Evaluating Small UAS Near Midair Collision Risk Using AeroScope and ADS-B

Ryan J. Wallace  
*Embry-Riddle Aeronautical University*, ryan.wallace@erau.edu  
Kristy W. Kiernan  
*Embry-Riddle Aeronautical University*, kiern4fd@erau.edu  
Tom Haritos  
*Embry-Riddle Aeronautical University*, tharitos@k-state.edu  
John Robbins  
*Embry-Riddle Aeronautical University*, robbinsj@erau.edu  
Godfrey V. D'souza  
*Embry-Riddle Aeronautical University*, dsouzag1@my.erau.edu

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Cover Page Footnote
The authors appreciate the participation of Mr. Ryan English and the rest of the FLYMOTION team, whose valuable contributions led to the success of this research project.

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In February 2018, video footage from a small unmanned aircraft system (sUAS) operated near McCarran Airport was posted to YouTube. In the dramatic video, the unmanned aircraft can be seen taking off from a parking lot and climbing to an altitude in excess of 1,000 feet (AGL), when the drone’s camera revealed a passenger jet rapidly closing position on approach to nearby McCarran Airport (Pope, 2018). In an apparent attempt to get a better view angle, the unmanned aircraft operator maneuvered the sUAS upside down and behind the aircraft. The proximity of the sUAS to the aircraft revealed adequate detail to identify the plane as an A320, with the distinctive Frontier Airlines markings (Pope, 2018).

Only months prior, a U.S. Army UH-60M was struck by a Phantom 4 sUAS while conducting military operations near Hoffman Island, New York (National Transportation Safety Board [NTSB], 2017). The midair collision caused minor damage to the helicopter’s main rotor blade (NTSB, 2017). The NTSB identified the sUAS operator using a unique serial number affixed to a portion of salvaged drone wreckage (NTSB, 2017). The NTSB found the sUAS operator’s actions causal to the accident, specifically noting “the failure of the sUAS pilot to see and avoid the helicopter due to his intentional flight beyond visual line of sight” (NTSB, 2017, p. 1). Moreover, the agency determined the sUAS operator’s knowledge of regulations and safe operating practices was deficient and was a contributing factor in the accident (NTSB, 2017).

The common thread linking these anecdotes is a probable lack of compliance or safe operating behavior of sUAS operators.

Problem

The FAA has undertaken varied efforts to contain the problem of unsafe or non-compliant sUAS operations. From June 2007 to May 2018, the FAA pursued action against 518 sUAS operators (Government Accountability Office [GAO], 2018). The spectrum of FAA responses to unsafe or unauthorized sUAS operations included compliance actions such as counseling or correction; administrative actions such as the issuances of warning notices or letters of correction; and legal enforcement actions such as levying civil penalties or suspending or revoking airman certificates (GAO, 2018). Despite these diverse efforts to curb unsafe or non-compliant sUAS operations, the problem seems to be accelerating.

Encounters between manned and unmanned aircraft are becoming increasingly common events. “From February 2014 to April 2018, the FAA
collected 6,117 reports of sightings of potentially unsafe use[s] of UAS” (GAO, 2018, p. 1). According to the GAO (2018), the number of reported UAS sightings by manned aircraft pilots increased by 19 percent in 2017 over the previous year. The FAA’s UAS Sighting Report Database—the source of GAO reporting data—provides an indirect barometer of unsafe UAS operations within the NAS. The FAA reportedly expects an elevated risk of unsafe UAS operations as more UAS platforms integrate into the NAS (GAO, 2018).

In a rebuke to the FAA, the GAO (2018) concluded that FAA safety efforts are hindered by a lack of reliable sUAS operations data. The report acknowledged that the agency is taking steps to close the data gap, such as assessing detection and tracking technologies, but these efforts are still underway. The agency relies on indirect methods of operational data collection such as accident and near-miss reporting. To date, there have been few efforts to directly sample and assess operations data.

