Integrating Expanded and Non-Segregated UAS Operations into the NAS: Impact on Traffic Trends and Safety

Final Report

June 30, 2022

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16. Abstract The Federal Aviation Administration (FAA) tasked its Center of Excellence (COE) for Unmanned Aircraft Systems (UAS), ASSURE (Alliance for System Safety of UAS through Research Excellence), to conduct research to inform the safe integration of sUAS (small UAS) for expanded (e.g., beyond-visual-line-of-sight) and non-segregated UAS operations. The objectives of this research focus on the evaluation of data, projection of demand for UAS operations, and development of a risk-based framework for an SMS (Safety Management System) process that incorporates Probability Risk Assessments (PRAs). The research has been conducted in three Phases. Phase 1 has produced a descriptive analysis providing a quantitative characterization of current sUAS (small UAS) activity in the National Airspace System (NAS). Phase 2 has completed a study of the factors potentially influencing trends in the future growth of sUAS activity, using that analysis to forecast future operations. The Phase 3 results present a framework for the quantitative assessment of the risk associated with sUAS operations and illustration of its application.

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TABLE OF CONTENTS

TABLE OF FIGURES

TABLE OF TABLES

TABLE OF ACRONYMS

Acronym	Meaning
ADSB-Out	Automatic Dependent Surveillance-Broadcast-Out
AGL	Above Ground Level
APR	Approach
ARIMA	Auto Regressive Integrated Moving Average
ASSURE	Alliance for System Safety of UAS through Research Excellence
BLOS	Beyond Line Of Sight
BVLOS	Beyond Visual Line Of Sight
CFR	Code of Federal Regulations
COA	Certificate of Authorization (or Waiver)
COE	Center Of Excellence
DAA	Detect And Avoid
DFW	Dallas-Forth Worth International Airport
FAA	Federal Aviation Administration
FCC	Federal Communications Commission
GPS	Global Positioning System
IPP	Integration Pilot Program
LAANC	Low Altitude Authorization and Notification Capability
LDG	Landing
LOS	Line of Sight
m	Meter
MLS	Mission Logging System
MNV	Maneuvering
NAS	National Airspace System
NM	Nautical Miles
NMAC	Near Mid Air Collision
NOTAM	Notice to Airmen
NPRM	Notice of Proposed Rule Making
PMERJ	Operations Over People
PRA	Probabilistic Risk Assessment
RPIC	Remote Pilot In Command
SME	Subject Matter Expert
SMS	Safety Management System
SRM	Safety Risk Management

SRMP	Safety Risk Management Program
sUAS	small UAS
UAH	University of Alabama - Huntsville
UAS	Unmanned Aircraft System
USS	UAS Service Supplier
UTM	Unmanned Traffic Management
VO	Visual Observer
VTOL	Vertical Take-off and Landing
WAG	Waiver Application Guidelines

1.0 EXECUTIVE SUMMARY

With the advent of requests for complex unmanned aircraft systems (UAS) operations in the National Airspace System (NAS), the Federal Aviation Administration (FAA) sought solutions for a more standardized, scalable approach to the waiver submission and review process for operations outside the auspices of Title 14 Code of Federal Regulations (CFR) Part 107. The FAA identified its need to move toward a more quantitative approach to assess the risks associated with different types of small Unmanned Aircraft Systems (sUAS) operations. The development of such a quantitative risk assessment framework was further motivated by Section 345 ("Small Unmanned Aircraft Safety Standards") of Public Law 115-254.

In support of this need, ASSURE (Alliance for System Safety of UAS through Research Excellence) researchers developed a standardized and scalable quantitative risk assessment framework in three phases: (1) they evaluated existing data and established the quantitative impact of expanded sUAS operations; (2) they developed a forecast of the future scope of sUAS operations; and (3) they developed the quantitative framework to assess the risk associated with the operation of sUAS.

In the Phase 1 effort, the ASSURE team collected, cataloged, analyzed, and provided visualizations of data collected by the FAA and its partners, including CONcept of OPerationS (CONOPS) trends and data needs based upon interviews of Test Site and Integration Pilot Program (IPP)/Beyond lead participants, sUAS registrations, remote pilot examinations and certificates issued, flight waivers issued, sighting reports, and operational data (2015-2020). In addition, the research team studied third party sUAS detection data of more than 162,000 separate operations in the vicinity of DFW (Dallas Fort Worth International Airport) over an 18-month period (August 2018 – January 2020). Of concern, the team identified Part 107 compliance issues including 4,700+ operations above 500 feet AGL (Above Ground Level), over 200 flights within 0.5 miles of DFW, and nearly 1,100 flights within 0.5 miles of a heliport. Additionally, the team's analysis found that only 4 of the 47 sighting reports in the DFW area were in the general vicinity of the reporting aircraft and in all these 4 cases the manned aircraft were safely separated from the sUAS laterally or vertically.

In the Phase 2 forecasting effort, after extrapolating from FAA forecasts, the team collected data from 4 subject matter experts to develop a forecast of the expected number of daily flight operations. The resultant forecast was an average in 2024 of 1,019,200 daily flight operations and an average number of daily flight operations in 2032 of 2,730,000. Given the small sample size, it is recommended that additional data be collected in order to increase the precision associated with these estimates.

The team also interviewed 66 experts (sUAS pilots, manufacturers, operators, researchers, and regulators) to better understand and predict the challenges, opportunities, advancements, timelines, and other factors associated with 68 different technologies and influencing concepts (such as regulatory items, standards, and initiatives) that could affect the integration of sUAS into the NAS. Overall, these results provide considerable insight into future sUAS operations and should be used to help guide decisions on where to focus integration efforts.

Finally, in Phase 3, ASSURE researchers developed a risk-based framework using a blend of statistical methods for quantitatively evaluating safety risks associated with a proposed flight operation using sUAS. This final report includes an illustration of how this framework can be used to evaluate an operation of a sUAS equipped with or without a parachute. The team recommends that the FAA incorporate the use of this scalable and standardized quantitative framework as a key component to guide the design of a broader Safety Risk Management Program (SRMP) for the integration of sUAS operations into the NAS.

2.0 INTRODUCTION

The ASSURE team was tasked by the FAA with research in support of the integration of expanded and non-segregated sUAS in the NAS. Such expanded and non-segregated operations include flights over people, flights flying beyond visual line of sight and flights in airspace shared with manned aircraft.

To help meet needs identified by the FAA, the National Academies of Science, Engineering, and Medicine (NASEM) and Congress, this project completed the research in three phases:

- Phase 1. Evaluation of Data and Establishment of Quantitative Impact of Expanded and Non-Segregated Operations
- Phase 2. Forecast of the Future Scope of UAS Operations
- Phase 3. Development of a Quantitative Framework for the Assessment of the Risk Associated with the Operation of sUAS

More specifically, the focus of these three phases has been:

- Phase 1 focuses on a quantitative assessment of current sUAS activity in the NAS and associated regulatory activities. The results include a catalog identifying relevant data sets and the properties of the contained data attributes such as completeness and consistency. The results also examine sUAS CONcepts of OPerations (CONOPs) in order to identify associated data needs for waiver approvals. And the results provide an analysis of current sUAS activity in order to characterize this activity and to identify trends. These results are designed to inform proposed sUAS rulemaking efforts and to identify gaps in current data collection practices necessary for improvements in the FAA's safety management system (SMS) process. In addition, the results of Phase 1 provide an analysis of sUAS detection data in the vicinity of a large urban airport terminal environment in order to examine the validity of UAS sighting reports and sUAS operator compliance with current FAA Part 107 sUAS rules (FAA, 2016).
- Phase 2 provides a forecast of trends in the growth of sUAS traffic associated with the integration of expanded and non-segregated sUAS operations into the NAS. In addition, the factors restraining such growth are identified and evaluated in terms of their urgency, difficulty of development or maturation and impact on the growth of sUAS operations.
- Phase 3 defines and demonstrates the application of a quantitative risk-based framework that can be integrated into the FAA's SMS process, guiding the development and application of risk-based performance standards that incorporate quantitative probabilistic risk assessment in order to demonstrate that a proposed operation achieves the requisite level of safety.

The need for the development of such a framework, and thus the motivation for Phase 3 of this project, was a set of conclusions in the NASEM (2018) report titled "Assessing the Risks of Integrating Unmanned Aircraft Systems", which included the following recommendations to the FAA:

- Recommendation: “The FAA should expand its perspective on a quantitative risk assessment to look more holistically at the total safety risk.”
- Recommendation: “The FAA should establish and publish specific guidelines for implementing a predictable, repeatable, quantitative, risk-based process for certifying UAS systems and aircraft and granting operations approval. These guidelines should interpret the Safety Risk Management Policy process described in Order 8040.4B (and in accordance with International Civil Aviation Organization Doc. 9859) in the unique context of UAS" (FAA (2017).
- Recommendation: “Over the next 5 years, the FAA should evolve away from subjectivities present in portions of the Order 8040.4B process for UAS to a probabilistic risk analysis (PRA) process based on acceptable safety risk" (FAA (2017).

Highlights of the findings from these three phases of the research are described in the following sections. Further details regarding the methods, results, and implications are then provided in Supplements A-F.

3.0 PHASE 1. EVALUATION OF DATA AND ESTABLISHMENT OF QUANTITATIVE IMPACT OF SUAS EXPANDED OPERATIONS

Phase 1, led by faculty at Embry-Riddle Aeronautical University, with primary support from faculty at the University of North Dakota, has been dedicated to examining the data available today (regardless of whether it is in segregated or non-segregated domains) and characterizing trends within the currently available data. Supplements A and F provide a detailed report on the results of Phase 1 along with the references cited for Phase 1. Note that Supplements A and F have been written to serve as complete stand-alone reports for those only interested in the Phase 1 results.

That effort was broadly divided into the following six research activities.

Cataloging Available Data Sets. A data catalog identifies relevant data sets, their attributes and such as completeness, consistency, etc. that affect their utility in data analysis.

Understanding Current Data Collection Practices. An analysis of UAS CONOPS examined the data requirements of a SMS-based evaluation of UAS CONOPs.

Analyzing and Visualizing the Data. A quantitative analysis and visualization of the results of the available data sets providing insights into current sUAS activity and trends within the cataloged data.

Waiver Requirement Data Gaps. An assessment of data collection needs for the development of future operational standards was conducted analyzing proposed rulemaking against the existing SMS process’s existing data collection practices to identify data collection gaps (i.e., need for data standards, collection of additional data, etc.).

Validating UAS Sighting Reports with UAS Detection Data. An analysis was conducted focusing on the validation of the UAS sightings database through a combined analysis of UAS detection data in the vicinity of Dallas-Fort Worth International Airport (DFW) and the data catalogued/analyzed in the previous tasks. UAS detection data was used to determine compliance of current operators with UAS rules and a comparison of UAS detections with other catalogued data sets, including UAS registrations within the areas of operation and UAS sighting reports, was conducted.

Interview Study with FAA Test Sites and Integration Pilot Programs. An additional study was conducted to provide insight into data needs for evaluating UAS CONOPs. Data were collected using interviews, with a total of 9 FAA Test Sites or IPP (Integrated Pilot Program)/Beyond lead organizations providing input.

3.1 Summary of Phase 1 Findings

A brief summary findings and recommendations from Phase 1 are provided below. The full details of the findings and recommendations from Phase 1 are contained in Supplements A and F.

Data Sources. In this project, quantitative data were collected from the FAA's available and sharable UAS data, including the following areas:

- UAS registrations for Section 336 (hobbyists) and Part 107 (commercial)
- Remote Pilot in Command (RPIC) Registration Databases
- Notices of Proposed Rulemaking (NPRM)
- UAS Facility Maps
- Certificate of Authorizations (COA) Application Processing System (CAPS)
- Remote pilot certificates
- Part 107 exams and exam results
- Mission Logging System (MLS) operations and incidents
- Waiver Acceptance Letters
- Reported UAS Sighting Incidents
- Interview Study with FAA Test Sites and Integration Pilot Programs
- Other applicable COE (Center of Excellence) ASSURE research projects.

This project also utilized the available qualitative data sources for UAS, including Waiver Safety Explanation Guidelines (WAG) for Part 107 Waiver Applications, NPRMs database, FAA Safety Management System, FAA Unmanned Aircraft Systems Safety Risk Management Policy, and Federal Aviation Administration Safety Risk Management Guidance: The 5 Step Process (AVP-300-003-JA1). The following documents were used for our project:

- Beyond Visual Line of Sight (107.31) Waiver
- OOP Operations Over People (107.39(a)) Waiver
- Night Operations (107.29) Waiver
- FAA-2018-1084-0001- 7 CFR Part 48- External Marking Requirement for Small Unmanned Aircraft
- FAA-2018-1086-0001- 14 CFR Part 107- Safe and Secure Operations of Small Unmanned Aircraft Systems

- FAA-2018-1087-0001- 14 CFR Part 107- Operation of Small Unmanned Aircraft Systems Over People
- FAA-2019-0364-0001- 14 CFR Part 107 - Exception for Limited Recreational Operations of Unmanned Aircraft
- FAA-2019-1100-0001- 14 CFR Parts 1, 47, 48, 89, 91, and 107- Remote Identification of Unmanned Aircraft Systems

UAS data was collected for the period of 2015 – 2020. Results are included in the report in Supplement A highlighting trends observed within the current data sets.

<u>Waiver Approval vs. Denial</u>. As one example, an illustration of the proportion of approved versus rejected waivers is provided in Figure 1. As this figure shows, the vast majority of waivers during this time period were rejected.

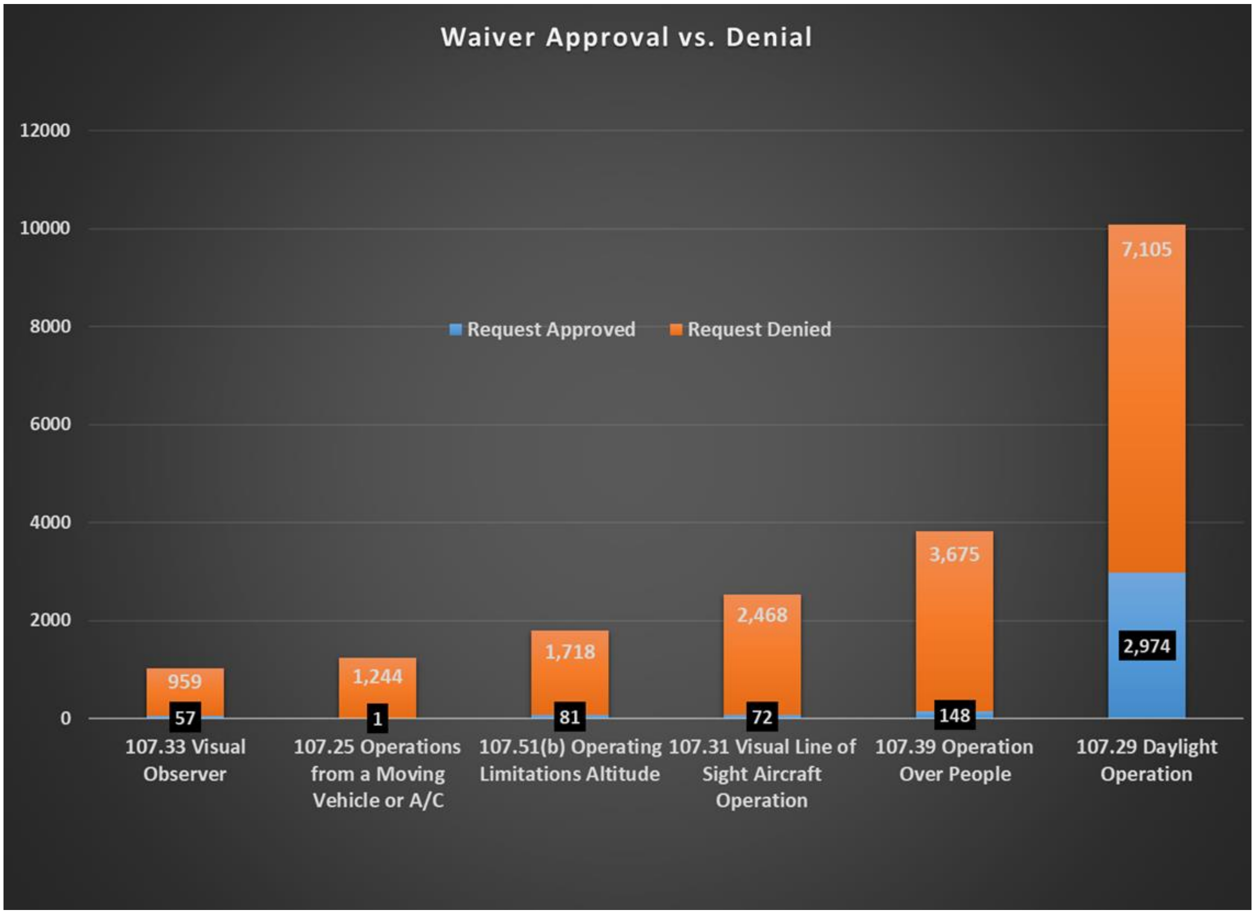

Figure 1. Illustration of Proportion of Accepted and Rejected Part 107 Waivers for Different Waiver Categories. From D. Bhadra (Personal Communication)

Part 107 waivers were rejected because the associated safety cases were insufficient. A trend analysis was completed for both 107.31 (BVLOS) waivers and 107.39 (operations over people) waivers (FAA, 2020c). This analysis identified the following deficiencies for these types of waiver applications:

- BVLOS

    - Command and Control (C2): Lacking operational data (e.g., operating range) and/or Federal Communications Commission (FCC) approval
    - Detect And Avoid (DAA): Lack of information regarding methods or procedures and performance for DAA
    - Operational Limitations: Lack of information regarding how environmental hazards would be mitigated
    - Crew: Lack of information regarding crew qualifications (who has what training) and how the training of the crew is assured
- Operations Over People
    - Ground Collision Severity: Either test data that were not based on the sUAS to be used were provided or calculations (estimates) were provided instead of test data.
    - Laceration Injuries: Either test data that that were not based on the sUAS to be used were provided, or statements were provided regarding propeller guards that would be used without supporting test data evaluating their efficacy, or no information was provided.
    - Description of Operation: Operational limitations/conditions/procedures were not described in enough detail (e.g., lost-link procedures).
    - Pilot Experience: Information showing that a pilot could safely operate over people was not provided.

Analysis of Part 107 Approval Letters. Approved Part 107 waivers provided insight into CONOPS and data associated with CONOPS. Approved Part 107 waivers were extracted from the FAA Part 107 website on 18 April 2020 (data spans 6/15/2016-4/18/2020). These Part 107 Waiver Approval Letters were analyzed using a combined approach of mining the PDF files using code and manual analysis to identify types of mitigations that were utilized and any restrictions on authorized operations.

