was sent to the state agencies with the objective of collecting information regarding the technology used to count aircraft.

QUESTIONNAIRE FOR COUNTING AND ESTIMATING AIRCRAFT OPERATIONS AT NON-TOWERED AIRPORTS

Name of state agency: ____

We are gathering information about methods of estimating aircraft operations at non-towered airports from each State. We respectfully request your time to complete the attached questionnaire. If more than one method is used in your State, we would appreciate it if you complete and submit a separate questionnaire (as many as four) for the most accurate methods listed in Question 1) that are used at airports within your State.

Thank you for your assistance in this research. This project could not be possible without your time and participation. Please return your questionnaire by November 30, 2021.

Regards,
NEAR Lab
Embry-Riddle Aeronautical University

Questionnaire

1. What method of estimating aircraft operations at non-towered airports is used in your state? (This is the number of operations used in the airport master record form, system planning, master planning, forecasting, and for other managerial uses.)

   A) Multiply a predetermined number of operations per based aircraft by the number of aircraft based at the airport

   B) Expand a sample count using seasonal or monthly adjustment factors
   (i) What method does your state use to collect the sample data (whatever is applicable)?
      a. Acoustical counters
      b. Pneumatic counters
      c. Visual counts
      d. ADS-B
      e. RADAR
      f. Camera
      g. Other (please specify the method below):
      ____

   C) Expand Statistical model
   (i) Please indicate the type of statistical model you employ to estimate aircraft operations. ____

   D) Other (please specify below): __________________________________

2. For the technology used, what is the approximate total annual cost of the system (or technology)?

   A) Less than $2,000
   B) $2,000 up to but not including $4,000
   C) $4,000 up to but not including $8,000
   D) More than $8,000
   E) Unknown

3. For the technology used, please specify the name, manufacturer, or type of the equipment or service, if known _____________________________________

4. For the technology used, how many runways will this system or technology cover?

A) 1 runway
B) 2 or more parallel runways
C) 2 or more intersecting runways
D) 2 or more parallel and intersecting runways
E) Other (please specify below):
____

5. What is the accuracy of this system (or technology) for which you are answering? (100% indicates all operations were accounted for, none were omitted, and none were erroneously included.)

A) 95%–100%
B) 90%-95%
C) 80%-90%
D) Less than 80%
E) Don't know

6. Did you answer Question 5 based on your opinion/estimate, or was any methodology (accuracy test) performed (either formal or informal)?

A) Estimate/opinion
B) Accuracy Test:
   i. Formal ____
   ii. Informal accuracy tests ______________________________________

7. What are the strengths and limitations of this method?
____
____
____
____

8. How long have you been using this method to collect and estimate aircraft operations at non- towered airports if known?

A) Less than 5 years
B) 5 years up to but not including 10 years
C) 10 years up to but not including 15 years
D) 15 years up to but not including 20 years
E) More than 20 years

9. Why, specifically, do you collect these data? (Select all that apply).

A) Justification for airport development projects
B) Justification for airport control towers
C) Use in airport environmental assessment or impact documentation

D) Forecasts
E) Economic Impact Statements
F) Measure of Performance
G) Include in Airport Master Record— (5010 Form)
H) Other (Please indicate what other uses you have for these data below)

____
____
____
____

10. Include any comments you would like to make here:

____
____
____
____
____
____

Your name and phone number are optional; however, this information would be very helpful to us if we have any questions regarding your responses.

Name:________________________________

Title:_________________________________

Phone: ___-_____-_______ ext: _______

Will you be willing to be contacted if additional information is required?

Yes___
No ___

Would you like to receive a copy of the report/results?

Yes ___
No ___

Florida Airport Questionnaire

The following questionnaire was used when contacting Florida airports for additional information and comments.

1. What type of aircraft operate at your airport?
2. What type of operations are performed at their airport?
3. Regarding system/technology usage assisting your operation counts:
    - How do you execute the counting when the tower is in operation?
    - How do you execute the counting when the tower is closed?
    - What feature, function, technique works best to assist with operation counts?
    - What feature, function, technique works least to assist with operation counts?
    - What Ideal feature or function you would like it to have?
    - What level of maintenance will be expected?
    - What is your tolerance for system outages?

Vendor Data Exported Parameters

Table 25. Virtower Exported Parameters

Value	Example
Date	07/06/2023
Time	22:47
Registration	N433ER
Callsign	ERU433
Type	Single Engine
Model	C172
ADG	A1
Wx	VFR
Operator	ERAU
Operation	TAKEOFF RWY 5

Table 26. Airport Monitoring Systems Exported Parameters

Value	Example
Record_Number	39893
Last_Update	7/6/2023 22:46
Demo_Flag	A
Sensor_Name	KDED-ADSB
Operation_Date_Time	7/6/2023 22:46
Operation_DT_UTC	7/7/2023 3:46
Operation_Type	LA
Rwy_Used	5
RADAR_Record_Number	0
Adsb_Icao_Id	A52EB7
Adsb_N_Number	N433ER
Adsb_Squawk_Code	Not Received
Master_N_Number	N433ER
AC_Serial_Number	172S11455
AC_Mfr_Code	2072439
Engine_Mfr_Code	41597
AC_Year_Mfr	2014
Type_Registrant	Corporation
Registrant_Name	EMBRY-RIDDLE AERONAUTICAL UNIVERSITY INC
Registrant_Street_1	ATTN: FLEET MAINTENANCE CENTER
Registrant_Street_2	600 S CLYDE MORRIS BLVD
Registrant_City	DAYTONA BEACH
Registrant_State	FLORIDA
Registrant_Zip_Code	321143966