**Purpose**

The purpose of this study was to evaluate potential aviation interference and safety hazards caused by small unmanned aircraft at an airport in Class C airspace. This study represents the second of a multi-phase research project about sUAS safety risks to the National Airspace System. The authors sought to detect unmanned aircraft activity passively using an RF detection device and assess the data based on NAS infrastructure within the collection area such as airport traffic patterns, approaches, departures, local airspace categories and other factors. Additionally, the authors conducted a temporal evaluation of sUAS flight locations in comparison with manned aircraft positional data to model midair collision risk.

**Research Questions**

The authors sought to answer the following research questions:

1. What are common characteristics of sUAS flight locations?
2. What are common characteristics of sUAS operations?
3. What is the potential impact of detected unmanned aircraft activity to aerodromes and aviation operations?
4. How effective are geofencing restrictions in preventing sUAS flights from entering protected areas?
Methodology

This project utilized an applied research method using exploratory research and case study approaches. The authors secured a DJI AeroScope to detect small unmanned aircraft activity near Daytona Beach International Airport (KDAB) in Daytona Beach, Florida. The device was mounted to the top of a three-story education building and collected data for a 13-day period. Data was evaluated to determine the number of individual UAS flights, establish a census of unique UAS platforms, determine operating locations, and measure maximum flight altitudes. The authors also assessed temporal factors such as the day/time distribution of sUAS operations. This research was performed in accordance with institutional review board protocols for the protection of human subjects.

After the sampling period, sUAS detection data was downloaded from the device. Geolocation coordinates were input into EasyMapMaker, an online conversion tool used to generate KML datasets (Easy Map Maker, 2018). KML data was imported into Google Earth Pro for further analysis. The researchers integrated several georeferenced overlays into Google Earth Pro to further assess location data, including aeronautical chart data from the Jacksonville Raster Charts (FAA, 2018). AirNav (2018) site data was used to determine location information for private heliports which were added to the aeronautical chart overlays to highlight additional aviation risk areas. GoogleMaps data was used to identify operating locations proximate to detected sUAS positions. UAS flight detection times were correlated with historical ADS-B data derived from Symphony OpsVue, a commercial software suite that records and queries historical NextGen surveillance data (Harris Corporation, 2018). Geofencing location information was extracted from the DJI Fly Safe Geo Zone Map website and plotted as an overlay on Google Earth Pro to assess geofencing effectiveness (DJI, 2018).

Data Collection: AeroScope

The AeroScope is a passive radio-frequency sensor designed to detect, identify, and track DJI-manufactured small unmanned aircraft. The device collects, decodes, and records existing datalink communication signals exchanged between the sUAS remote controller and the aerial platform (DJI, 2017). The AeroScope collects and records a wide variety of telemetry and parametric data on sUAS platform activity conducted within electronic line of sight of the sensor.
including: aerial vehicle location, remote controller location, home point, vector, altitude, speed, serial identification, and other parameters (DJI, 2017).

Assumptions & Limitations

The authors acknowledge the following study assumptions and limitations:

- The 13-day collection period was a notable limitation of the study. Operational activity may vary seasonally and require longer collection periods to accurately capture.
- The AeroScope device only detects DJI-manufactured platforms. According to Skylogic Research (2017), it is estimated that the DJI holds a market share of 72%. Parrot and Yuneec each hold an estimated 7% market share, with other manufacturers making up the final 14% of the market.
- The AeroScope device detects only platforms within electronic line-of-sight. In the event the sensor view of the UAS is impeded, the device may register the same sUAS platform as a separate flight.
- Some DJI platforms are not fully supported for AeroScope identification. The device has a known issue identifying DJI Matrice 100 platforms, which inadvertently display as “unknown” platform types.
- The authors assumed that manned aircraft altitude reporting/transponder equipment provided accurate data. Historical aircraft traffic data derived from OpsVue does not include aircraft that lack Mode C, Mode S, or ADS-B Out capability.
- The authors were unable to assess which operational ruleset individual sUAS platforms were operating under (i.e. [FAA Reauthorization Act of 2012] 333 Exemption with Certificate of Authorization, 14 CFR 107, 14 CFR 101[E], 14 CFR 107[D] waiver, etc).
- The authors did not assess the impact of weather conditions or other environmental or seasonal factors.