The types of Part 107 waivers examined include:

- Part 107.31 – Beyond Visual Line of Sight (BVLOS)
- Part 107.35 – Flying Multiple Small Unmanned Aircraft Systems (sUASs)
- Part 107.39 – Flying Over People
- Part 107.51b – Operating Limitations: Altitude Above 400 ft Above Ground Level (AGL)
- Part 107.51c – Operating Limitations: Minimum Visibility
- Part 107.51d – Operating Limitations: Minimum Distance from Clouds

It is noted that operations at night, which is the most approved Part 107 waiver category (> 2000 waivers), were not analyzed as this type of operation was generally following all Part 107 requirements except for daytime operations and, in doing so, was not considered to be an "advanced" operation like BVLOS or flying over people.

Mitigations were identified initially by considering approved BVLOS waivers. Thus, the consistent set of identified mitigations is:

- Visual Observers (VOs)
- DAA technology
- Onboard cameras
- Chase planes
- Tethers

As a second example of Phase 1 analyses, as shown in Figure 2, VOs were the primary mitigation technique for all approved Part 107 waivers, and none of these waivers utilized a chase plane (Figure 2 only considers waivers that utilize one of the aforementioned mitigations). Notably, for BVLOS waivers, only 4 waivers involved DAA technology. Of the 4 BVLOS waivers utilizing DAA technology, 2 of them also used VOs. This indicates that establishing that DAA technology can provide enough mitigation to achieve a desired level of safety is a major barrier to advanced BVLOS operations. Results for the other categories as well as results of analyses focusing on restrictions are presented in Supplement A.

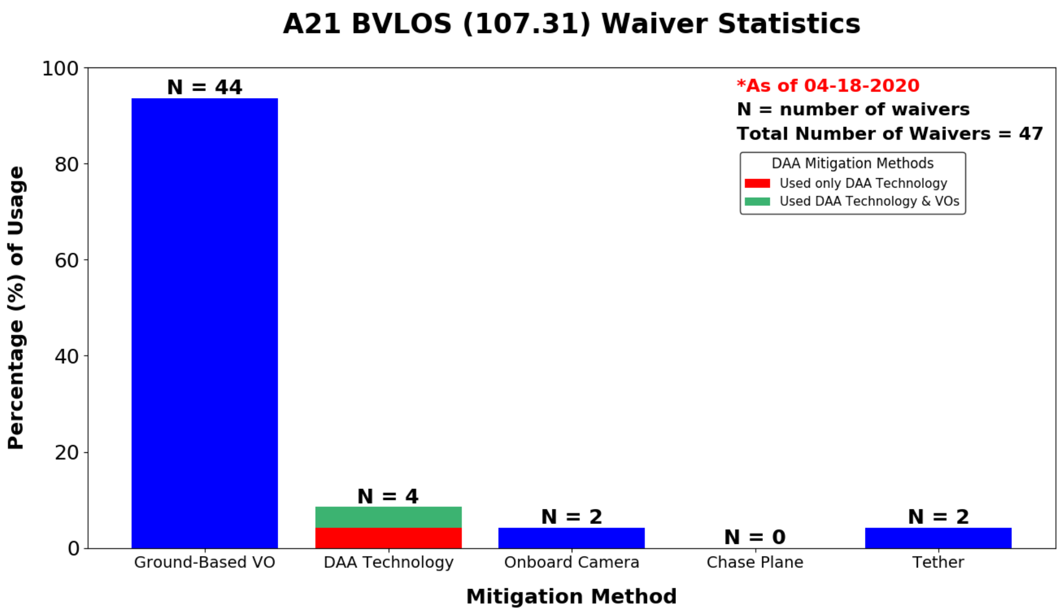

Figure 2. Mitigations Utilized in BVLOS (.31) Part 107 Waivers (some waivers use multiple mitigations).

Further information regarding rejected waivers also was provided (D. Bhadra and M. Lukacs, personal communication, 13 August 2020). This input indicated that waivers are often rejected owing to:

- Inadequate CONOPS descriptions.
- Inadequate description/demonstration of safety measures.
- Inadequate description of area specific information (e.g., population density).

UAS Registrations Data Analysis Results. Regarding the analysis of UAS registrations, Figure 3 presents the bar chart for section 336 (hobbyists) registrations in the US from December 2015 to November 2019. The results show a very high number of registrations in late 2015 and early 2016, after which there was a sharp decrease in March 2016. This decrease could be explained by a possibility that all registrations from the beginning of the registration process were aggregated and reported in December 2015 and January 2016. The chart shows an increase in registrations from the fourth quarter of 2015 to the first quarter of 2016. However, registrations appear to have decreased between 2017 to 2019. Interestingly, the downward trend occurred as the NPRM rulemakings were published, which were intended to gather information from the public to help inform the FAA's efforts to assess options for reducing risks to public safety and national security associated with further integration of UAS into the NAS.

For Part 107 (commercial) registrations, as shown in Figure 4, the results indicate a much higher fluctuation in the registration counts. While the average number of registrations per month for Part 107 is relatively lower than for section 336, the registrations changed from month to month between 2016 and 2017. It appears there was an increase in September 2016, followed by a decrease in next several months. This trend could be explained by the announcement of the Operation and Certifications of sUAS requirements on June 28, 2016, which required UAS pilots to get certified. Then the number of registrations increased again in February and March 2017 to more than 6,000 registrations per month, before it decreased slightly in the remaining of 2017. The figure showed a big jump in December 2017 and stayed very high at about 14,000 registrations per month until August 2018. This substantial increase in Part 107 registrations could be explained by the announcement of the IPP on November 2, 2017, which enhances the safe drone integration, and the availability of LAANC (Low Altitude Authorization and Notification Capability) on November 17, 2017, which provides near real-time processing of airspace authorization requests for drone operators. Then, the number of registrations decreased slightly in October 2018 and then increased again in December 2018. It appears that registrations reached the highest of approximately 14,000 registrations per month for several months before they began to decrease in June 2019. Due to the lag in the effects of NPRMs, as mentioned above, this increase is mainly due to the implementation of IPP and LAANC. Finally, an increase in Part 107 registrations can be observed in May 2020, which could be explained by the implementation of NPRMs, which were published in February, March, and December 2019.

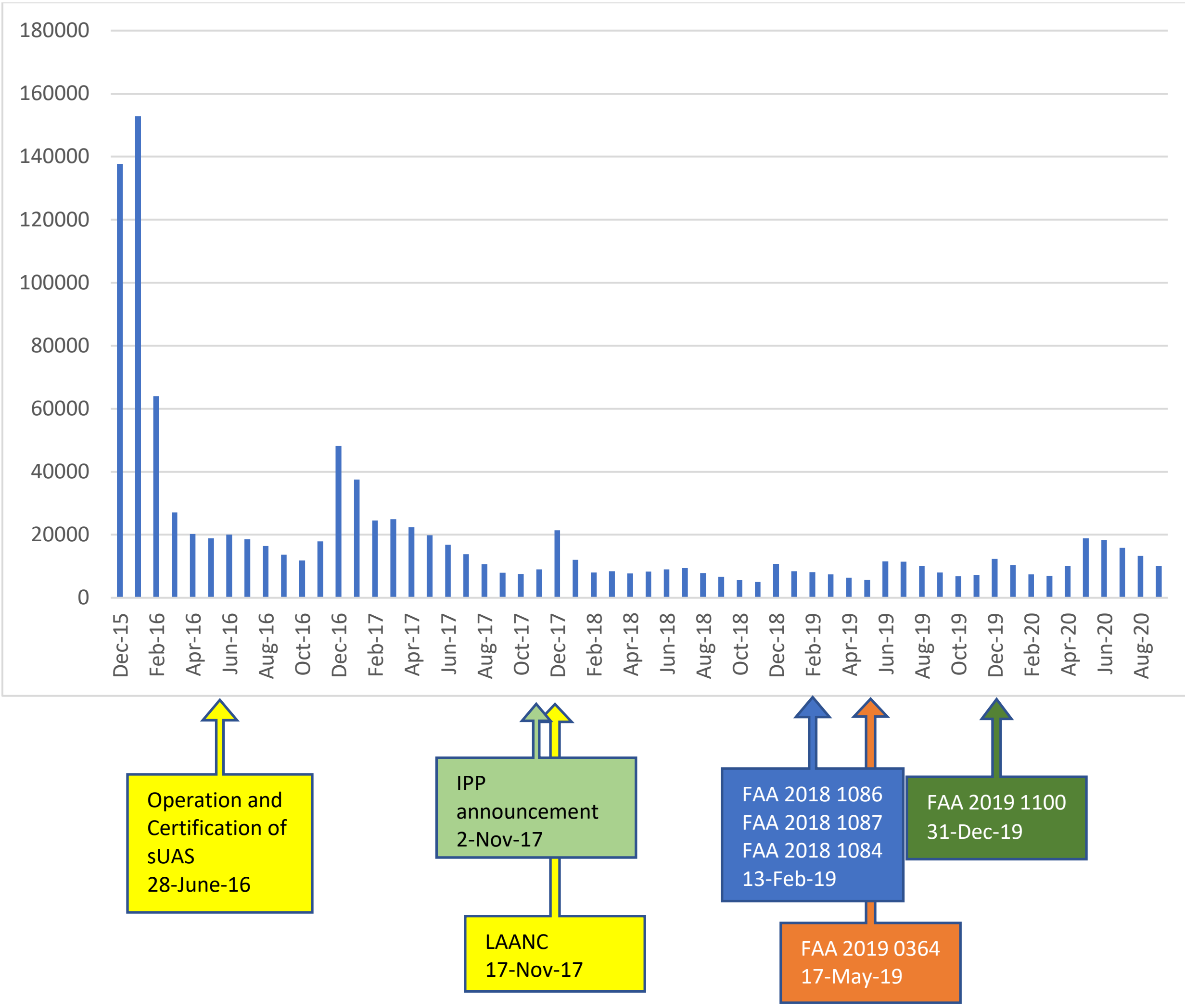

Figure 3. UAS Registration Numbers in the United States - Hobbyists (section 336) with Rulemaking Dates.

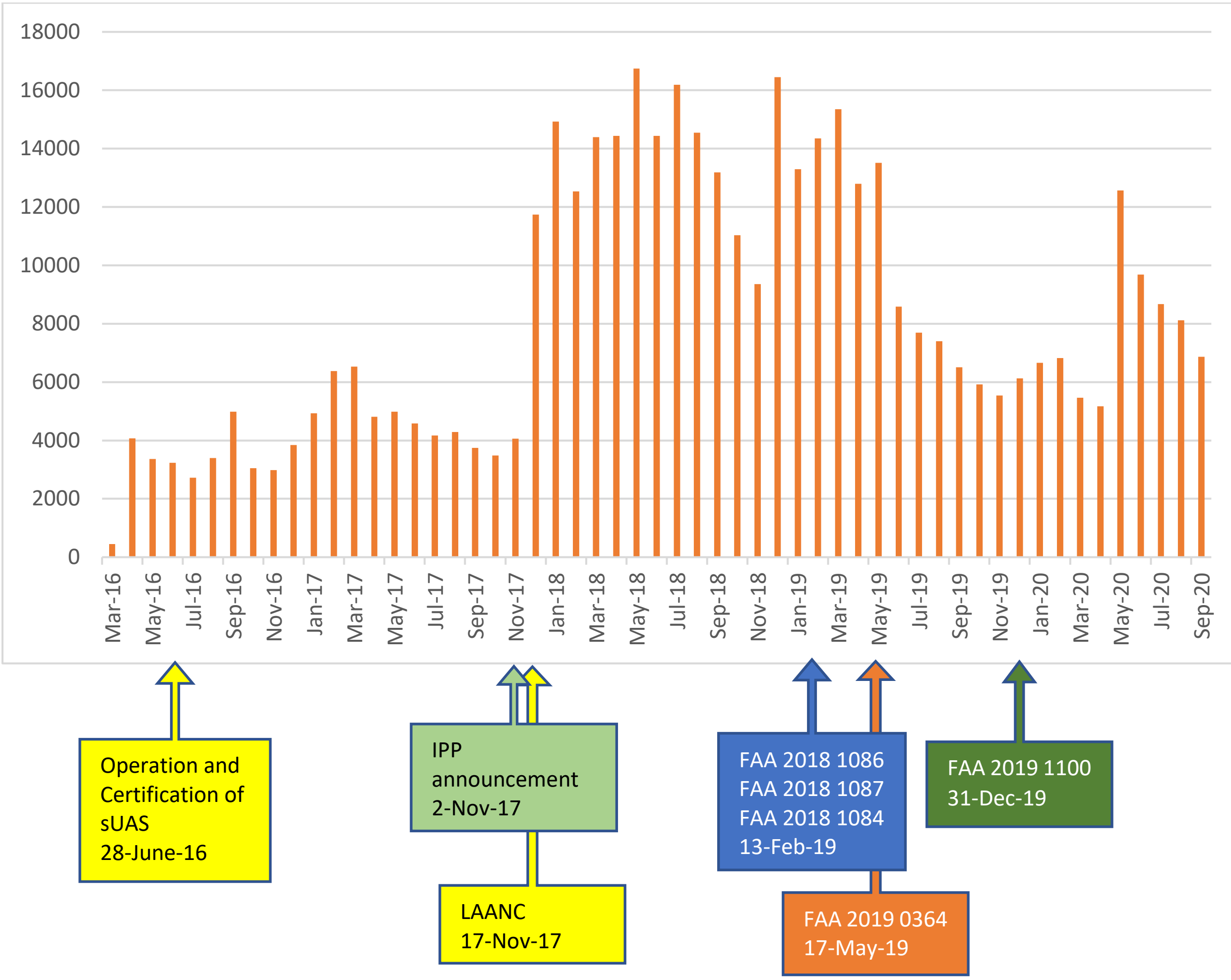

Figure 4. UAS Registration Numbers in the United States with Rulemaking Dates.

Next, frequency analysis was conducted to compare across states, using registration data by quarters. The results from 2017 showed that the four states with the highest registrations are California, Florida, New York, and Texas for both hobbyists and commercial (see Figures 5 and 6). Accordingly, the trend analysis for registrations in those states was conducted and compared. It is worth noting that since the full UAS registration data does not include city and state information, the breakdown analysis by states was conducted with quarterly registration data collected from the FAA Freedom of Information Act (FOIA) Library. There may be some discrepancies between the two data sets, so the outcomes must be interpreted with caution.

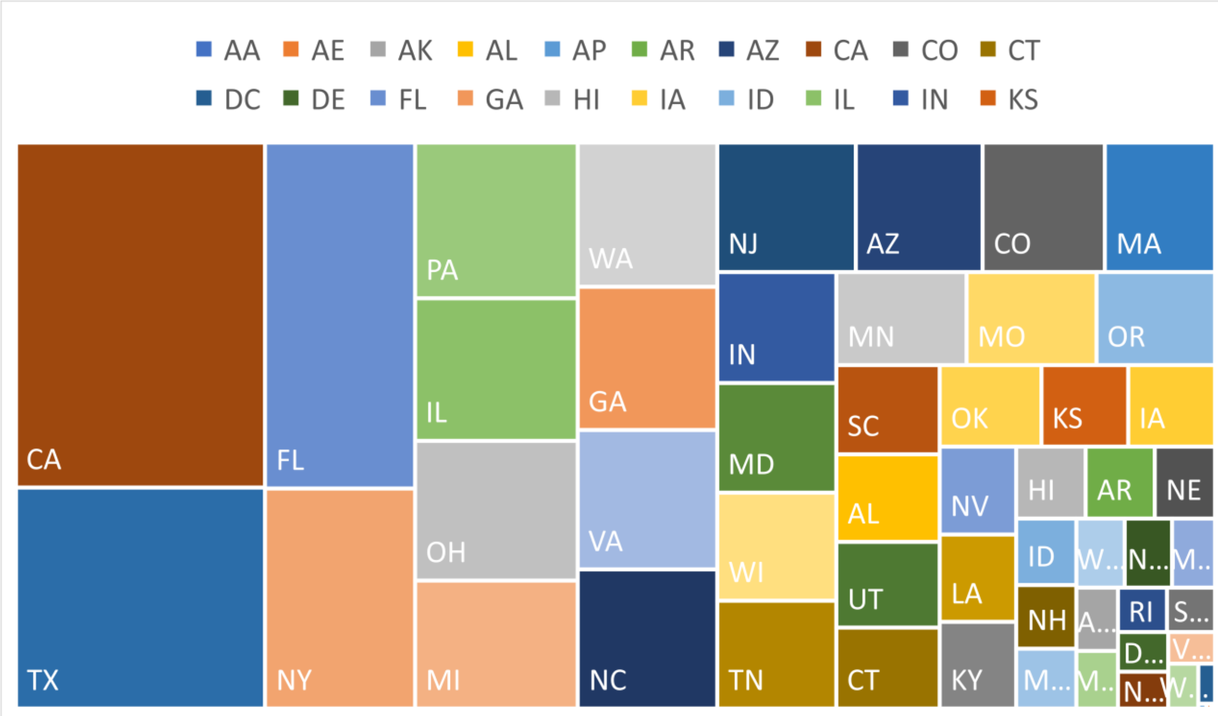

Figure 5. UAS Registrations by State in 2017 – Section 336 Hobbyists.

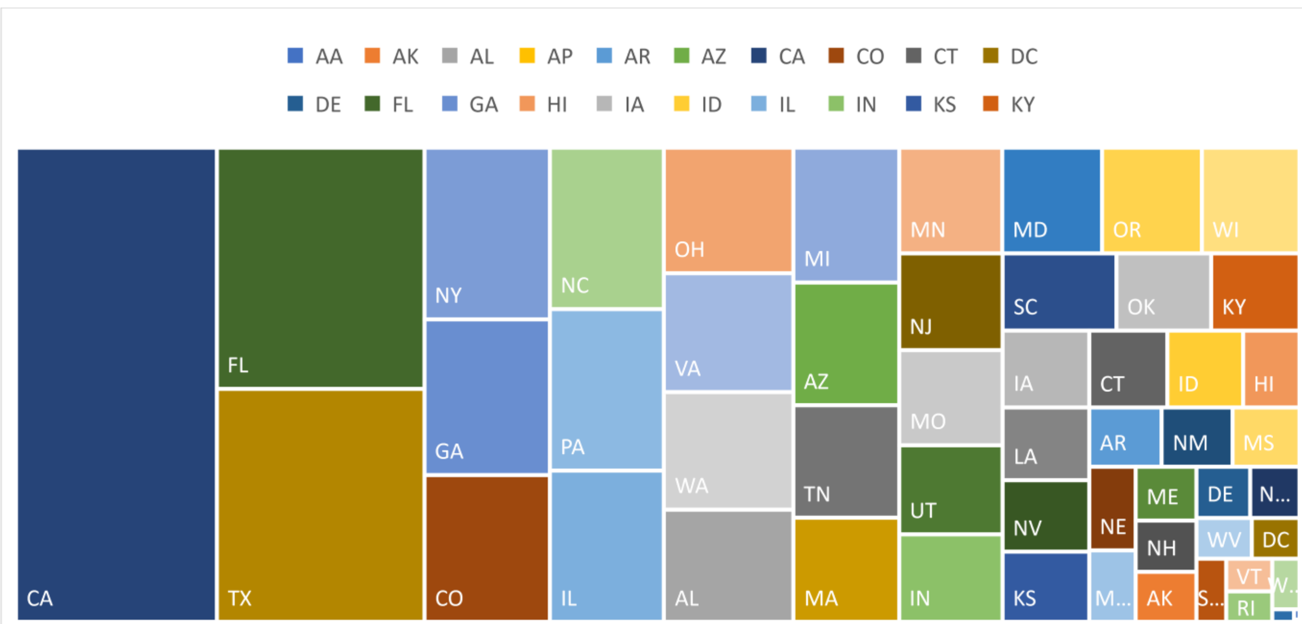

Figure 6. UAS Registrations by State in 2017 – Part 107 Commercial.