Table 27. Table 26 Continued, Airport Monitoring Systems Exported Parameters

Value	Example
Record_Number	39893
Last_Update	7/6/2023 22:46
Demo_Flag	A
Sensor_Name	KDED-ADSB
Operation_Date_Time	7/6/2023 22:46
Operation_DT_UTC	7/7/2023 3:46
Operation_Type	LA
Rwy_Used	5
RADAR_Record_Number	0
Adsb_Icao_Id	A52EB7
Adsb_N_Number	N433ER
Adsb_Squawk_Code	Not Received
Master_N_Number	N433ER
AC_Serial_Number	172S11455
AC_Mfr_Code	2072439
Engine_Mfr_Code	41597
AC_Year_Mfr	2014
Type_Registrant	Corporation
Registrant_Name	EMBRY-RIDDLE AERONAUTICAL UNIVERSITY INC
Registrant_Street_1	ATTN: FLEET MAINTENANCE CENTER
Registrant_Street_2	600 S CLYDE MORRIS BLVD
Registrant_City	DAYTONA BEACH
Registrant_State	FLORIDA
Registrant_Zip_Code	321143966
Registrant_Region	SOUTHERN
Registrant_County	VOLUSIA COUNTY
Registrant_Country	US
Last_Activity_Date	3/17/2023
Cert_Issue_Date	9/5/2014
Cert_Requested_Uses	Standard
Type_Aircraft	Fixed wing single engine
Type_Engine	Reciprocating
Status_Code	Valid Registration
Mode_S_Code	51227267
Fractional_Ownership	
Airworthiness_Date	7/15/2014
Other_Owner_Name_1	
Other_Owner_Name_2	

Table 28. Table 26 Continued, Airport Monitoring Systems Exported Parameters

Value	Example
Record_Number	39893
Last_Update	7/6/2023 22:46
Demo_Flag	A
Sensor_Name	KDED-ADSB
Operation_Date_Time	7/6/2023 22:46
Operation_DT_UTC	7/7/2023 3:46
Operation_Type	LA
Rwy_Used	5
RADAR_Record_Number	0
Adsb_Icao_Id	A52EB7
Adsb_N_Number	N433ER
Adsb_Squawk_Code	Not Received
Master_N_Number	N433ER
AC_Serial_Number	172S11455
AC_Mfr_Code	2072439
Engine_Mfr_Code	41597
AC_Year_Mfr	2014
Type_Registrant	Corporation
Registrant_Name	EMBRY-RIDDLE AERONAUTICAL UNIVERSITY INC
Registrant_Street_1	ATTN: FLEET MAINTENANCE CENTER
Registrant_Street_2	600 S CLYDE MORRIS BLVD
Registrant_City	DAYTONA BEACH
Registrant_State	FLORIDA
Registrant_Zip_Code	321143966
Registrant_Region	SOUTHERN
Registrant_County	VOLUSIA COUNTY
Registrant_Country	US
Last_Activity_Date	3/17/2023
Cert_Issue_Date	9/5/2014
Cert_Requested_Uses	Standard
Type_Aircraft	Fixed wing single engine
Type_Engine	Reciprocating
Status_Code	Valid Registration
Mode_S_Code	51227267
Fractional_Ownership	
Airworthiness_Date	7/15/2014
Other_Owner_Name_1	

Table 29. Table 26 Continued, Airport Monitoring Systems Exported Parameters

Value	Example
Other_Owner_Name_2	
Other_Owner_Name_3	
Other_Owner_Name_4	
Other_Owner_Name_5	
Expiration_Date	9/30/2027
Unique_ID	1151452
Kit_Mfr_Name	
Kit_Model_Name	
Mode_S_Code_Hex	A52EB7
AC_Mfr_Name	CESSNA
AC_Model	172S
AC_Category_Code	Land
Builder_Cert_Code	Type Certified
Number_of_Engines	1
Number_of_Seats	4
Gross_Takeoff_Weight	Up to 12,499 lbs.
Cruising_Speed	0
Engine_Mfr_Name	LYCOMING
Engine_Model_Name	IO-360-L2A
Engine_Horsepower	180
Engine_Pounds_of_Thrust	0
AP_Customer_ID	
AP_State	
AC_Home_Base_AP	Other
N_Number_Mismatch	Y
Group_Membership_1	Other
Group_Membership_2	
Group_Membership_3	
Group_Membership_4	
AP_Pressure_Altitude	-38.6
AP_Wx_Category	VFR
AAC	A
ADG	I
TDG	
Adsb_RSSI	0
Adsb_SQ_Code	0
AP_Baro_Elevation	40.34

Table 30. Table 26 Continued, Airport Monitoring Systems Exported Parameters

Value	Example
AP_Baro_Elevation	40.34
Time_Since_Last_Op	226:31:09
Previous_Op_Type	TO
Previous_Op_Time	6/27/2023 12:15
Part_135	