Findings & Discussion

The AeroScope was deployed on an educational building adjacent to Daytona Beach International Airport from May 17, 2018 through May 29, 2018. During the sampling period, the AeroScope detected 192 individual sUAS flights from among a total detected population of 73 separate DJI platforms. Two data points were removed from this dataset, since they did not contain geolocation
information. Cumulative data regarding the detected population of sUAS platforms and related number of detected flights is presented in Figure 1.

The DJI MavicPro was the most commonly detected platform, representing 36.6% of all flight detections ($n = 70$), followed by the Phantom 4 (24.6%), and the Phantom 3 Standard (18.3%). While the Mavic Pro and Phantom 4 platforms appear to make up a larger segment of the sUAS population, the utilization ratio suggests that operators are flying the MavicAir nearly twice as often as MavicPro or Phantom 4.

![Figure 1. UAS population and flight count detected during sampling period.](image)

**Detection Date/Time**

On average, the most prevalent flying days were detected mid-week on Wednesdays and Thursdays. The mean detection rate for Wednesday was 29 flights-per-day and Thursday was 21.5 flights-per-day. It is likely that these results may be highly skewed due to the limited collection window, as well as other seasonal or temporal factors not considered within the scope of this study.

UAS detections occurred as early as 01:24 and as late as 23:49 local time (L). The preponderance of flight activity—nearly 17.3%—occurred between the hours of 19:00-20:00L. The mean detection time was 15:48L, with the median detection time being 16:48L. Results are presented in Figure 2.
Detection Altitude

UAS flights were detected at altitudes ranging from ground level to as high as 1,286 feet AGL. UAS operated at a mean altitude of 238 feet AGL and a median altitude of 195 feet AGL.

At least 6.8% of platforms (n = 13) were detected in excess of 400 feet AGL, which included eight platforms between 400-500 feet AGL, two platforms between 500-1,000 feet AGL, and three platforms above 1,000 feet AGL. Results are presented in Figure 3.
Operating Location

UAS detections ranged from as close as 0.83 statute miles (SM) to as far as 10.58 SM from the detection device, which was located proximate to the Daytona Beach International Airport. Figure 4 depicts a proportional breakdown of detection locations. The majority of detections occurred within urban areas surrounding Daytona Beach (Center), Ormond Beach (North), and Port Orange (South). Nearly 48.7% of detections occurred in residential neighborhoods, with 28.3% occurring near single-family homes, and 20.4% near multi-family structures. Commercial, industrial, or public properties accounted for 21.5% of detections. Only 23 detections (12.0%) occurred near unimproved land and parks. This was an unexpected finding, as researchers anticipated that most operators would select relatively open areas that offered a safety buffer from obstructions, urban structures, and other hazards.

The authors believe that these detection ratios are not generalizable, as this distribution is likely to change based on local factors. In the case of Daytona Beach, it is likely that waterway detections are higher than most communities due to the proximity of the Halifax River and Atlantic coastline. Additionally, the presence of the Daytona International Speedway likely creates a larger proportion of stadium or venue detections than would be encountered in many other communities.
Distance from Aerodromes

Of particular interest to researchers was the relative location of detected sUAS activity proximate to local aerodromes. Researchers calculated the distance from each sUAS detection location to the center point for 10 local aerodromes, which included three public airports, two private airfields, four heliports, and one seaplane base. Unmanned aircraft operated as close as 0.50 NM to public airports and 0.35 NM to heliports. Of the 190 data points, 96.8% (n = 184) were detected within 5 SM (~4.34 NM) of an aerodrome, with 84.2% (n = 160) detected within 5 SM of two or more aerodromes. Results are presented in Table 1 and Figure 5. Figure 6 shows a graphical depiction of detected sUAS relative to local aerodromes.