While Figures 5 and 6 depict the total registration counts by state, Figures 7 and 8 present the number of UAS per capita within zip codes. In Figure 7, much of the map remains uncolored or lightly colored indicating across much of the United States only a small number of commercial

UAS were registered. However, the map frequently shows higher per capita registrations around major US cities with the highest being near active commercial and research and development centers including the San Franscisco Bay area, New York City metropolican area, Los Angeles, etc. The highest rate depicted was 3.58 UAS per person in the San Franscisco.

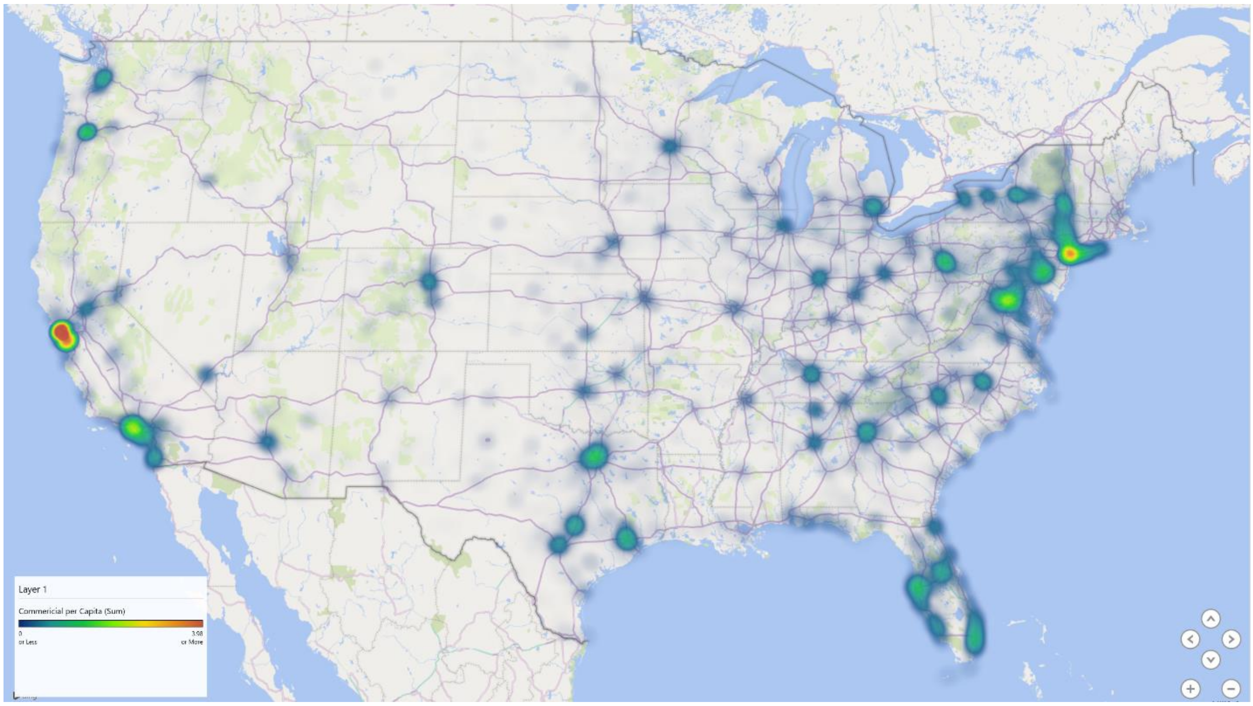

Figure 7. Heatmap of Commercial UAS Registrations per Capita (max score = 3.58 UAS per person).

Figure 8's heatmap depicts a hobbyist registrations across US zip codes per capita with a maximum measure of 0.38 UAS per person. With much of the country colored in, it seems that UAS registrations occurred across the United States with large red areas indicating a higher trend for hobbyist registrations near cities.

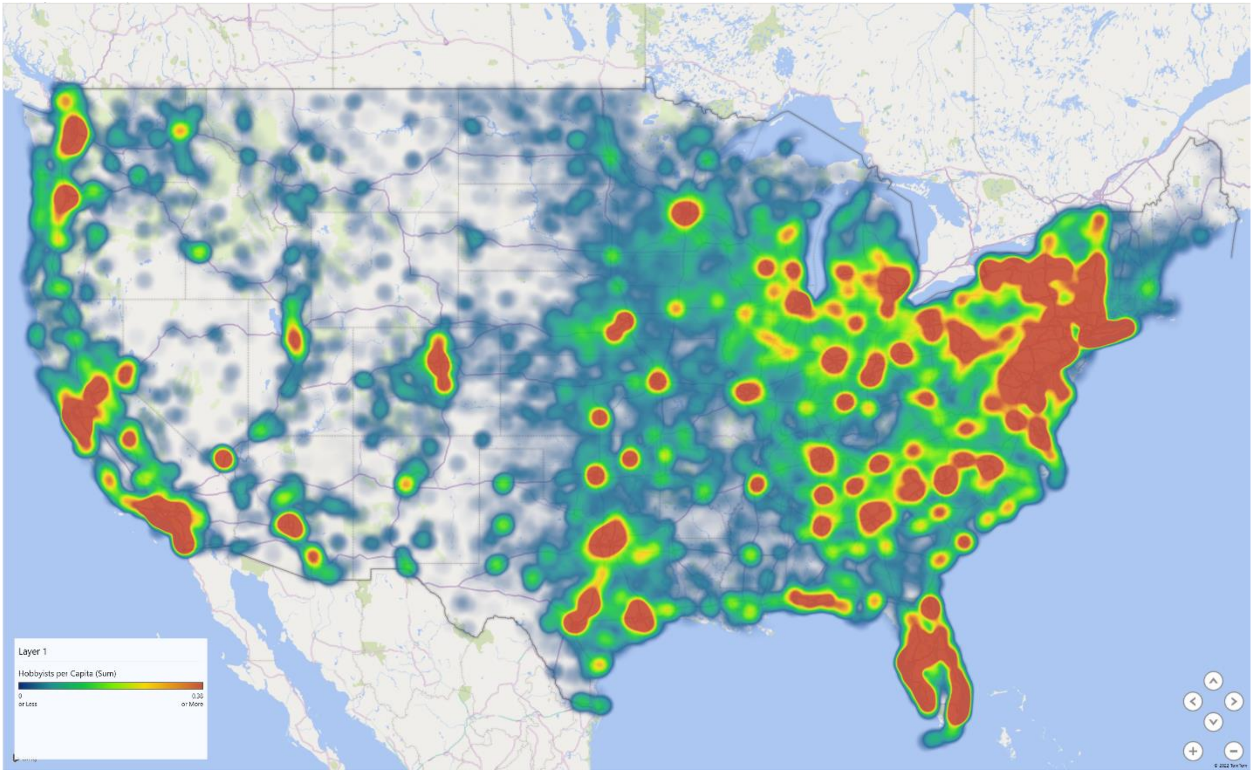

Figure 8. Heatmap of Hobbyist UAS Registrations per Capita (max = 0.38 UAS per Person).

Mission Logging System (MLS) Operations Trend Analysis. Figure 9 shows the total number of MLS operations over time. The UAS test sights utilize MLS to log information regarding the operations they host. Most MLS flight operations occurred in the third quarter of 2016, followed by quarter 2 of the same year. Then, the operations initially decreased before stabilizing through the second quarter of 2018, after which they started to decrease further. Note that there was an increase in operations in the second quarter of 2019, and a sharp fall in quarter 3 of that year.

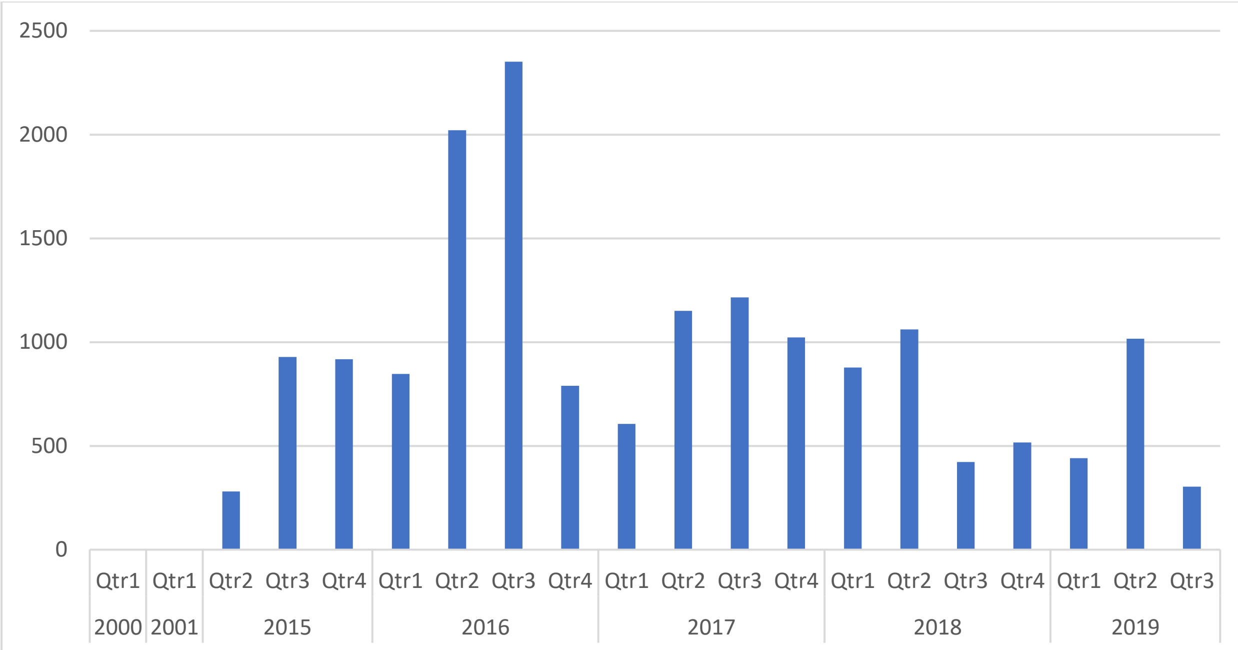

Figure 9. MLS Operations Over Time.

Figure 10 shows that the number of operations by UAS weight category fluctuated from month-to-month between 2015 and 2020. The totals increased from June 2016 to July 2016, with the highest value of approximately 1010. The second peak occurred in October 2019 with a value of about 850, and then the number of MLS operations decreases towards February 2020. It can be seen that most flights from April 2015 to March 2019 are sUAS, while most flights from April 2019 to January 2020 are large UAS.

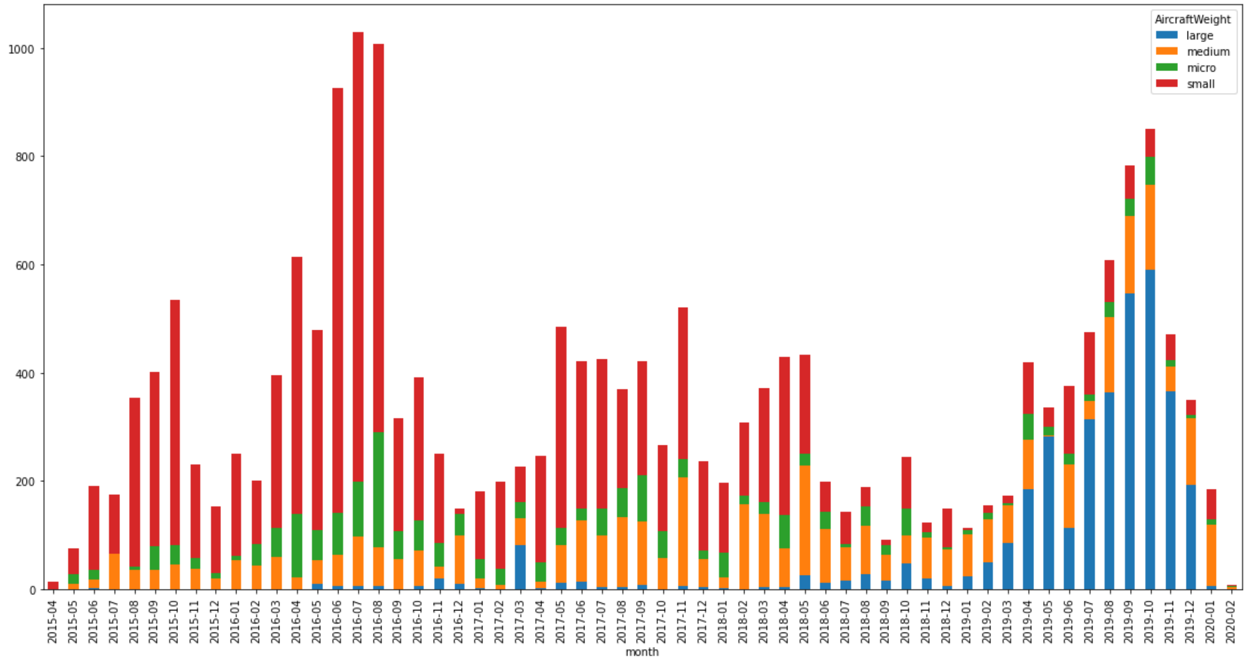

Figure 10. MLS Operations by Weight Category (micro: under 5 lbs.; small: 5-55 lbs.; medium: 55-300 lbs.; large: 300+ lbs.).

UAS Test Site Incidents and Accidents. Descriptive statistics for MLS incidents and accidents from the FAA-recognized UAS test sites are shown in Figures 11 to 14. The bar chart shown in Figure 11 shows that the state of Nevada has the highest number of MLS incidents/accidents (9) by the operator from 2015 to 2019, followed by Virginia (6), North Dakota (5), Alaska (3), and New Mexico (3). Additionally, Figure 12 illustrates the number of MLS incidents/accidents by event type from 2015 to 2019. The result shows that unusual equipment malfunctions had the highest number of incidents/accidents (24), followed by accident (21), lost control link events (8), and aircraft collisions (1). Next, Figure 13 depicts the number of MLS incidents/accidents by the flight phase from 2015 to 2019. The result shows that the Takeoff phase had the highest number of MLS incidents/accidents (12), followed by Maneuvering MNV (10), En Route ENR (7), Landing LDG (7), Initial Climb ICL (4), Approach APR (3), and Uncontrolled Descent UND (2). Finally, Figure 14 shows the number of MLS incidents/accidents by airspace class from 2015 to 2019. The result indicates that Class G has the highest number of incidents/accidents (28), followed by Class D (17), Class E (3), and Class B (1). It should be noted that out of total 16,770 operations, only 54 incidents or accidents were reported from May 2015 to June 2019. Due to missing values in the data, the total number of incidents in the charts below do not always sum up to 54. There may be more actual incidents that were not reported. The results only capture the reported incidents or accidents.

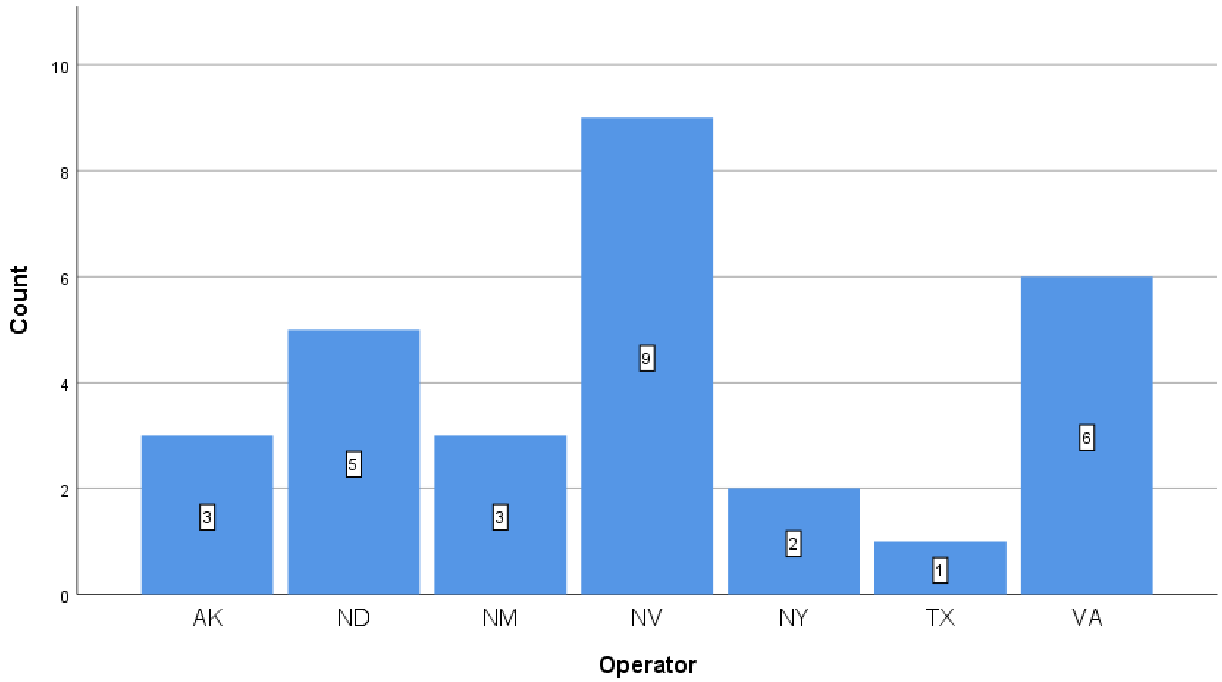

Figure 11. MLS Incidents by UAS Test Site.