Table 1

| UAS Detection Distance from Sample Location Aerodromes (NM) |
|---|---|---|---|---|---|---|---|---|---|
|      | DAB | 29FL | FA79 | FL44 | F15 | 4FL6 | OMN | 04FL | 7FL6 | EVB |
| Min  | 0.50 | 0.35 | 0.66 | 0.90 | 0.99 | 0.45 | 1.20 | 1.41 | 0.84 | 5.33 |
| Max  | 10.39 | 9.96 | 12.50 | 10.93 | 10.92 | 11.92 | 15.78 | 17.58 | 15.50 | 20.81 |
| μ    | 4.25 | 4.06 | 4.84 | 4.82 | 5.02 | 5.53 | 8.29 | 10.72 | 8.88 | 12.31 |
| M    | 4.15 | 3.80 | 3.97 | 4.46 | 4.74 | 4.88 | 7.25 | 10.59 | 8.83 | 12.75 |
| Q3   | 5.79 | 5.76 | 6.61 | 6.12 | 6.80 | 7.52 | 10.78 | 12.80 | 11.63 | 15.08 |
$Q_1$  2.50  2.58  3.24  3.14  3.26  3.36  5.98  9.10  6.82  9.23  
$\sigma$  2.11  2.01  2.55  2.21  2.41  2.70  3.32  3.14  3.39  3.65

*Figure 5.* Plot of UAS detection range (NM) from proximate sample location aerodromes.
Figure 6. UAS detection locations with relative aerodrome locations. Airports are displayed with green symbology, and heliports with red symbology. Individual pins indicate initial detection location of sUAS with altitude in nearest hundreds of feet (AGL).

Of the 190 data points, 66% ($n = 126$) were operated within the Daytona Beach International Airport Class C Surface Area. No sUAS flights penetrated the outer Class C shelf. Seven sUAS (3.7%) were operated within the Ormond Beach Municipal Airport Class D Surface Area [North]. One additional notable finding was a single sUAS operated within 0.3 NM from the Tomoka Correctional Institution. Figure 7 displays sUAS detections overlaid on a VFR sectional chart.
Figure 7. UAS detections overlaid on sectional chart. Note: plotted locations represent initial detection location and does not account for sUAS movement. The adjacent numbers represent sUAS-reported detection altitude in nearest hundreds of feet (AGL).

Risk Analysis

Researchers assessed sUAS detections against the FAA’s UAS Facility Map (UASFM) established for the Daytona Beach area as a barometer for potential interference with manned aircraft operations. According to the FAA (2017a), “UAS Facility Maps show the maximum altitudes around airports where the FAA may [author emphasis] authorize Part 107 UAS operations without additional safety analysis” (p. 1). According to FAA (2017b), UAS Facility Map
maximum altitudes were established by a collaboration of local air traffic controllers, and air traffic management personnel. “These FAA employees reviewed manned aviation approach and departure procedures, aircraft and helicopter operations, and a variety of other factors to determine where small UAS operations could operate safely” (FAA, 2017b).

Of the 190 data points, 93.2% (n = 177) were contained within a designated UASFM area. The detected altitude of each sUAS was compared against the corresponding UASFM maximum. At least 21.5% (n = 38) were determined to exceed the maximum defined altitude limits of their UAS Facility Map area. A graphical depiction of sUAS detections overlaid against the UAS Facility map is contained in Figure 8. Composite results are displayed in Figure 9.
Figure 8. UAS detections overlaid on UAS Facility Map near Daytona Beach, Florida. Airports are displayed with green symbology, and heliports with red symbology. UAS detections depicted by colored pins with adjacent number indicating altitude in nearest hundreds of feet (AGL). Green pins represent UAS flights that occurred below the maximum UASFM altitude; red pins indicate UAS flights that exceeded UASFM maximum altitude; cyan pins indicate UAS flights that were outside a UASFM defined area.
Detected UAS flights in UASFM areas by altitude compliance with UASFM prescribed maximums.

It should be noted that the Low Altitude Authorization and Notification Capability (LAANC)—the FAA system designed to make use of UAS Facility Maps—has not yet been fully implemented across the United States. LAANC is expected to be implemented at the Daytona Beach airport on July 19, 2018. As such, compliance with UASFM altitudes were not mandatory at the time of the data collection. Nevertheless, the authors assert that this data provides a reasonable gauge of the risk posed to aerodromes around the sample area.

Historical Near Midair Collision/Encounter Analysis

To better understand the collision risk presented by sUAS, the researchers correlated sUAS detection times, locations, and altitudes with historical aviation traffic data derived from ADS-B (Out), Mode C, and Mode S transponder signals in the local area. Altitude and range data were compared between the detected sUAS and nearest lateral aircraft. Cumulative results are presented in Figure 10. A cross section of both aircraft and sUAS data detected within a one nautical mile (NM) proximity of each other is presented in Figure 11. Several sample datasets were included to highlight specific risk cases. UAS detection altitudes were converted to mean sea level (MSL) to align with the OpsVue aircraft altitude reporting datum.
Figure 10. Aircraft/UAS range and altitude differential in feet. Positive values for altitude indicate the aircraft was higher than the UAS.

Figure 11. Correlated aircraft/sUAS range and altitude pairs displayed in feet. Red data points indicate aircraft altitudes, whereas blue data points indicate sUAS altitudes.

Case 1: Shoreline Operations
Figure 12 shows sUAS activity along the Daytona Beach coastline, with parallel aircraft traffic. Aircraft traffic is displayed in green with a data block that indicates altitude and speed. The sUAS is located at the end of the blue bearing and range line at the altitude listed in white. In this case, the detected sUAS was at 462 feet (MSL) with the nearest lateral aircraft 0.30 NM away at 650 feet (MSL). Perhaps more notable is the second aircraft in the dataset. Although slightly further away than the first, at 475 feet, the second aircraft was nearly co-altitude with the sUAS. Based on known local aircraft activity, it is likely both aircraft were performing banner towing operations. Considering the low altitude and slow speed, it would be difficult for these aircraft to safely perform evasive maneuvers.

Figure 12. UAS activity near shoreline banner towing operations. (Data point #13)

Case 2: Approach and Landing

Figure 13 was perhaps the most egregious finding among the dataset. In this case, the sUAS was detected at 90 feet (MSL) within 0.25 NM from the approach path of Daytona Beach International Airport, Runway 7L. Just seconds before this detection, an aircraft was on approach to Runway 7L. Assuming the pilot was performing the published ILS approach, the aircraft would have crossed the Runway 7L threshold crossing at a height of 58 feet AGL (88 feet MSL). It is highly probable that the aircraft descended through the UAS altitude while on approach. A subsequent sUAS detection in the same approximate location was
found at more than 190 feet MSL, but was not proximate to aircraft traffic. See Figure 14.

Figure 13. sUAS activity on DAB Runway 7L approach (Data point 48)

Figure 14. UAS activity near DAB Runway 7L (Data point 49).
Eight unmanned aircraft were detected within 1 NM of the Daytona Beach International Airport center point. The most common launch points included the nearby NASCAR Speedway parking lots (Figure 15), Volusia Mall parking lots (Figure 16), and commercial parking lots near Builder’s Square (Figure 17). In the case of data point 41 (Figure 15) and data point 190 (Figure 16), detection altitude never exceeded ground level. It is likely that established geofencing restrictions prevented the launch of both flights. In contrast, data point 57 (Figure 17), a sUAS was detected at nearly 200 feet (MSL) only 0.68 NM from the Runway 7L centerline. Similarly, Figure 18 shows a sUAS detected at 58 feet (MSL) within 0.29 NM from the Runway 7L centerline.

Figure 15. UAS activity near south Daytona Beach Speedway parking lot (Data point 41).
Figure 16. UAS activity over the Volusia Mall parking lot (Data point 190).

Figure 17. UAS activity near north Daytona Beach Speedway parking lot (Data point 57)
Figure 18. UAS activity near Builder’s Square, a commercial sector near the Daytona Beach Speedway (Data point 59).