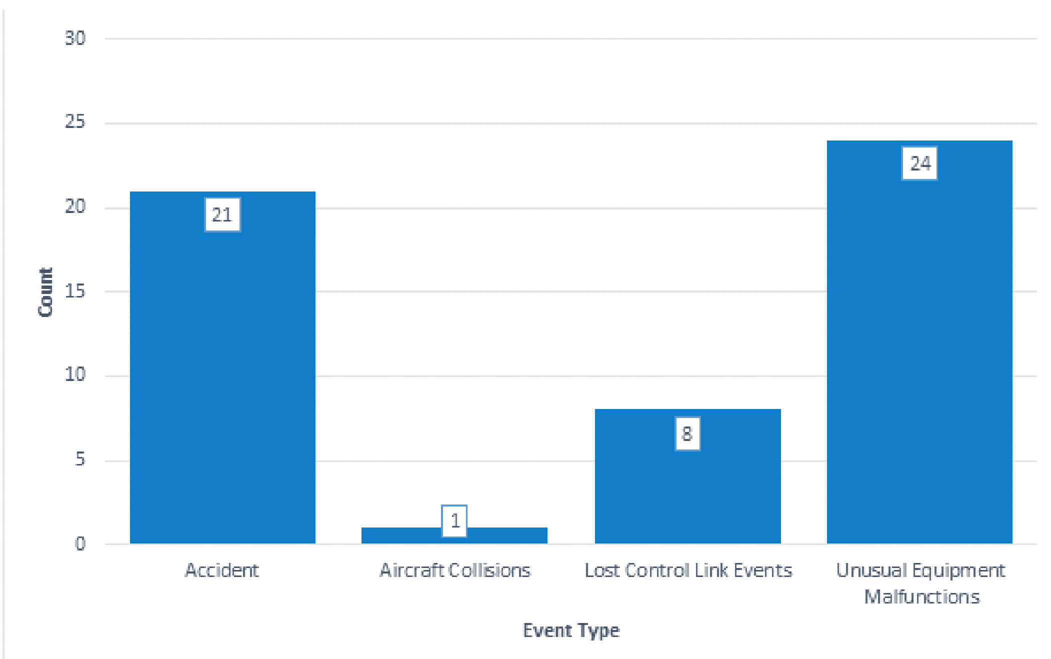

Figure 12. MLS Incidents by Event Type.

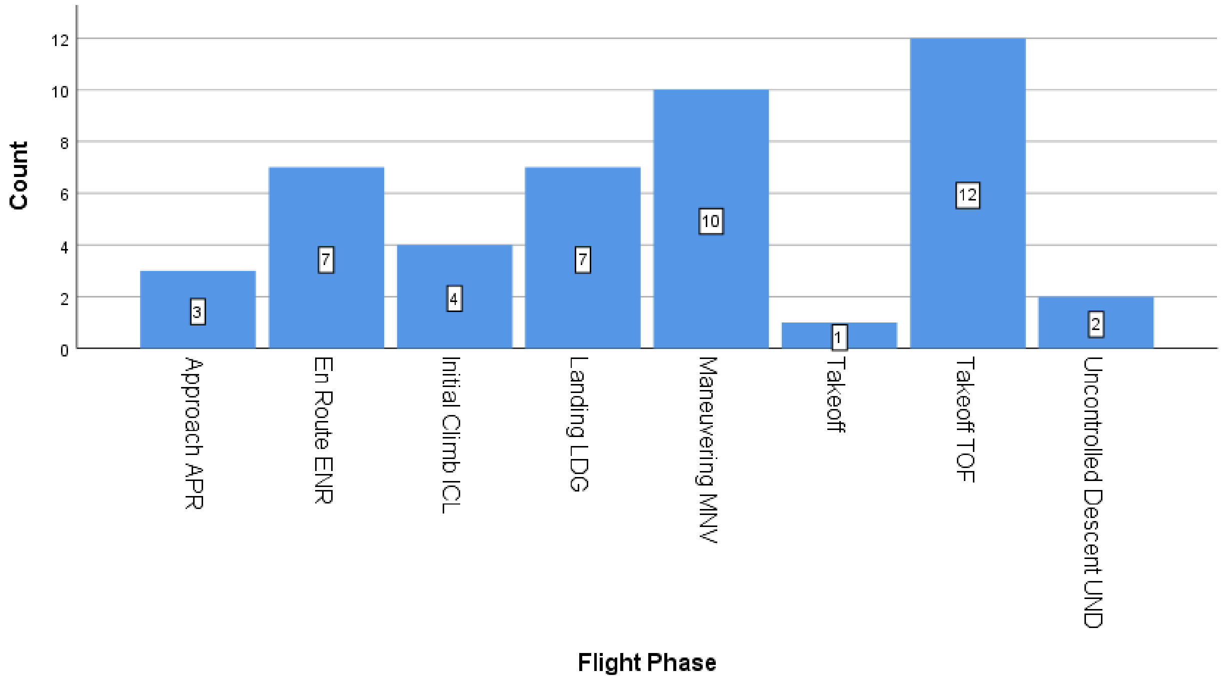

Figure 13. MLS Incidents by Flight Phase.

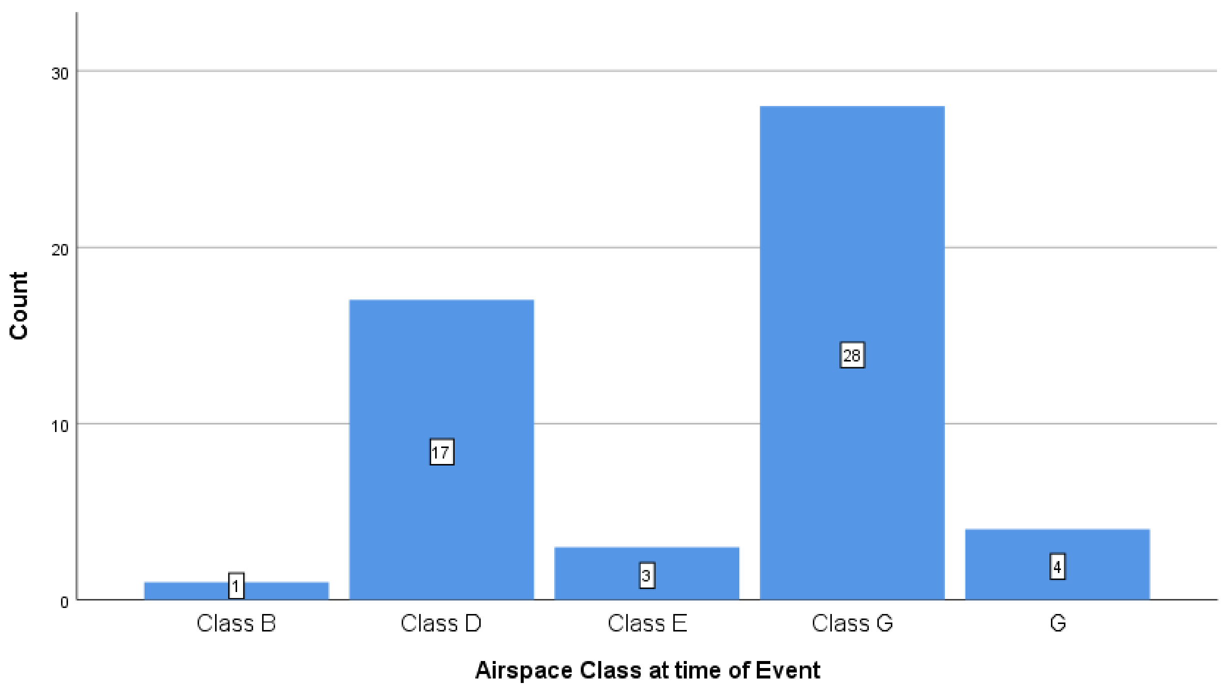

Figure 14. MLS Incidents by Airspace Class.

<u>UAS Sightings Data</u>. As the use of UAS is rapidly increasing, the information on UAS sightings reported by pilots, air traffic controllers, military personnel, and civilians has been collected and released by the FAA to proactively address the challenges of UAS integration into the NAS. An analysis of sighting incidents across various regions and climate zones and projected future sighting incidents within the next twelve months is summarized below.

Figure 15 shows the trend of sighting reports over time at the national level. It is worth noting that the overall number of incidents has increased from 2015 to 2019, with a peak of about 300 reports per month in June 2018, followed by 250 reports in June 2019. The trend is seasonal, with a lower number of reports in the wintertime and a much higher number of reports in the summertime. This finding is expected since there are more UAS operations in the summer than the winter. For future research, a more in-depth look at different climate regions in subsequent data analyses could give more insight into the sighting incidents by weather.

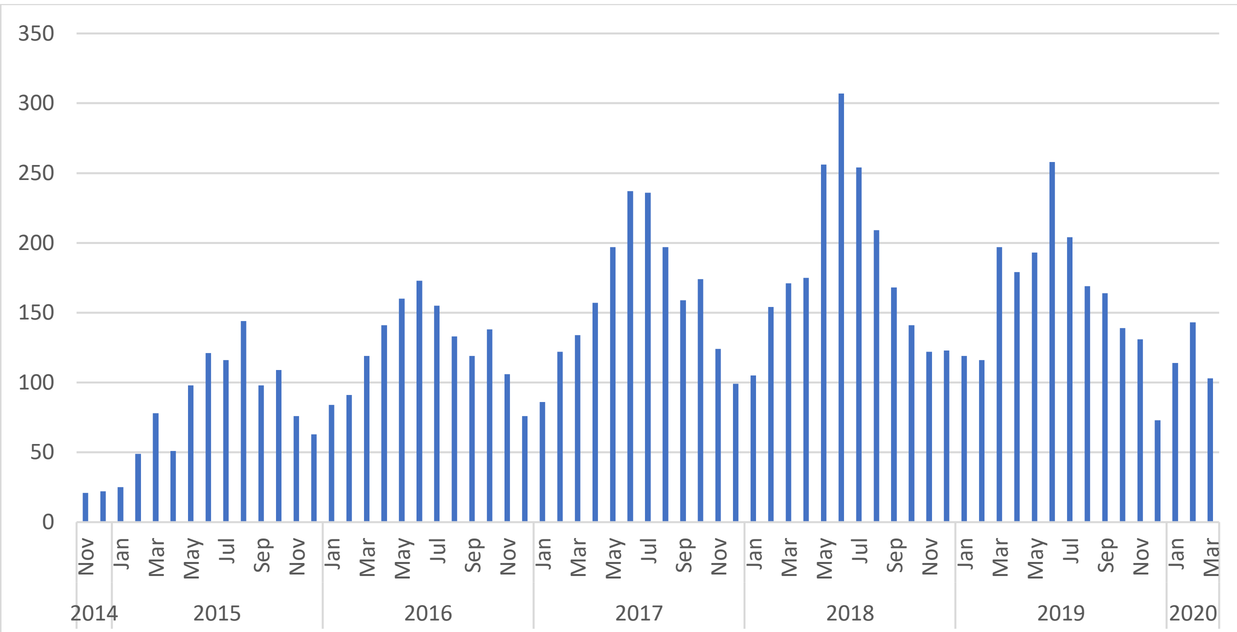

Figure 15. National Sighting Incidents Over Time.

Regarding the relationship between time of day and the occurrence of reported sighting incidents, the results are presented across nine different climate regions (Figure 16) to identify any potential relationship between weather and sighting incidents. The project uses nine climatically consistent regions as recommended by the National Oceanic and Atmospheric Administration (NOAA), including West, Southwest, South, Southeast, North East, Central, East North Central, West North Central, and Northwest (Figure 17). Figure 1517 shows a cyclical pattern based on time of year with a noteworthy decrease in operations in northern regions over the winter months. The figure shows that more populated states trend higher with respect to the number of sighting reports.

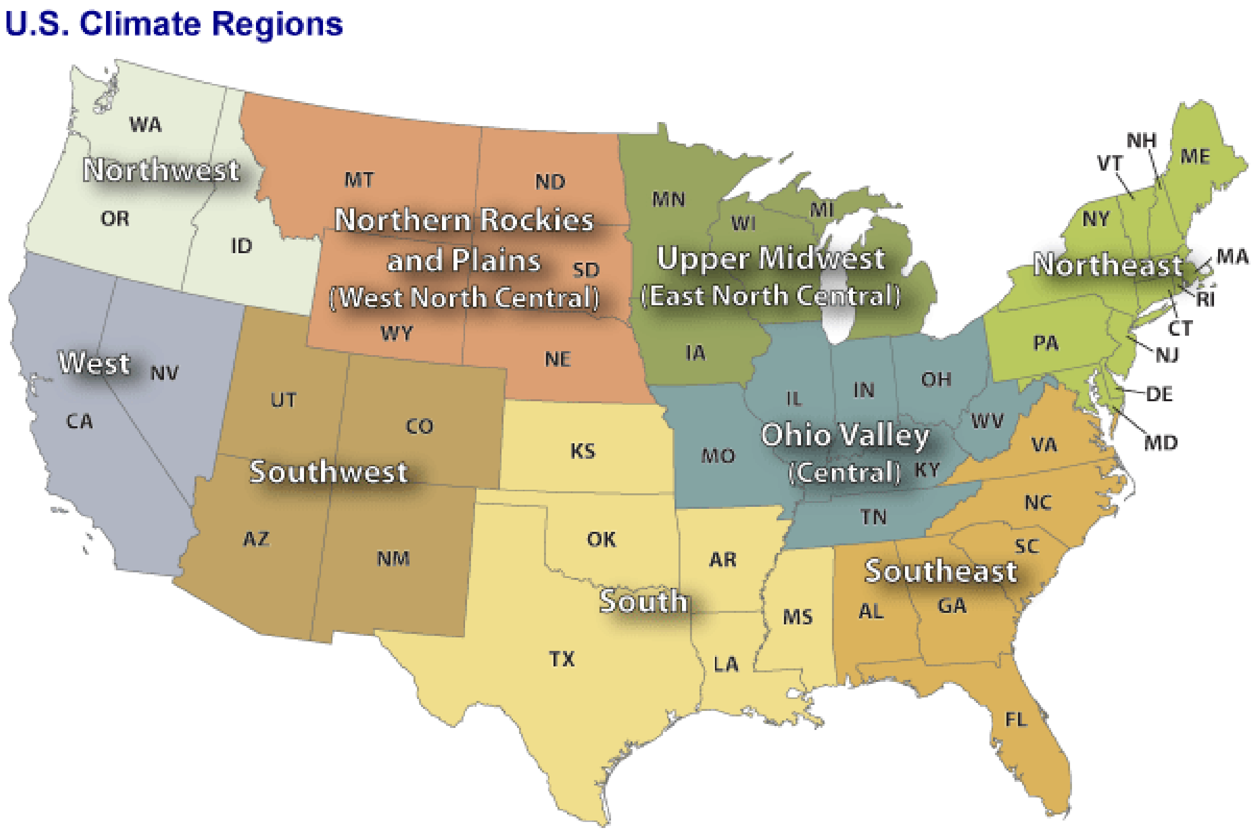

Figure 16. NOAA Nine Climate Regions[1].

[1] Source: https://www.ncdc.noaa.gov/monitoring-references/maps/us-climate-regions.php

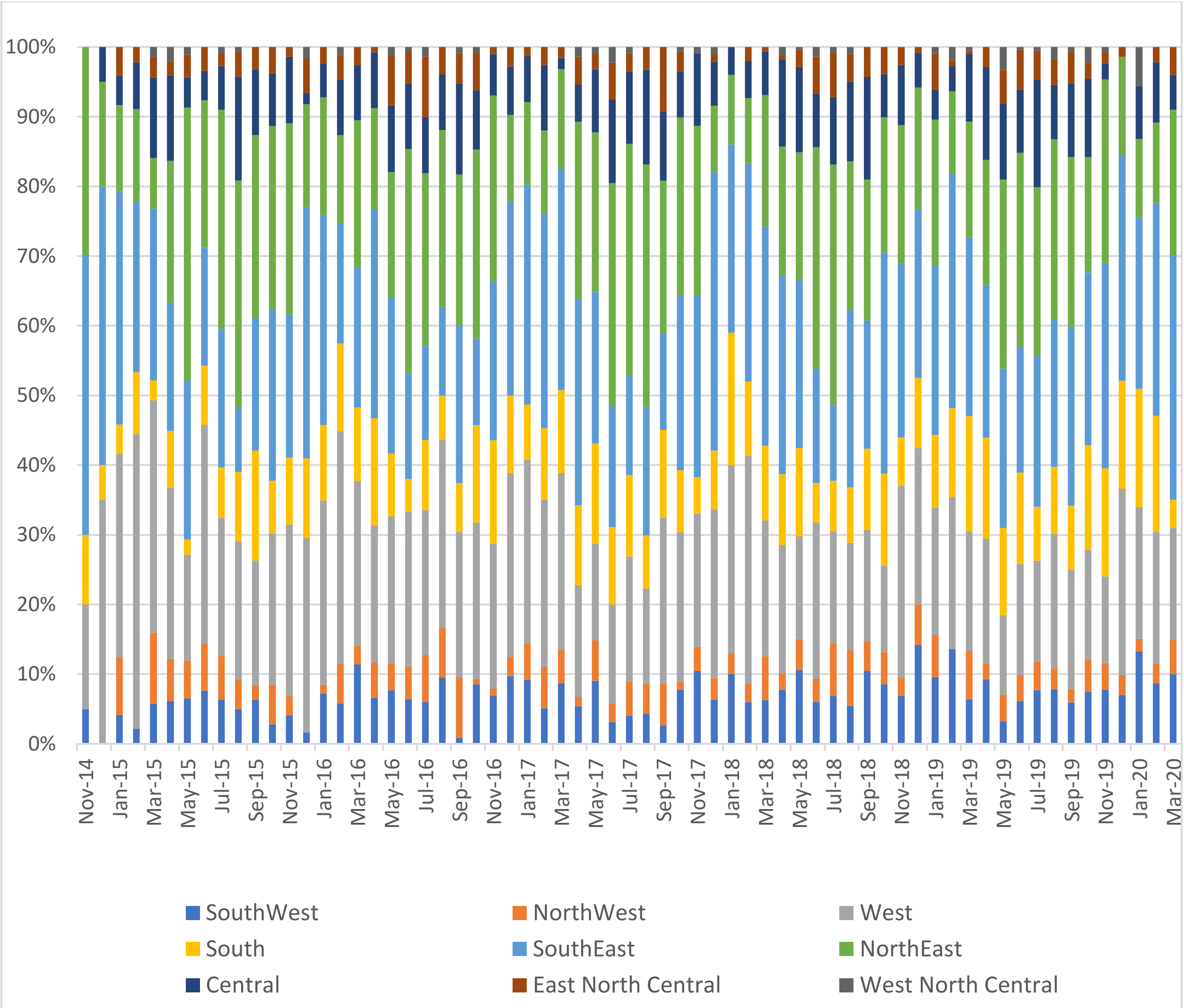

Figure 17. Number of Sighting Incidents by Climate Region.

Auto Regressive Integrated Moving Average (ARIMA) models were constructed for sighting incidents at the national level and in the nine climate regions to project future trends of sighting reports (see the detail of ARIMA method in Supplement A). Ten ARIMA models are constructed with a 95% confidence interval to forecast the incidents at the national level and nine different regions. For each model, the autocorrelation analysis results were examined to determine the appropriate p-value for the model. Then, the iterative process was used to find the appropriate values for q and m to ensure the model fit. Table 1 presents the forecast results for ten ARIMA models, including the model configuration, and model fit based on R^2 and Ljung-Box Q statistics. Overall, all models achieved a good model fit with R^2 greater than 0.5. In addition, all models have non-significant Ljung-Box Q statistics, indicating that there is no evidence of lacking model fit. In other words, the residuals are mainly white noise.

Table 1. ARIMA Models and Statistical Results.

Forecast Model	ARIMA	R^2	Ljung-Box Q statistics	Sig
National	10, 1, 1	0.765	10.911	0.143
West	16, 1,1	0.418	03.077	0.079
Southwest	15, 1, 1	0.55	3.296	0.192
South	12, 1, 1	0.624	4.454	0.486
Southeast	10, 1, 1	0.637	8.08	0.326
Northeast	11, 1, 1	0.728	12.22	0.06
Central	10, 1, 1	0.647	11.574	0.115
Northwest	11, 1, 1	0.5152	7.297	0.294
East North Central	11, 1, 1	0.539	8.421	0.209
West North Central	11, 1, 1	0.666	5.858	0.439

Figure 18 shows the forecast of future sighting incidents at the national level based on the developed ARIMA model above. The data is seasonal with peak numbers in the summer and lowest in the winter. The model projected that in the next twelve months, sighting reports would increase in the summer toward September 2020 and then start decreasing until January 2021, before they begin climbing again.

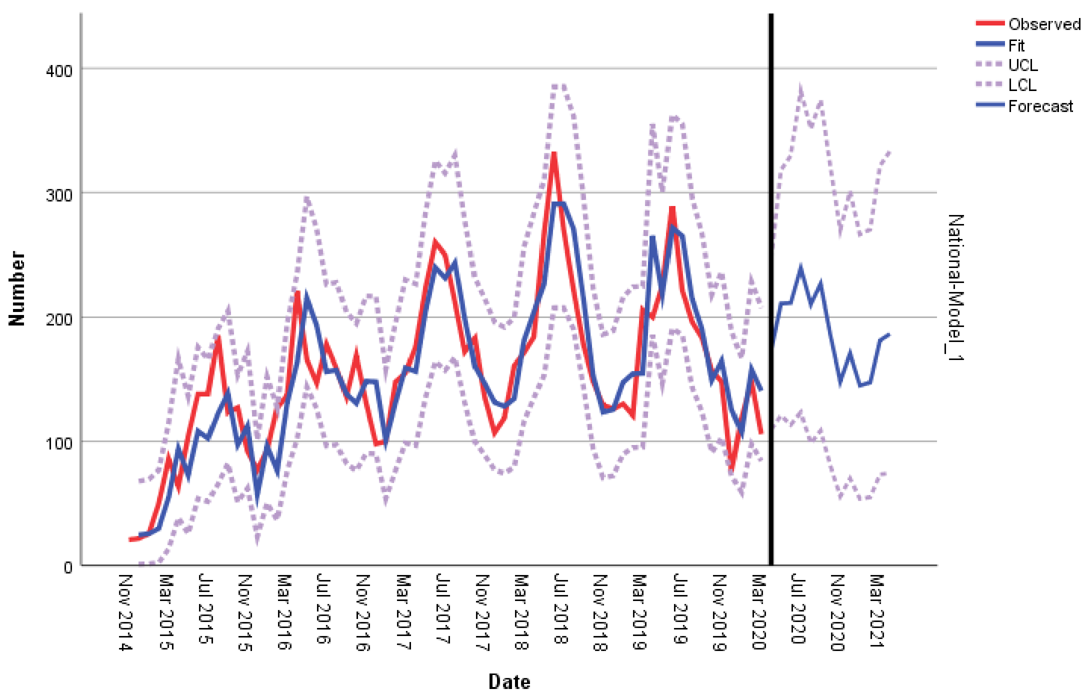

Figure 18. Sighting Incidents 12-month Forecast – National.

Data Gaps and Recommendations: UAS Registrations, Certificates, Waivers, and MLS Operations. Overall, the quantitative and trend analyses provide useful observations regarding UAS registrations, certificates, waivers, UAS operations, and UAS incidents. These observations are based upon the data trends shown and rulemaking milestones that may have a relationship to the changes. These observed correlations do not indicate causation, but instead point to opportunities for further analysis of the relationship between trend and milestone.

The data showed that UAS registrations for both hobbyist and commercial operations increased following the UAS Registration Rule in December 2015. Registrations have fluctuated over time, but there appears to be an influence on registration numbers from LAANC, the release of operational and certification requirements, and the IPP. There were increased registrations in mid-2020, possibly due to the publications of rulemaking milestones in 2019, especially Part 107 registrations.

The registration heat maps revealed that New York, Florida, Texas, and California are the four states with the highest registrations for both hobbyist and commercial use. There seem to be more activities in the eastern vs. western U.S. Urban areas with high population densities and near large airports have more registrations by zip code.

According to the trend analysis of UAS certificates, the number of certificates for remote pilots seems to be impacted by operation and certification requirements for sUAS (see Supplement A, section 6.4). Additionally, the number of certificate exams passed is consistent with the number of certificates issued. In addition, the trend analysis of UAS waivers shows a fluctuating pattern, but the impacts of LAANC and IPP could be observed. Most waiver applications use the simple and routine request process, and the waiver approval rate seems very low, except for 107.29 daylight operations.

The trend analysis of MLS operations and MLS incidents present some interesting findings at the test sites. The number of MLS operation was quite high in 2016 and then decreased over time. The trend for MLS operations was broken down by test site, aircraft type, operating altitudes, weight category, airspace class, line of sight (LOS), and flight hours. In addition, the MLS incidents were analyzed by operator, event, flight phase, and airspace class. It should be noted that the number of reported MLS incidents was too low to provide meaningful findings. See Supplement A, section 6.4 to read more about this analysis.

The main gaps in these analyses are the quality and format of the data. The lack of standardization limits the type of analysis that can be conducted, thus, limiting the findings. Listed below is a discussion of those gaps and recommendations for those datasets.

- Registration data: Part 107 registration variables can be further standardized to be usable for further analysis, such as standardization for manufacturing groups and UAS models.
- Certification data: Remote pilot certificate data do not differentiate initial certification from re-certification; therefore, there is a possibility that these data only include the number of initial certificates, not the total number of certificates actually issued. Clarification could be added to the dataset. Additionally, remote pilot certificate data on the FAA FOIA are only available by quarter. Certificate data by day could be provided.
- Waiver data: Waiver application data are available only as textual data from the FAA FOIA library in PDF format. There is no information regarding approved and denied requests.

Several waiver applications cover multiple regulations, which require standardizing the data for further analysis. Additionally, address fields should be standardized and broken into individual elements to aid geospatial analysis, such as mapping results to a specific locality. Standardization of variables is recommended to allow further analysis.

- MLS data: For MLS operations, aircraft type and operation variables should be standardized for further analysis. For MLS incidents, only 55 incidents or accidents were reported from May 2015 to June 2019. The incident reporting system may need to be updated.
- With more standardization for those datasets, they can be consolidated for further analysis. Appropriate multivariate statistical analyses could be conducted to examine the correlations among those variables and effects of specific events on the changes of registrations, certificates, or waivers.

Visual Sightings Database Validation. The use of UAS detection technology was demonstrated for an evaluation of UAS user activity within the NAS. In addition, an evaluation was conducted to demonstrate the assessment of the accuracy of UAS sighting reports using aviation traffic data coupled with UAS detection technology.

To accomplish this, the research team leveraged historical UAS detection data from DJI AeroScope sensors placed across the country at various convenience sample locations. Detection data sets were furnished for the project by a series of UAS detection service companies.

Manufactured by drone-maker DJI, the AeroScope is a comprehensive UAS detection solution designed to detect and glean information from UAS datalink communication, including flight status, telemetry, and other information in real-time. The device is designed for continuous, passive monitoring of unmanned aircraft at ranges up to 50km. Flight data is stored on a cloud-based server, which facilitates monitoring, system control, and data analysis tools (DJI, 2020). The AeroScope does not provide a complete detection solution, as the device reportedly only detects unmanned aircraft manufactured by DJI (Goode, 2017). The Aeroscope will generally not detect platforms manufactured prior to 2014, which utilize a different communications protocol than current models (911 Security, 2022). According to Drone Industry Insights, DJI drones account for approximately 77% of U.S. drone sales, commanding a market share nearly 20 times that of the closest competitor (Schmidt & Vance, 2020).

Primary data for the study was collected from a G-18 AeroScope device located at DFW, Texas. UAS flight activity was collected from 15:30 (ET) August 22, 2018 to January 31, 2020 at 23:00 (ET). The device was operated continuously during the sampling period, with minimal interruptions for service or maintenance functions. The research team was provided direct server access to the dataset. The research team performed all data inquiries, downloads, data management, and analysis functions.

During the sampling period, the AeroScope detected a total of 12,520 unique DJI serial numbered UAS. During the sampling period, the system registered a total of 162,162 separate flights. Detections ranged from .03 NM to a maximum of 62.32 NM from the sensor, with a mean of 10.48 NM (see Figure 19). Of the complete dataset, 848 flights lacked geolocation information and were removed from distance calculations.

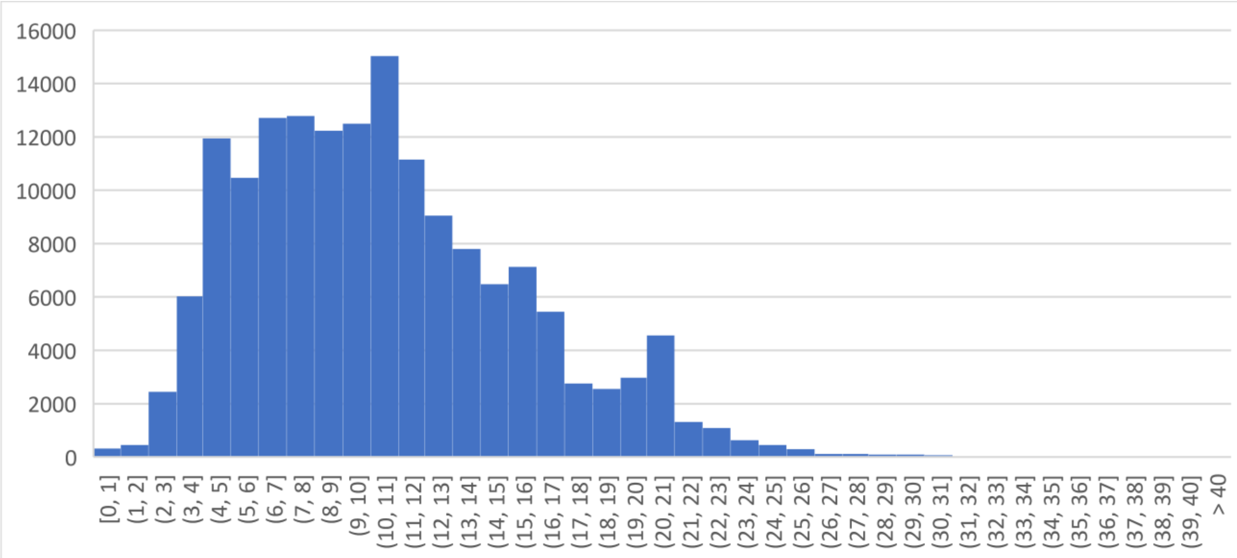

Figure 19. UAS Detections by Range (NM) Taken from DFW Airport, August 2018-January 2020 (Zero duration flights removed).

Of the detected 12,520 unique unmanned aircraft, three model types dominated the dataset, including the MavicPro (31.0%), Mavic 2 (25.5%), and MavicAir (10.8%). Approximately 9.8% of the detected unmanned aircraft were unable to be identified.

The duration of detected flights tended to be extremely short, with a mean of 76 seconds and a median of 18 seconds. It is notable that among the 162,162 flights, there were 59,006 with a recorded duration of 0 seconds—these have been removed from the dataset for analysis purposes unless otherwise noted. A graphical depiction of flight durations is provided in Figure 20. It is unclear to the research team why UAS flights would be so short, from an operational perspective. The researchers also assess that it may be possible that the AeroScope is not capturing the full extent of flights, due to obstructions in line of sight between the sensor and low-altitude UAS platforms. Additional analysis will have to be performed to validate this suspicion.

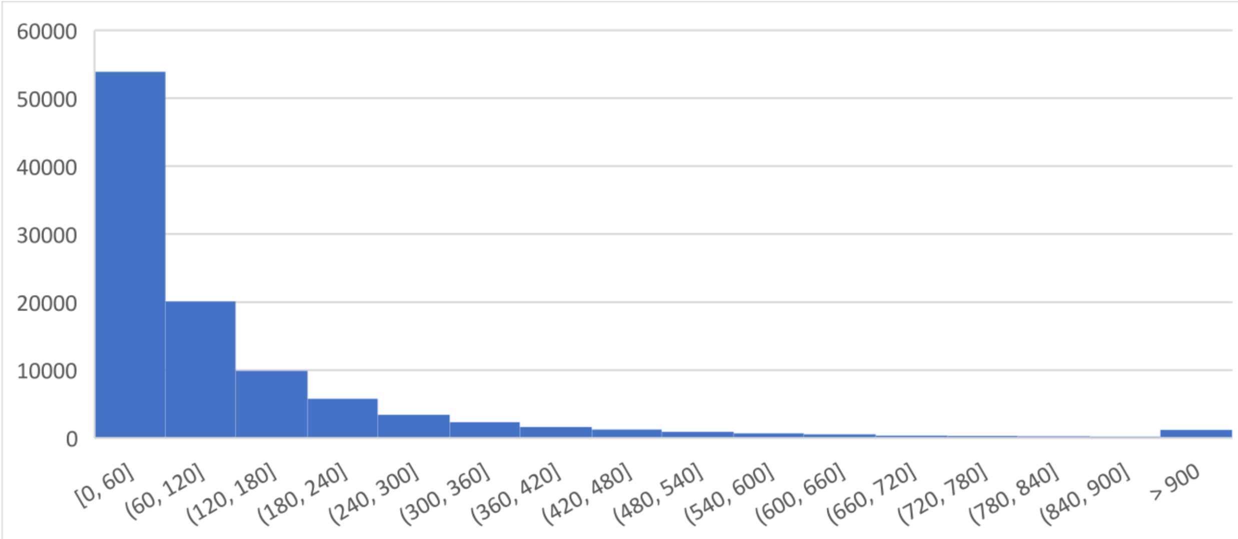

Figure 20. Histogram of UAS Flight Durations in Seconds, Taken from DFW Airport, August 2018-January 2020.

The data were further distributed to show the flight duration by each platform type (Figure 21). Elevated flight durations were seen in the Phantom 4 (P4) product line, as well as the Inspire 2 (In2) and MavicPro. Duration analysis was also provided for platforms in which identifying information was not available (null) or those which could not be identified by the system (unknown).

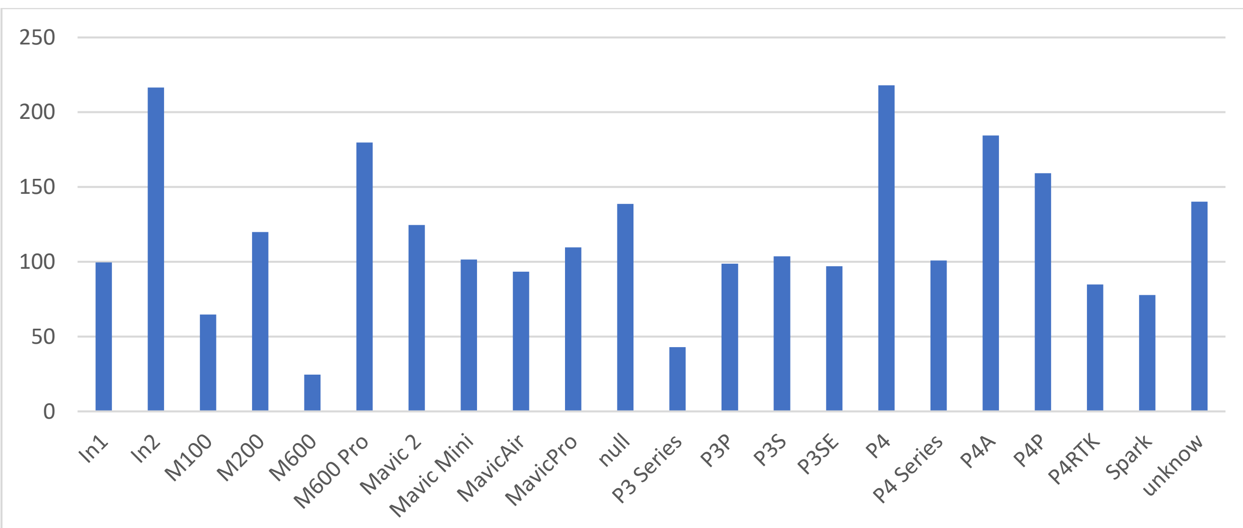

Figure 21. Average Flight Duration of Detected UAS Operations in Seconds, Taken at DFW Airport, August 2018-January 2020.

Figure 22 depicts platform flight durations as a proportion of total platform detections. Generally, flight durations for most detected platforms are quite consistent. For example, the Mavic 2, Mavic Mini, MavicAir, and MavicPro all show that approximately 50% of the detected flights had durations of less than one minute. Only a small proportion of flights from each of those platforms lasted more than 10 minutes. Flights involving other platforms, such as the Phantom 4 and Phantom 4A, exhibited more variability in flight duration.

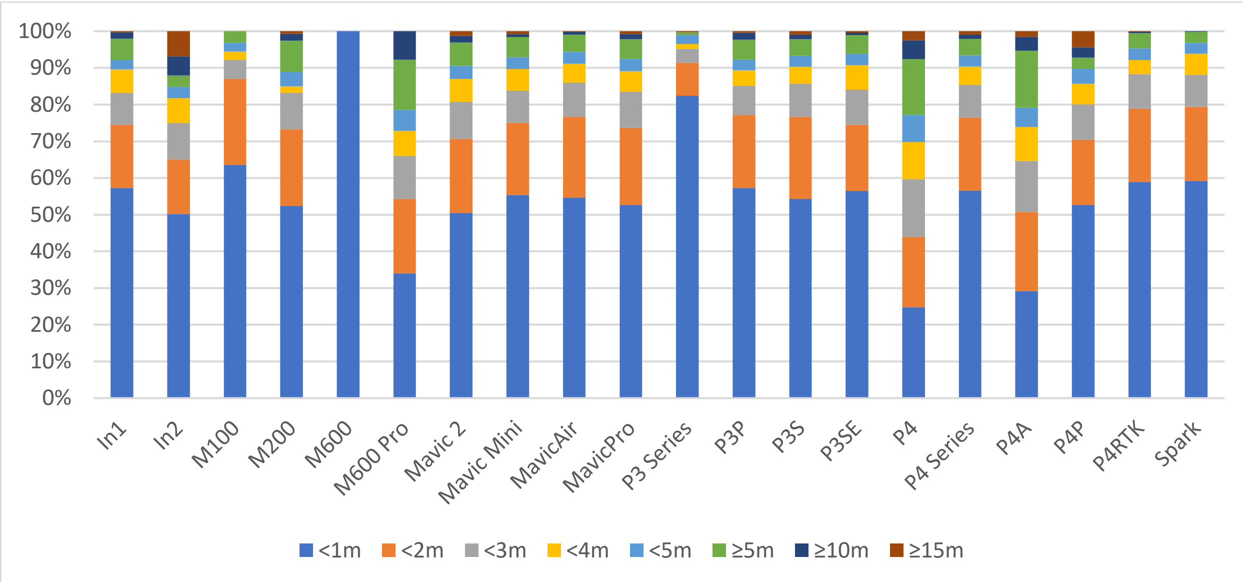

Figure 22. Detected Platform Flight Durations by Proportion of Total Platform Detections, Taken at DFW Airport August 2018-January 2020.