**Case 3: UAS Activity Above 500 Feet**

Five detected sUAS flights were operated in excess of 500 feet AGL (~534 feet MSL), three of which were detected operating above 1,000 feet AGL. Such activity is hazardous to low-flying manned aircraft. Regulations provide with few exceptions, that aircraft must operate at least 500 feet above the surface when flying in other than congested areas, and at least 1,000 feet above proximate obstacles when overflying congested areas (14 CFR 91.119). Certain aircraft operations such as takeoff, landing, and helicopter flights are exempted from this rule, thus, some manned aircraft activity occurs at altitudes considerably lower than 500 feet.

Figure 19 highlights one relatively high-altitude sUAS flight proximate to the shoreline. The many banner towing operations conducted near this area makes detection problematic. Fortunately in this case, the nearest aircraft was offset from the sUAS operation both laterally and vertically. Similarly, Figure 20 displays historical aircraft traffic data for one sUAS flight detected in excess of 1,200 feet (MSL) conducted above a residential community adjacent to a community golf course. Again, the data did not show nearby aircraft activity at that time. These findings demonstrate that at least some sUAS operations are penetrating altitudes traditionally reserved for manned aircraft operations.
Figure 19. High-altitude sUAS activity near Daytona Beach shoreline (Data point 109)
Geofencing Effectiveness

DJI sUAS platforms implement certain geofencing restrictions. Geofencing is one or more location-specific, programmed flight restrictions or limitations designed to prevent or restrict sUAS flights over or near areas that would create a security or safety risk (DJI, 2018). Some geofencing zones do not prohibit flight, but provide a warning to operators of possible flight risks (DJI, 2018). Geofencing is generally tied to aerodromes, critical infrastructure, or other facilities or areas that prohibit or limit sUAS flights, such as airports, power plants or prisons (DJI, 2018). For DJI platforms, geofencing is divided into four categories:

- **Warning Zones**: Operation in these zones prompts a warning message to operators on the sUAS user interface regarding risks contained within the zone.
- **Enhanced Warning Zones**: Operators receive a user interface message indicating that flight is restricted, however, the user can override the restriction(s).
• **Authorization Zones:** Operators receive a user interface message indicating that flight is restricted, however, the user can override the restrictions by logging into the DJI Go application with a verified DJI account.

• **Restricted Zones:** Operators receive a user interface message and flight is prevented in the subject zone. Such flight is only accessible with a special unlock code from DJI.

All sUAS flights detected during the field sampling occurred within one or more geofencing zones. The collection area contained one Restricted Zone, two Authorization Zones, two Enhanced Warning Zones, and five Warning Zones. Figure 21 shows the distribution of UAS flights occurring within each of the four categories of DJI geofencing. Figure 22 displays sUAS detections with geofencing areas overlaid on a FAA Raster Chart.

The detection data revealed that 100% of sUAS flights were conducted within two or more Warning Zones. More than 85% of the sUAS flights took place within an Enhanced Warning Zone. Only 7.4% of sUAS flights occurred within Authorization Zones; and, 6.3% of sUAS flights occurred within Restricted Zones. Only two sUAS flights in the dataset (1.0%) were prevented from taking off due to flight limitations within a Restricted Zone. As displayed in Figure 21, most geofencing zones are generally nested such that entry into a more restrictive area, such as a Restricted Zone, would also place the sUAS inside less restrictive Authorization Zones, Enhanced Warning Zones, or Warning Zones. While sUAS platforms can interact with more than one zone type, the imposed operational limitations default to the most restrictive zone.
Figure 21. Cumulative distribution of detected sUAS activity within categories of DJI geofencing zones.

Figure 22. DJI Geofencing plotted on FAA VFR Raster Chart with selected heliport overlays. Individual UAS detections indicated by pins with altitude displayed in nearest hundreds of feet (AGL). Figure depicts four DJI geofencing categories with Restricted Zones in red, Authorization Zones in orange, Enhanced Warning Zones in cyan, and Warning Zones in green. Geofencing data derived from https://www.dji.com/flysafe/geo-map on June 27, 2018.