Approximately 94.7% (n = 153,535) of all detected UAS flights occurred below 400 ft AGL. Researchers noted 4,735 UAS flights exceeded 500 feet AGL, with 1,168 of those exceeding 1,000 ft AGL. The distribution of UAS flight altitudes among the detection dataset is presented in Figure 23. A geographical presentation of UAS flights detected above 1,000 ft AGL is presented in Figure 24.

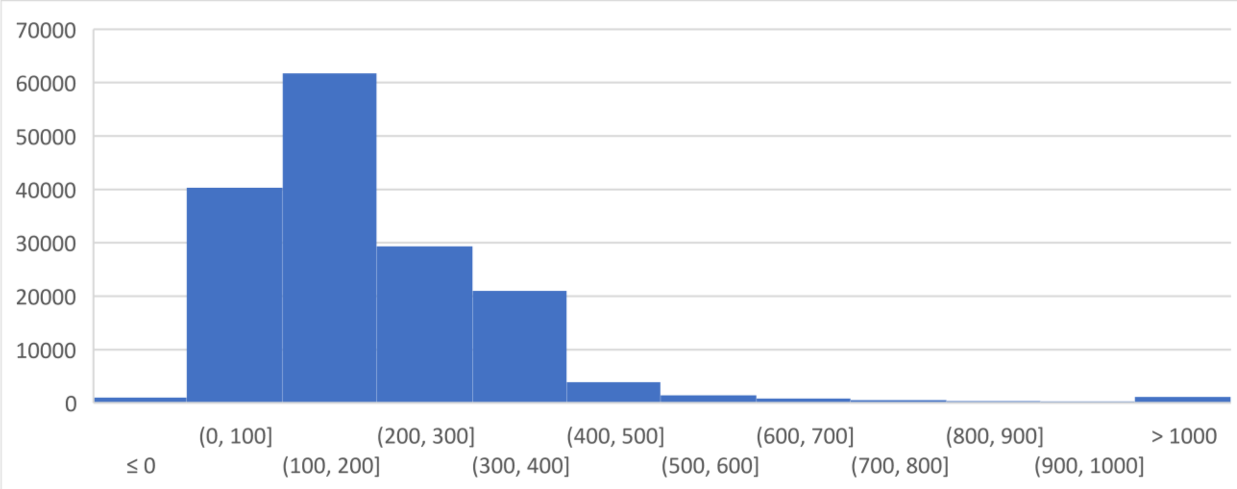

Figure 23. Histogram of UAS Flight Altitudes (ft AGL) Taken from DFW Airport, August 2018-January 2020.

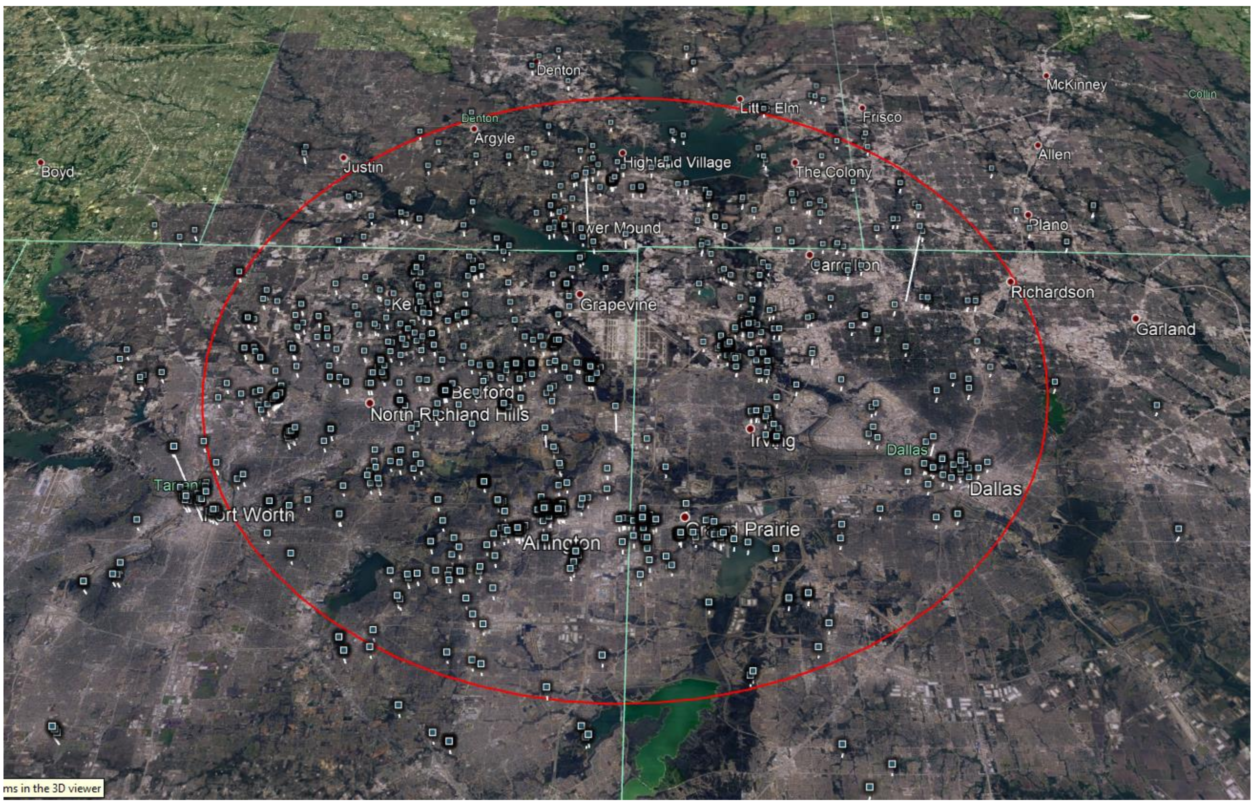

Figure 24. Location of UAS Detections Exceeding 1,000 ft AGL, Taken from DFW Airport, August 2018-January 2020 (red circle has a 15 NM radius perimeter centered at DFW).

While the dataset shows that most operators adhere to altitude restrictions, a small portion of the dataset indicated gross non-compliance, with three flight detections from three separate DJI MavicPro operators exceeding 21,000 feet AGL.

Using geolocation information, the research team assessed each flight's proximity to area airports. The following airports were included in the analysis:

- Dallas-Fort Worth International Airport (DFW)
- Addison Airort (ADS)
- Fort Worth Alliance Airport (AFW)
- Forth Worth Meacham International Airport (FTW)
- Grand Prairie Municipal Airport (GPM)
- Dallas Executive Airport (RBD)
- Dallas Love Field (DAL)
- Arlington Municipal Airport (GKY)
- Mesquite Metro Airport (HQZ)

Figure 23 highlights the distribution of detected sUAS flights within various proximities (Nautical Miles or NM) to airports within the sample area. DFW encountered 226 UAS flights within .5 NM of the airfield, with some flights occurring on the airfield. Grand Prairie Municipal (GPM) encountered eight flights within .5 NM of the field (see Figure 25). It is notable, however, that authorized UAS operations are performed on the airfield and ramp areas on a regular basis by both DFW Airport and American Airlines. Without additional LAANC or airspace approval data, it is not possible to assess if these flights were authorized.

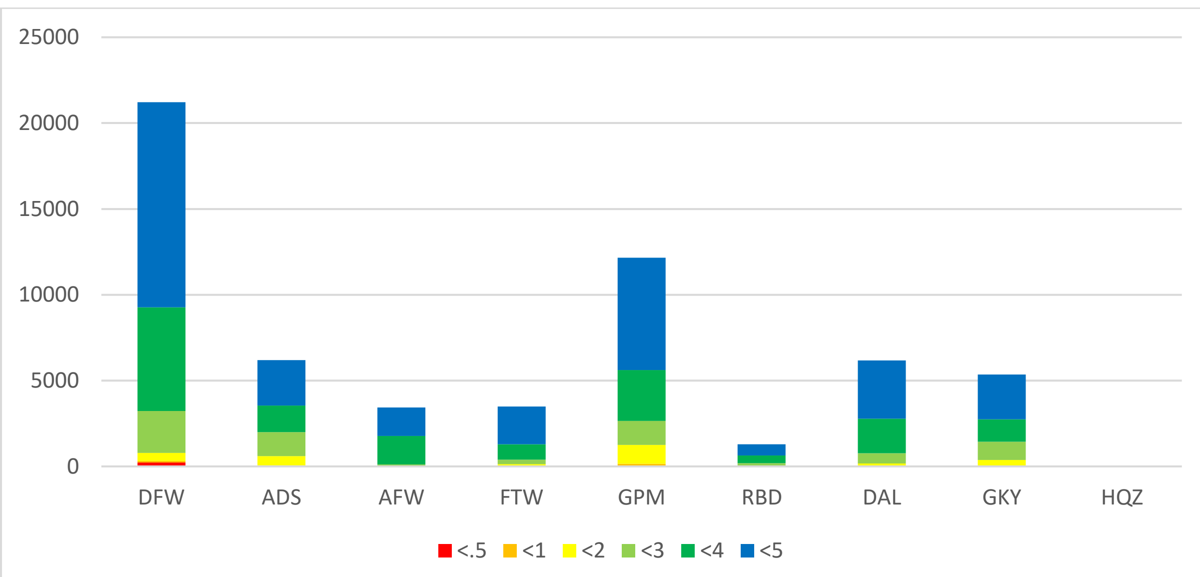

Figure 25. UAS Flight Detections in Proximity to Airports (NM), Taken from DFW Airport, August 2018-January 2020.

The research team also assessed UAS flight proximity to known heliports. Fifty-one heliports in the DFW area were assessed in the initial sample (see Figure 26). A total of 10,919 UAS flights were detected within .5 NM of heliports during the sampling period.

The research team believes these areas represent a significantly higher risk for NMAC (Near Mid Air Collision) than airports for the following reasons:

- Remote pilots are likely less aware of heliport locations than airport locations
- Helicopter operations tend to operate at lower altitudes, such as those shared with UAS operations

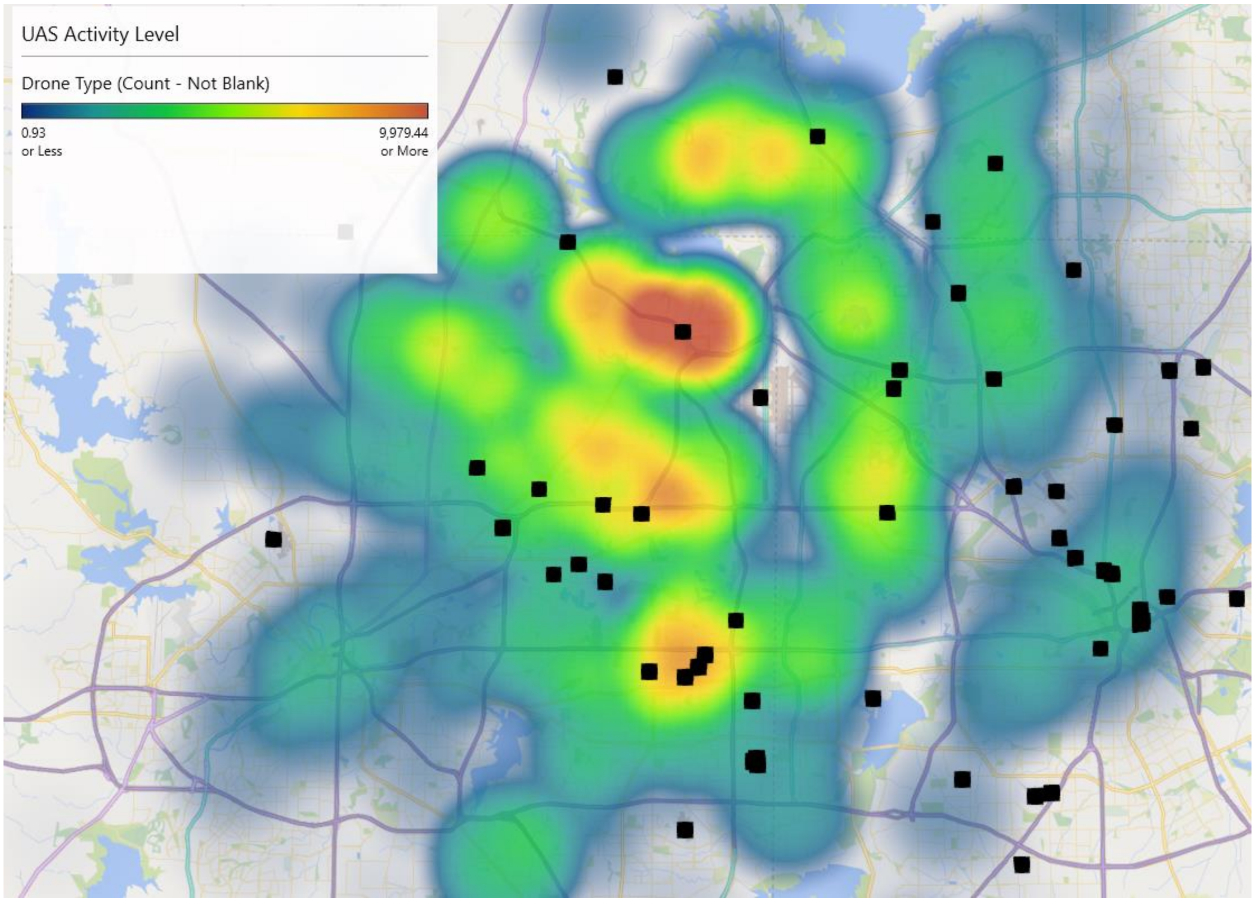

Figure 26. UAS Flight Detections in Proximity to Heliports (NM), Taken from DFW Airport, August 2018-January 2020.

Data Gaps and Recommendations: UAS Sighting Reports. The analysis results show the importance of UAS sighting reports in identifying violations in UAS operations and encounters between UAS and aircraft, helicopter, or tower. Those violations and encounters could lead to hazards, such as evasive maneuvers, mid-air collisions or runway incursions which eventually lead to incidents and accidents resulting in human injury, loss of property, or both. Having valid and usable sighting reports plays an important role in aviation analytics to identify the contributing factors and their effects on sighting incidents. The FAA could use the analytical results to develop necessary risk profiling and assessment mechanisms to evaluate the likelihood and severity of the hazards, based on which necessary risk mitigation strategies can be developed. As a result appropriate rules, and regulations in the UAS registration, waiver request, and certification processes can be further developed or revised to ensure the safety of non-segregated UAS operations into the NAS.

The General Accounting Office (GAO, 2019) has investigated UAS operations and how the FAA integrated UAS operations into its safety oversight framework. Based on the findings of their project, GAO recommended the FAA improve data and communication, which is the key to enforcing compliance with UAS rulemakings (GAO, 2019). More specifically, GAO provided three recommendations to the FAA:

- Identify UAS-specific education and training needs for inspectors and develop appropriate training to address any needs identified.
- Develop an approach to communicate key information more effectively to local law enforcement agencies regarding their expected role with regard to sUAS safety oversight.
- Recommend existing or new data and information needed to evaluate oversight activities and develop a mechanism for capturing these data as needed.

In order to improve the data and communication related to UAS operation safety, it is important to improve the quality of the UAS sighting reporting system. The current sightings report data collection processes have yielded data sets with inconsistencies in data element format and content reported, which limits quantitative analysis for risk assessment. Only the date, time, city, and state of each occurrence can be used in the available data formats. The sighting report is largely comprised of a narrative summarizing the incident reported by the spotters. This free-form field lacks the uniformity and consistency necessary for extracting the requisite and valuable information. Additionally, it lacks explicit mechanisms to validate that the report captures all information desired for data analysis.

It is recommended the FAA revisit the sighting report mechanism, identify necessary variables, and redevelop the reporting form. More checkboxes and/or radio buttons and multiple-choice questions should be used to improve the reliability and usability of the data through standardization. Text fields may still be used but only to identify and capture unique information that cannot be captured through the use of standardized fields. Truong and Choi (2020) used machine learning algorithms to predict the risk of UAS violations in the NAS and recommended specific variables, scales, and coding formats that could be incorporated into the reporting process (Table 2). This instrument could be considered for further improvement of the sighting reporting process.

Table 2. Recommended Variables and Coding Format for Sighting Reports.

Data Field	Subcategory	Measure	Coding Format
Incident Time	Day of week	Nominal	1 = Mon, 2 = Tue, …. 6 = Sat, 7 = Sun
	Time (Local)	Nominal	1 = Morning (06:00 - 11:59) 2 = Afternoon (12:00 - 16:59) 3 = Evening (17:00 - 20:59) 4 = Night (21:00 - 05:59)
Spot by		Nominal	1= Pilot (including passenger) 2 = Airport Operator, Tower, Tenants 3 = Police, Agents 4 = Citizen
Location		Nominal	1 = Airport (within 5 miles), 2 = Downtown, 3 = Suburban, Sea, Shore
UAS Profile	Type	Nominal	1 = Fixed wing, 2 = Single rotor, 3 = Multi rotors
	Size	Nominal	1 = Large (≥ 3ft), 2 = Small (< 3ft)
	Color	Nominal	1 = white, 2 = black, 3 = other color
	Lighting	Nominal	1 = flashing, 2 = continuous lighting
Violation Type		Nominal	1 = flying beyond 400ft 2 = flying within 5 miles from an airport 3 = flying in restricted airspace
Incident Altitude (UAS)		Continuous	ft
Related Airport		Nominal	1 = Large Hub: 1% or more 2 = Medium Hub: 0.25% - 1% 3 = Small Hub: 0.05% - 0.25% 4 = Nonhub or Regional: 2,500 - 10,000 5 = Regional or GA Airport 6 = Airbase Based on FAA NPIAS Airport Categories (FAA, 2022)
Distance from Airport		Continuous	Mile
Manned Aircraft Type		Nominal	1= Jet, 2= Prop, 3 = Helicopter/Blimp/Glider, 4 = Fighter / Military Jet
Manned Aircraft Operation		Nominal	1 = Landing or approach, 2 = departure, 3 = cruising
Position from Manned Aircraft	Distance	Continuous	ft
	Direction	Nominal	1 = front, 2 = above, 3 = below, 4 = side, 5 = behind
Aircraft Involved		Binary	1 = yes, 2 = no
Reported as NMAC		Binary	1 = yes, 2 = no
Evasive Action		Binary	1 = taken, 2 = not taken
Law Enforcement Notification		Binary	1 = notified, 2 = not notified

3.2 Interview Study with FAA Test Sites and Integration Pilot Programs

In addition to the quantitative analyses of current sUAS activity summarized above, an additional study was conducted to provide insight into data needs for evaluating UAS CONOPs. Data were collected using interviews, with a total of 9 FAA Test Sites or IPP/Beyond lead organizations providing input.

The first set of information gathered focused on current types of waivers held by respondents. These data show that the Part 107 route is preferred for certain types of waivers (relative to COAs) and that the Certificates Of waiver or Authorization (COA) route is preferred for other types of waivers (relative to Part 107). These data also show that the acquisition of waivers and COAs that have more than one deviation/waiver type is common, and that demand for waivers related to BVLOS operations is high. An additional insight is that publication of the "Operation of Small Unmanned Aircraft Systems Over People" rule (Department of Transportation 2021) likely impacted waiver requests.

Interview data regarding CONOPs enabled identification of the most common CONOPs. The same set of CONOPs, with minor variations, were identified with current waivers, waivers requested in the past year, and expected future CONOPs to be developed in the next year. The expected future CONOPs indicated a shift in relative importance of some of the common CONOPs.

The most common current mitigations used to enable common CONOPs are Detect And Avoid (DAA), Visual Observer (VO), and Strategic (e.g., low traffic density airspace). Respondents indicated that DAA systems are commonly used as mitigations. This is noteworthy given that such systems are not generally approved as a sole means for avoiding conflicts with other aircraft. DAA systems are likely being utilized as part of the overall set of mitigations with other mitigations, such as VOs, providing a layer of safety that enables the CONOPs/testing.

The dominant emerging/future technology for hazard mitigation/UAS National Airspace System (NAS) integration identified by respondents is DAA. Many other technologies/capabilities were also identified. Except, possibly, for Remote ID, improved payloads, and improved data feed capability, all of the emerging technologies identified support BVLOS operations.

CONOP performance evaluation metrics were placed into categories, and then reorganized into an alternative taxonomy of 5 primary categories. This taxonomy can be used to develop a dynamic list of specific metrics and their applications that would serve the UAS industry.

The final question regards types of data that contribute to safety cases that are routinely collected. With few exceptions, the FAA Test Sites and IPP/Beyond lead participants that responded are comprehensive in their data collection. Exceptions include data regarding security and communication processes, which are not surprising given that these are likely not viewed as safety critical as other types of data.

Additional details on this interview study with FAA test sites and IPP programs are available in Supplement F.

4.0 PHASE 2. FORECAST FUTURE SCOPE OF SUAS OPERATIONS

Phase 2 focused on developing a forecast regarding future sUAS activity and the factors that are likely to influence the rate at which UAS activities are likely to progress in the future given dependencies on things such as technology development and regulation. Supplement B provides a more detailed discussion of the methods and results of Phase 2.

4.1 System Wide Forecast 1: Total Commercial/Non-Model Fleet – 2020-2025

At the beginning of each fiscal year, the FAA produces an FAA Aerospace Forecast report. These reports are developed to support budget and planning needs of the FAA. Forecasts presented within these reports are developed using statistical models that capture emerging aviation industry trends. In the FAA's 2021 Aerospace Forecast report titled, *FAA Aerospace Forecast Fiscal Years 2021-2041*, a forecast was presented on the total number of commercial/non-model sUAS units (Federal Aviation Administration, 2021). Using trends in previous years of commercial/non-model sUAS aircraft registration, review of industry forecasts, and internal market/industry research, the FAA generated the 5-year forecast presented in Table 3. It is important to note that this forecast predicts the number of aircraft units, not the number of flights. This forecast predicts that under the base scenario, from 2020 to 2025, commercial sUAS units will likely increase 1.7 the original base in 2020 (825 units/488 units).

Table 3. FAA sUAS Commercial Fleet Size Fiscal Year Forecast.

Total Commercial/Non-Model Fleet (Thousand sUAS Units)

Fiscal Year	Low	Base	High
Historical			
2020	488	488	488
Forecast			
2021	543	589	691
2022	569	665	871
2023	583	729	1,028
2024	601	784	1,094
2025	614	835	1,144

4.2 System Wide Forecast 2: University of Alabama – Huntsville (UAH) Extrapolation of Total Commercial/Non-Model Fleet

Referencing the FAA forecasted data, the UAH team calculated percentage differences between each of the five years for the low, base, and high forecasted U.S. total commercial sUAS fleet size. These percentage differences were plotted over each of the time intervals. Based on the behavior of the graphs, a decaying exponential function was selected for data fitting. Using the curve fitting function in MS Excel, an exponential equation was derived for percentage differences associated with the low, base, and high forecasted sUAS commercial units. Using these equations, the forecast was extended over an additional 7 years to 2032 for the low, base, and high forecast. This forecast was created by curve fitting the FAA projected total commercial fleet size data. These data were to be used as a helpful reference for the Subject Matter Experts (SMEs) to answer the interview questions. UAH's extrapolated forecast is offered in Table 4. The UAH team extended the FAA forecast through the years 2026, 2028, 2030, and 2032. These forecasts are based on the following assumptions:

1. Data was calculated based on the trends observed in the FAA sUAS total commercial/non-model fleet size.
2. As the present base (i.e., the cumulative total) increases, the FAA anticipates the growth rate of the sector will slow down over time (Federal Aviation Administration, 2021).
3. The UAH team did not make any adjustments to the total number of commercial/non-model fleet size forecast based on future technology availability and future FAA-specified procedures/regulations.

Curve fitting the percentage difference generates a more conservative (i.e., lower) estimate than a logarithmic or linear fit of the FAA forecasted number of sUAS units for each year. For example, a linear extension of the FAA's forecast would estimate nearly 1330-thousand commercial sUAS units by 2032 instead of 975-thousand produced by the conservative extrapolation. A more conservative estimate was favored based on the following assumptions:

1) The FAA anticipates the growth rate of the sector to slow down over time (Federal Aviation Administration, 2021).
2) Aircraft will be retired over time.

Based on this analysis, the UAH team projects that the total U.S. commercial/non-model sUAS fleet size in the base scenario will have likely doubled within 12 years relative to 2020.

Table 4. Projected sUAS Commercial Fleet Based on an Exponential Curve Fit (FY 2026-2032)

Forecasted Total Commercial/Non-Model Fleet Size (Thousand sUAS Units)

Fiscal Year	Low	Base	High
2026	622	873	1160
2028	631	925	1174
2030	637	957	1178
2032	640	975	1180

4.3 Converging Evidence on System Wide Forecast

In the preceding two subsections, information has been provided regarding system wide forecasts of UAS commercial/non-model fleet size. In order to collect converging evidence by comparing these estimates with forecasts based on SME estimates, a study was designed to elicit Subject Matter Expert (SME) judgments regarding a system wide forecast for sUAS activity as well as more specific forecasts focused on different mission types and different classes of airspace. The UAH team developed a set of interview questions that were designed to provide specific insights into sUAS operations in the NAS (including expanded and non-segregated sUAS operations). Questions within this expert elicitation prompted participants to provide inputs related to sUAS traffic volume, aircraft configurations, airspace classes occupied, and specific expanded and non-segregated sUAS operations in the NAS.

4.3.1 Method

The UAH team identified and contacted 15 sUAS SMEs. Individuals invited included SMEs working in academia, industry, and for the FAA. These individuals were invited to participate and were sent the expert elicitation, which is contained in Supplement B.

4.3.2 Converging Evidence: Results and Conclusions

Four participant responses are described below (two from academia – individuals whose academic research focus is on UAS and two individuals from industry – an individual from an international aircraft services company which offers solutions to a wide variety of air transportation and related service needs and an large international company that offers consulting services, including financial advice and risk management with a focus on UAS operations). One significant finding was the judgment by four other of the invited SMEs who responded to the elicitation by indicating that they did not feel qualified to make the types of forecasts requested in the elicitation. Each of these other four respondents shared a concern that there are too many uncertainties associated with the numerous factors that will determine future sUAS activity. An additional common concern expressed by these four respondents focused on their specific expertise. They indicated that their expertise was only in a subset of the sUAS arena; therefore, they were unequipped to address nationwide sUAS trends.

Within the elicitation, the four SMEs who did provide input were prompted to provide a specific sUAS operations scaling factor indicating their forecasts relative to an extrapolation of FAA forecasts. The results for the average scaling factor across the SMEs for the 8-year future prediction is provided below in Table 5. The resultant forecast was an average in 2024 of 1,019,200 daily flight operations and an average number of daily flight operations in 2032 of 2,730,000. Given the small sample size, however, additional data collection is recommended to increase the precision of these estimates.

Table 5. Average SME Responses for Question 1.

Fiscal Year	Scaling Factor [Daily Ops/ sUAS]
2024	1.3
2026	1.5
2028	2.0
2030	2.4
2032	2.8

In regard to questions surrounding specific types of expanded and non-segregated operations such as whether the operations are controlled from a moving vehicle, include flights over 400ft AGL, or are over moving vehicles (Questions 2-6 as found in the Phase 2 report in Supplement B), it appears as though one of the respondents (Response 2) provided information as it applied specifically to their organization's commercial sUAS operations for some of the more detailed questions. Therefore, responses to these questions were treated separately in the analysis of responses to Questions 2-6.

Questions 7 and 8 as indicated in the Phase 2 report in Supplement B were specifically developed to provide responses to the categories of aircraft and classes airspace involved in future expanded and non-segregated sUAS operations. Upon review of the answers provided by the four SMEs, unfortunately multiple responses had to be flagged. Flagged responses are listed below.

- Response 1 Question 7: Provided percentage inputs for types of aircraft configurations per fiscal year over 100%. (For calculations, estimates were normalized to reflect a total sum of 100%.)
- Response 2 Question 7: Gives the impression to have provided answers specifically related to their organization's operations.
- Response 2 and 3 Question 8: Appear to have provided answers specifically related to their organizations' operations.

Table 6 provides the average of the responses for Question 7: What percentage of the total commercial sUAS usage will the following aircraft configurations be utilized in the fiscal year specified?)

Table 6. Average SME Responses for Question 7: What percentage of the total commercial sUAS usage will the following aircraft configurations be utilized in the fiscal year specified? (Based on Responses 1, 3 and 4).

Fiscal Year	**Rotorcraft/Multirotor [%]**	**Fixed Wing [%]**	**Hybrid VTOL [%]**
2024	53	30	13
2026	49	27.9	23.1
2028	44.1	25.9	30
2030	40.5	26.1	33.4
2032	38	23.3	38.7

Upon assessment of the responses provided by SMEs for Question 8, Class G airspace is expected to experience the majority of expanded and non-segregated sUAS operations. However, SMEs project that over time all classes of airspace will be involved in such operations. This projection is certainly within reason as sUAS have the potential to emerge as solutions in day-to-day airport operations (i.e., fence and runway inspection). Additionally, UAS Service Supplier (USS) have made the process of receiving LAANC and Air Traffic Control authorization to operate in controlled airspace more accessible. Class E airspace is expected to have the second largest occupation of commercial sUAS operations. This could be within reason if it is assumed that operations involving sUAS inspection of structures with a maximum height greater than 300 feet above ground level are expected to experience large market growth. An average numerical value of the responses provided by Response 1 and Response 4 for Question 8 are provided in Table 7.

Table 7. Average Projected Expanded and Non-Segregated sUAS Operations Airspace Class Occupation (Question 8: Estimate the percentage (of total flight hours) by category of airspace where you believe these sUAS operations will occur in the corresponding fiscal years.) (Responses 1 and 4).

Fiscal Year	B [%]	C [%]	D [%]	E [%]	G [%]
2024	0	0	1.0	11.5	87.5
2026	1.0	2.5	3.5	12.0	81.0
2028	1.5	3.5	5.0	14.0	76.0
2030	2.0	4.0	7.0	21.0	66.0
2032	2.5	5.0	9.0	22.5	61.0

4.4 Extrapolations from Phase 1 Data Set

Figure 27 shows a times series forecast for the number of BVLOS operations for 2021-2025 based on the Phase 1 data reflecting the historical growth trend. (See Final Report Supplement A for details.) It was concluded, however, that while such a forecast is interesting as one source of input, there are a large number of factors that could influence future activity, suggesting caution when using current trend data to predict the future. Thus, the primary approach taken in Phase 2 was to make use of the collective knowledge and opinions of known experts in relevant areas of industry, academia, and government through online structured interviews. To make the process efficient and consistent from one participant to another, an on-line software application called PASAUT was developed to conduct the interviews.

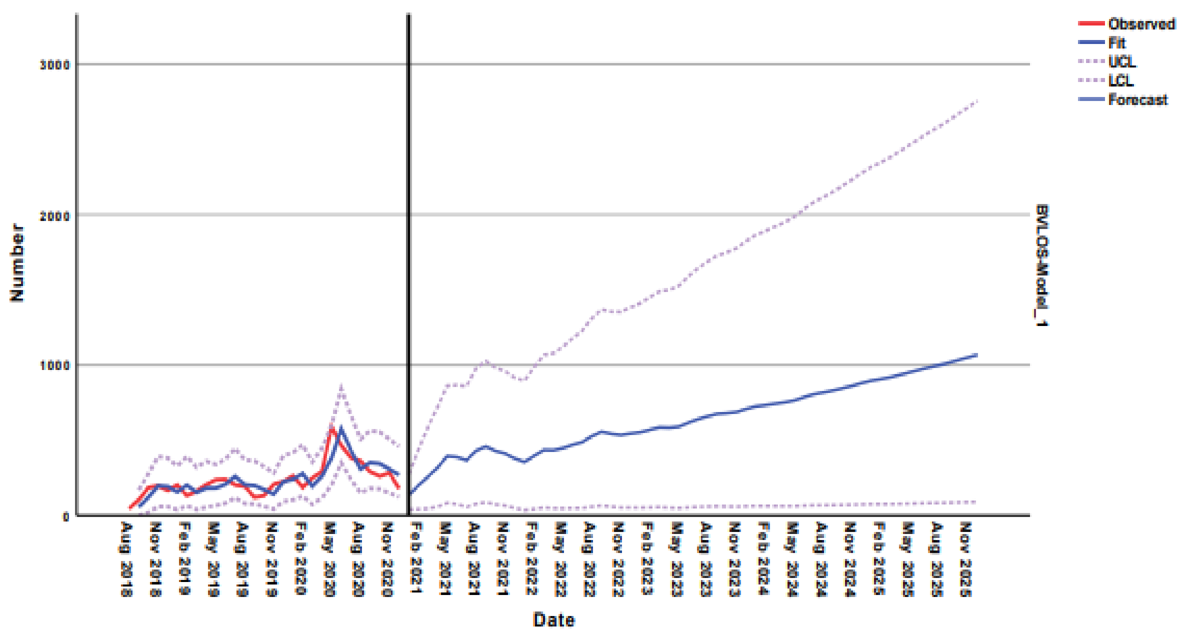

Figure 27. Phase 1 Extrapolation: Number of BVLOS Operations.

4.5 SME Forecast for the Maturation of Enabling Technologies and Standards

Given the hesitancy of a number of the SMEs who were solicited to provide system-wide forecasts in the interview study described in Section 3.3, another interview study was conducted with more narrowly focused questions. The expectation was that a greater number of SMEs would feel comfortable providing responses to these more narrowly focused questions that dealt with the impacts on sUAS activity of the future maturation of specific technologies, as well as the maturation of standards and regulations to provide greater clarity in terms of approval for sUAS operations.

4.5.1 Method

The UAH team interviewed a collection of industry, academia and government experts focused on aviation with the large majority being in the UAS area. Their expertise crossed the boundaries of pilots, developers, researchers, and regulators. To make the process efficient and consistent from one participant to another, an on-line software application called PASAUT was developed to conduct the interviews.

A list of 68 technologies and influencing concepts (such as regulatory items, standards, and FAA initiatives) that could affect the integration of UAS into the NAS was defined. This list was formulated over time through multiple discussions with the FAA representatives and ASSURE team members in A21 technical interchange meetings. 499 invitations were sent requesting individual SMEs to participate in the research. Each responding participant was assigned several[2] of the 68 areas representing different technologies and influencing concepts based on their known areas of expertise.

One challenge in a standardized interview process is developing questions that are universal enough to be applied to the broad spectrum of characteristics of the topics that have been defined. The team decided to use a scalar system, eliciting ratings on a range of possible factors for categories in which such a scaled approach could be applied to all the technologies and influencing concepts in all 9 categories (see Table 10). After substantial brainstorming, the final evaluation factors and their categories were delineated as seen in Table 8.

Table 3. Standardized Evaluation Factors and Their Categories.

Technical Factors	Enabling/Hindering Factors	Timeframe Factors
Difficulty of Development	Regulatory Hurdles	Estimate of Initial Technology Availability
Urgency of Need	Ease of Commercialization	Estimate of First Use in UAS
Scale of Market Impact	Public Opinion	Estimated Level of Uncertainty
Availability of Consituent Technologies	Environmental Considerations	
Ease of Integration/Testing	Infrastructure Considerations	
	Political Resistance/Acceptance	
	Impact of NPRMs	

Each of the standardized evaluation factors was translated into a question that could be answered with a numerical ranking. The questions were carefully worded to ensure that a lower number represented an easier (earlier) path to incorporation, whereas a higher score represented a more challenging (and likely therefore later) introduction into a standard operating environment. For

[2] In most cases, the number of topics assigned to any single SME was limited to eight in consideration of the time required and the fact that no compensation was being provided. The UAH research team felt that this would take no longer than one hour of the SME's time.

any question that required a timeframe, we allowed the SMEs to provide specific dates and ranges in their responses. These questions are presented in Table 9.

Table 4. The Questions which Evolved Out of Their Related Evaluation Factors.

Factors	Question: In all cases, higher score = more difficult, longer range, delaying; Lower score = easier, nearer-term, accelerating
Difficulty of Development	Rate the difficulty of bringing this technology to maturity on a scale of 1-10, with 10 being the most difficult.
Urgency of Need	Rate the urgency of using this technology to serve society's needs on a scale of 1-10, with 10 being the least urgent.
Scale of Market Impact	Rate the expected impact of this technology when mature on the UAS industry with 1=Small market impact, 5=Moderate market impact, 10=significant or substantial market impact
Availability of Consituent Technologies	Rate the availability of the technology components needed to bring this technology to maturity with 1 being currently available and 10 being the least available.
Ease of Integration/Testing	Assuming this technology has reached maturity, rate the ease of integrating and testing it in a UAS on a scale of 1-10. 1 is the easiest; 10 is the most difficult.
Regulatory Hurdles	For the selected technology, rate anticipated regulatory challenges required before it can be regularly available on a 1-10 scale. 1 is the easiest; 10 is the most difficult.
Ease of Commercialization	For the selected technology, rate anticipated commercialization challenges required before it can be regularly available on a 1-10 scale. 1 is the easiest; 10 is the most difficult.
Public Opinion	For the selected technology, rate anticipated public opinion (acceptance or resistance) affecting its regular availability on a 1-10 scale. 1 is acceptance; 10 is resistance.
Environmental Considerations	For the selected technology, rate anticipated environmental challenges required before it can be regularly available on a 1-10 scale. 1 is the easiest; 10 is the most difficult.
Infrastructure Considerations	For the selected technology, rate anticipated infrastructure development challenges required before it can be regularly available on a 1-10 scale. 1 is the easiest; 10 is the most difficult.
Political Resistance/Acceptance	For the selected technology, rate anticipated political challenges required before it can be regularly available on a 1-10 scale. 1 is the easiest; 10 is the most difficult.
Impact of NPRMs	For the selected technology, rate anticipated impact of Notices of Public Rulemaking (NPRMs) required before it can be regularly available on a 1-10 scale. 1 is the least impact; 10 is the most impact.
Estimate of Initial Technology Availability	What year do you estimate that this technology will first reach maturity?
Estimate of First Use in UAS	What year do you estimate that this technology will first be used operationally in a UAS?
Estimated Level of Uncertainty	For you previous estimate, please estimate your level of uncertainty: +/- (X) Months.