Conclusions

Common Characteristics of sUAS Flight Locations
The data suggests that cumulatively, single- and multi-family homes make up 48% of sUAS operating locations. This data strongly suggests that a preponderance of sUAS operators are flying for personal use around their own residences. Commercial, industrial, and public locations also appear popular flight locations of sUAS operations—primarily in parking lots or other adjacent open areas. Unfortunately, researchers were unable to determine definitively the operational purpose(s) of the flights conducted over such areas. The authors were particularly concerned that nearly 97% of all detected sUAS flights had been conducted within 5 SM of one or more aerodromes.

Common Characteristics of sUAS Operations

The data yielded significant information about common operator behavior. The MavicPro, Phantom 3 and Phantom 4 platforms were the most commonly detected unmanned aircraft. UAS operators appear to favor platforms that cost around $1,000 that are capable of flight outdoors.

The data indicates that most flights take place on Wednesday and Thursday, however, this data may have been skewed by uncharacteristically poor weather that was encountered during a portion of the collection period. Aside from this anecdotal observation, weather conditions were not assessed during this study.

Mean and median flight time data suggest that on average operators perform flights in the late afternoon hours between 16:00-17:00 (Local). Peak operations were detected between 18:00-20:00L, which may suggest recreational flyer activity conducted after work.

Generally, flights were detected around 200 feet MSL, however, there were several outlying data points that significantly exceeded this altitude, including the three flights detected in excess of 1,000 feet AGL. These flights represent a particularly hazardous threat to manned aviation.

Risk Assessment Based on Historical Aviation Traffic Data

Using UAS Facility Map information as a risk measurement metric, 21.5% \((n = 38)\) of the 177 flights conducted within a designated UASFM area exceeded prescribed altitude limits for their operating area. This data suggests that more
than 1 in 5 sUAS flights presented an unmitigated risk to nearby manned aviation operations.

Historical traffic data appears to support this assertion. While much of the data did not show evidence of historical near-miss events, two data points indicated uncomfortably-close operations that ultimately could have resulted in a collision. In the case of data Point #13 (Figure 12), shoreline sUAS operations came within approximately 0.5 NM of not one but two aircraft, one of which was co-altitude with the sUAS. Similarly, data Point 48 (Figure 13) detected a sUAS within 0.25 NM of an approach path at an altitude through which the aircraft descended to land. Considering that close encounters with other aerial objects are generally rare events, finding two within the span of a 13-day sampling period is particularly troubling. The recent GAO (2018) report documents a notable uptick in close encounter sightings of UAS, which is consistent with findings of this study.

Perhaps more importantly is the unknown human factor responses to sUAS encounters. The risks and consequences of a direct collision may pale in comparison to pilot-induced aggressive evasion maneuvers, as was the case in Levin (2018). A pilot’s natural, immediate response to maneuver—particularly at low altitude or airspeeds—can easily exacerbate an otherwise-survivable midair sUAS-aircraft collision into a fatal stall, spin, or other uncontrollable flight condition.

**Effectiveness of Geofencing**

It should be noted that geofencing is not an industry-wide standard and such protections are not provided by all manufacturers. Moreover, the authors strongly assert that geofencing does not alleviate sUAS operators from proper flight planning and airspace compliance responsibilities. Geofencing primarily serves as a supplemental tool to aid sUAS operators in maintaining situational awareness and augmenting sound aeronautical decision-making and flight discipline. Nevertheless, the data clearly shows sizable reductions in detected sUAS operations in more restrictive geofenced areas. This suggests that geofencing zones are relatively ineffective at preventing or deterring operators from flying unless they impose operational restrictions. Warning Zones merely provide situational awareness to the sUAS operator about local risks and neither enforces any accompanying flight restrictions, nor requires the operator to acknowledge the user interface warning. Authorization Zones provide some protection, as they require operator acknowledgement to override flight restrictions. Authorization Zones provide even further protection, since the
operator must login to their registered account to release flight restrictions. Authorization Zones permit sUAS activity to be tracked back to a specific operator account, thus promoting accountability and responsibility. Finally, Restricted Zones provide the most protection by curtailing all sUAS flights unless the operator inputs a unique unlock code. Since this requires direct contact with (and documentation furnished to) the manufacturer, this Zone effectively creates a barrier to entry by which only operators with a legitimate need to fly will tend to undertake. Succinctly, the authors assert that geofencing zones are only effective if sUAS operators are committed to proper flight planning, airspace compliance, flying responsibly, and using sound aeronautical decision-making skills.

**Recommendations**

**Geofencing Integration with the Low Altitude Airspace Authorization & Notification Capability System**

Manufacturer-imposed geofencing protections offer a viable solution to most problematic sUAS flights. There is, however, a clear disconnect between geofencing protections imposed by manufacturers and safety risk acceptable to regulators. The authors propose manufacturers consider modifying geofencing protections to align with the FAA LAANC UASFM grid system and impose altitude restrictions that align with UASFM altitude limits within each respective grid area. The proposed geofencing would prevent sUAS operations in all UASFM grid areas unless an unlock code that corresponds to the respective grid is entered. Unlock codes could be generated and delivered automatically. The authors believe that such a system would better utilize manufacturer geofencing by integrating and supporting with the LAANC system, the existing risk management strategy adopted by the FAA.

**Enhancement of UAS Situational Awareness: Tools for Pilots**

One key deficiency regarding sUAS operations is the lack of operational information sharing with manned pilots. There is currently no effective means for manned pilots to assess sUAS activity along their route of flight. This need is particularly relevant for flight operations by helicopters, aerial applicators, and other low-altitude NAS users that are likely to encounter sUAS activity. While the LAANC system currently works to segregate sUAS operations from manned aircraft, it remains to be seen if this separation tool will be effective in preventing sUAS and aircraft encounters.

To encourage information sharing, the authors propose the FAA strongly consider making LAANC request information available to manned pilots. Figure
22 illustrates the LAANC administrative tool currently used by FAA airspace managers. The tool shows LAANC airspace segments, maximum segment altitudes, and utilization data. Such information could be invaluable to manned aircraft pilots who wish to avoid sUAS activity while flying at low altitude.

To further reduce the risks posed by UAS activity to manned aircraft pilots, the author proposes “a method to furnish essential safety information to pilots in cockpits of manned aircraft through the use of Flight Information Service - Broadcast (FIS-B), as well as through other services and protocols. As proposed by Baum (2018), this information would provide enhanced awareness of nearby sUAS operations within active Unmanned Traffic Management (UTM) airspace; as addressed in this paper, it will make such information available within Low

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**Figure 22.** LAANC Administrative Tool. Provides LAANC segment information. Maximum altitudes of each segment are listed in black text, with utilization data indicated by numerical values in the white circle of each respective segment. The administrative tool contains filters that can display active authorizations or cumulative authorizations, including approved 14 CFR 107.205(h) airspace waivers. Used with permission, courtesy of Baum (2018).
Altitude Authorization and Notification Capability (LAANC)-enabled airspace. According to Baum (2018), “[t]his proposal responds to the regulatory obligation of manned aircraft pilot to be familiar with all available information concerning a flight, to avoid operating an aircraft so close to another aircraft as to create a collision hazard, and to see and avoid.” A conceptual prototype of the display output is presented in Figure 23.

![Figure 23. Conceptual display prototype of proposed ADS-B FIS-B/AIXM communication of active LAANC segments. Active segment locations are displayed with representative symbology with accompanying maximum altitudes in hundreds of feet (AGL).](image)

**Future Research**

The authors intend to replicate this research at additional airports. A future iteration of this work will employ the AeroScope device to determine sUAS operator compliance with LAANC approval restrictions. Additionally, the authors intend to evaluate sUAS flight behavior to identify potential security risks to critical infrastructure.
References