Having identified an SME, the team attempted to assign technologies that aligned with their area of expertise. For example, if a specific SME was recognized as a propulsion expert, they might be likely to be assigned Alternative Power, as well as Vectored Propulsion - Thrust Vector Control. The remaining technologies assigned would be generally aligned with or peripheral to their primary expertise.

For individuals who were generalists or for whom the research team might not be able to identify the primary area(s) of expertise, researchers assigned topics that needed evaluations to keep the overall numbers of evaluations in balance. To assist in this process, the team designed the technology assignment screen in PASAUT to display the number of evaluators already assigned to each technology.

Following discussions addressing the analysis of data, the research team refined the list and its defining categories, resulting in 68 technologies and influencing concepts organized into 9 categories as shown in Table 10.

Table 10. Technologies and Influencing Concepts by Category.

Aerodynamics/ Performance	Data/ Comm/ Security	Materials	Operations/ Flight	Power	Regulation	Research/ Design/ Systems	Sensors/ Imagery	Supply Chain/ Manufacturing
Adaptive Aerostructures	6G	Aluminum/Aluminum Alloys	Autopilots/Flight Control Systems (FCS)	Alternative Power	BLOS	ASSURE	3D Scanning	3D Printing/Additive Manufacturing
Autonomy Expert Systems	Cyber Security	Composites	Brain Control	Battery Management	BVLOS	Business Case Tool Sets	Advanced Sensing	Rapid Build
Beyond Aerodynamic Maneuvers (Supermaneuverability)	First Net	Conductive Inks	Gesture Control	Wireless Power	Certification	CONOPS Driven	Augmented Reality	Robotic Builds
Machine Learning	IOT Convergence	Metamaterials	GPS Denied		Integration Pilot Program (IPP)	Integrators	Off-board Sensors	Seamless Suppliers
Morphing Materials	Live Map	Plastics	LAANC		Notice of Proposed	Miniaturization	Radar	U.S. Only
Non Deterministic Approach	LVC	Resins	On-Board Autonomy		Part 135	Model Based Systems Engineering	Sensors	
Vectored Propulsion - Thrust Vector	Mesh Networks		Rapid Deployment		Remote ID	NanoTech	Smart Dust	
	Micro Clouds		Run Time Assurance		RTCA Standards: DO-178B - Software Considerations in Airborne	Singularity		
	Multi-Threading		Swarm		RTCA Standards: DO-254 - Design Assurance Guidance for Airborne	Virtual Prototyping		
			Transforming Robotics					
			UAS Service Suppliers (USS)					
			UAS Traffic Management					
			Vision-Based Navigation					

Each of the 66 participants was assigned several of the 68 technologies and influencing concepts areas based on known areas of expertise. The series of standardized questions, shown in Table 9, was used to elicit the opinions of the experts as applied to each of their assigned subjects.

4.5.2 Results – Maturation Forecast

This knowledge elicitation exercise was very successful in providing some important insights regarding:

- What are the most urgent needs in terms of technology advances and the development of standards and regulations by the FAA and standards organizations in order to allow the sUAS industry to progress?
- In addition to technology and regulatory factors, what are other important enabling or hindering factors such as political resistance or acceptance that need to be addressed in order to allow the sUAS industry to progress?
- When are the limiting factors for the development or use of a particular technology or operation expected to be sufficiently addressed for the relevant mission/market to progress?

- What is the expected market impact associated with the development or use of a particular technology or operation once the limiting factors have been addressed?

Below are the detailed responses for one technology (3D printing/additive manufacturing) and one class of UAS operations (BVLOS). These sample assessments are described as illustrations of how to interpret the results received. The responses for all of the other technologies and influencing concepts are contained in the Phase 2 report in Supplement B.

<u>3D-Printing/Additive Manufacturing</u>. Figure 28 and the associated text indicate the average ratings for each of the questions associated with this technology as defined below.

> *Additive manufacturing (AM), also known as 3D printing, is a transformative approach to industrial production that enables the creation of lighter, stronger parts and systems. It is yet another technological advancement made possible by the transition from analog to digital processes. In recent decades, communications, imaging, architecture, and engineering have all undergone their own digital revolutions. Now, AM can bring digital flexibility and efficiency to manufacturing operations. Additive manufacturing uses data, computer-aided-design (CAD) software, or 3D object scanners to direct hardware to deposit material layer upon layer in precise geometric shapes. As its name implies, additive manufacturing adds material to create an object. By contrast, when you create an object by traditional methods, it is often necessary to remove material through milling, machining, carving, shaping or other means. Although the terms "3D printing" and "rapid prototyping" are casually used to discuss additive manufacturing, each process is actually a subset of additive manufacturing (General Electric [GE], 2021).*

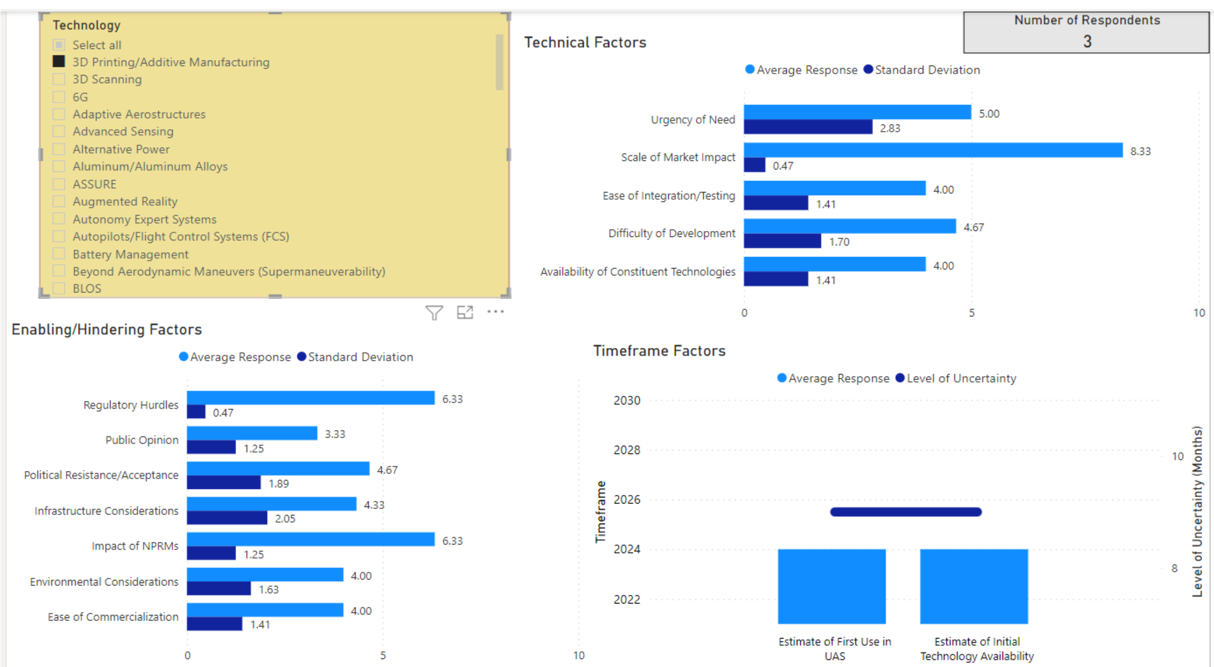

Figure 28. 3D Printing Responses.

Technical Factors

- **Urgency of Need:** Moderately Urgent
- **Scale of Market Impact:** Substantial Impact
- **Ease of Integration/Testing:** Moderately to Easy Integration
- **Difficulty of Development:** Moderate Difficulty
- **Availability of Constituent Technologies:** Mostly Available

Enabling/Hindering Factors

- **Regulatory Hurdles:** Substantial Regulatory Hurdles
- **Public Opinion:** Somewhat Acceptable
- **Political Resistance/Acceptance:** Moderate Political Challenges
- **Infrastructure Considerations:** Moderate Infrastructure Challenges
- **Impact of NPRMs:** Substantial NPRM Impact
- **Environmental Considerations:** Low to Moderate Environmental Concerns
- **Ease of Commercialization:** Low-Moderate Commercialization Challenges

Timeframe Factors

- Average Projected Times (Year ± Uncertainty):
    - **Estimated First Use in UAS:** January 1, 2024 ± 9 months
    - **Estimate of Initial Technology Availability:** January 1, 2024 ± 9 months

BVLOS. Figure 29 and the associated text indicate the average ratings for each of the questions associated with this regulatory factor.

> *Unmanned aircraft flying beyond an operator's visual line-of-sight present unique challenges to the FAA's existing regulatory framework. Most aviation regulations that would apply to UAS operations besides Part 107 assuming the aircraft has an onboard pilot who is responsible for avoiding other aircraft. Not only do UAS lack an onboard pilot, but even a remote pilot pushes the boundaries of the traditional regulatory role of a pilot. However, the UAS capability to fly without the pilot onboard and beyond the pilot's visual line-of-sight (BVLOS) is what offers the most economic and societal benefits. Today, companies, communities, and industrial sectors are eager to realize these benefits and have invested substantial resources developing UAS technologies. The FAA's existing regulatory framework must change to better support the long-term viability and sustainability of this evolving aviation sector. However, these are challenges the entire UAS community must confront together, because they have implications not only to safety, but also security and society at large. The FAA recognizes the significant safety, economic, and environmental value associated with BVLOS unmanned aircraft operations. Over the past five years, the FAA has engaged in multiple pilot programs and partnership arrangements – including the UAS Integration Pilot Program (IPP), Partnership for Safety Plans (PSPs), and currently BEYOND – to further both the Agency's and stakeholder community's collective understanding of the minimum performance criteria for safe BVLOS operations. The UAS BVLOS ARC will consider the various lessons and insights gained from these and other activities to inform the FAA on performance-based criteria to enable safe, scalable, economically viable, and environmentally advantageous BVLOS operations in the NAS (U.S. Department of Transportation Federal Aviation Administration (2021).*

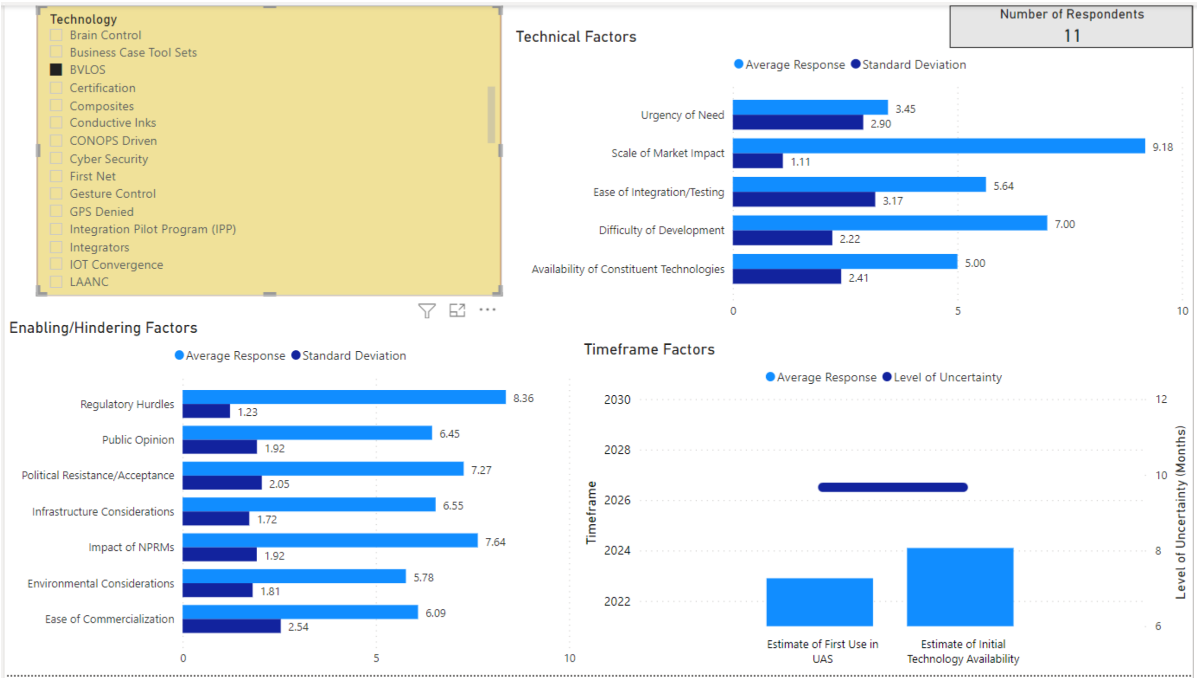

Figure 29. BVLOS Responses.

Technical Factors

- **Urgency of Need:** Quite Urgent
- **Scale of Market Impact:** Substantial Impact
- **Ease of Integration/Testing:** Moderately Difficult to Integrate
- **Difficulty of Development:** Substantially Difficult
- **Availability of Constituent Technologies:** Somewhat Available

Enabling/Hindering Factors

- **Regulatory Hurdles:** Serious Regulatory Hurdles
- **Public Opinion:** Somewhat Unacceptable
- **Political Resistance/Acceptance:** Substantial Political Challenges
- **Infrastructure Considerations:** Moderate to High Infrastructure Concerns
- **Impact of NPRMs:** Substantial NPRM Impact
- **Environmental Considerations:** Moderately Concerned Regarding Environmental Issues
- **Ease of Commercialization:** Significant Commercialization Challenges

Timeframe Factors

- Average Projected Times (Year ± Uncertainty):
  - **Estimated First Use in UAS:** Average=329th day of 2022 ± 9.67 months
  - **Estimate of Initial Technology Availability:** Average=37th day of 2024 ±9.67 months

Similar detailed results are presented for all 68 factors in the Phase 2 report in Supplement B.

Urgency of Need. Figure 30 indicates the average ratings for each of the technologies and influencing concepts regarding urgency.

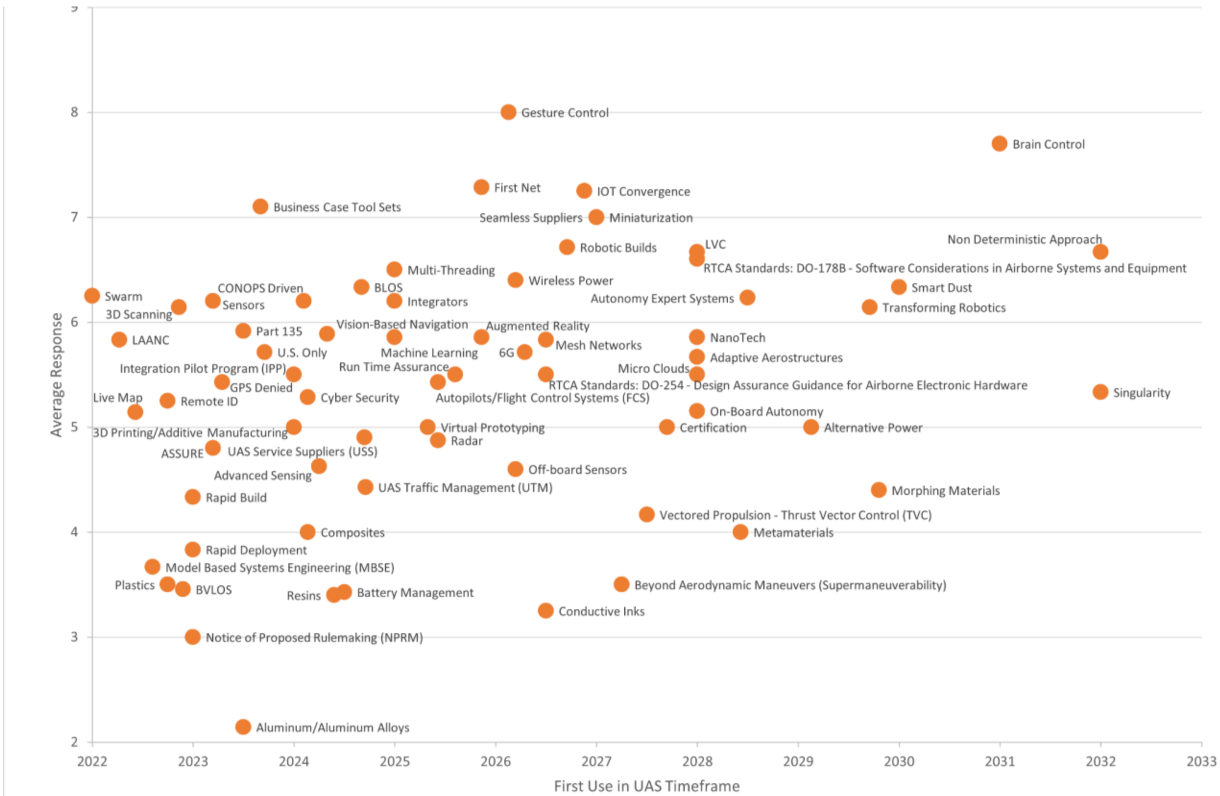

Figure 30. Urgency of Need for Each of the Technologies and Influencing Concepts **(**First Use in UAS Timeframe=Average rating from expert interviews on a scale from 1-10; Average Response: Low value=More urgent need; High value=Less urgent need).

Difficulty of Development. It makes sense to assume that those technologies and influencing concepts with the highest difficulty of development are likely to take longer to reach first use or introduction into non-segregated air space. Looking at Figure 31 from a distance reveals a distinct line of data points that aligns from lower left to upper right, just as we would expect based on the definition of the axes.

The results indicate that the respondents ranked Brain Control, Transforming Robotics, Smart Dust, Singularity, Nano Tech, Alternative Power, Certification, Machine Learning, On-Board Autonomy, Autonomy Expert Systems, and Cyber Security as the eleven most difficult items to develop. With the exception of Certification, these all involve complex software development and equally challenging hardware/software interfaces that will need to be fail safe. It makes sense that the SMEs consensus opinion is that these items will not be realized until between 2025 and 2032.

Some of the influencing technologies and concepts provided interesting results as they possess the unlikely combination of a high difficulty of development combined with a relatively short-term forecast of first use. These outliers include technologies and concepts like vision-based navigation and BVLOS. This likely reflects a perception by the respondents that these areas are getting a great deal of focus and effort.

It is beneficial to seek out those items that have a high difficulty of development along with a short-term forecast first use but not already in use. These include Cyber Security (an on-going evolutionary introduction), Vision-Based Navigation, Machine Learning, (Beyond Line Of Sight (BLOS), Integrators, UAS Traffic Management (UTM), Multi-Threading, and Run Time Assurance. These are items that may require specialized attention on the part of the FAA with regard to guidance and regulation.

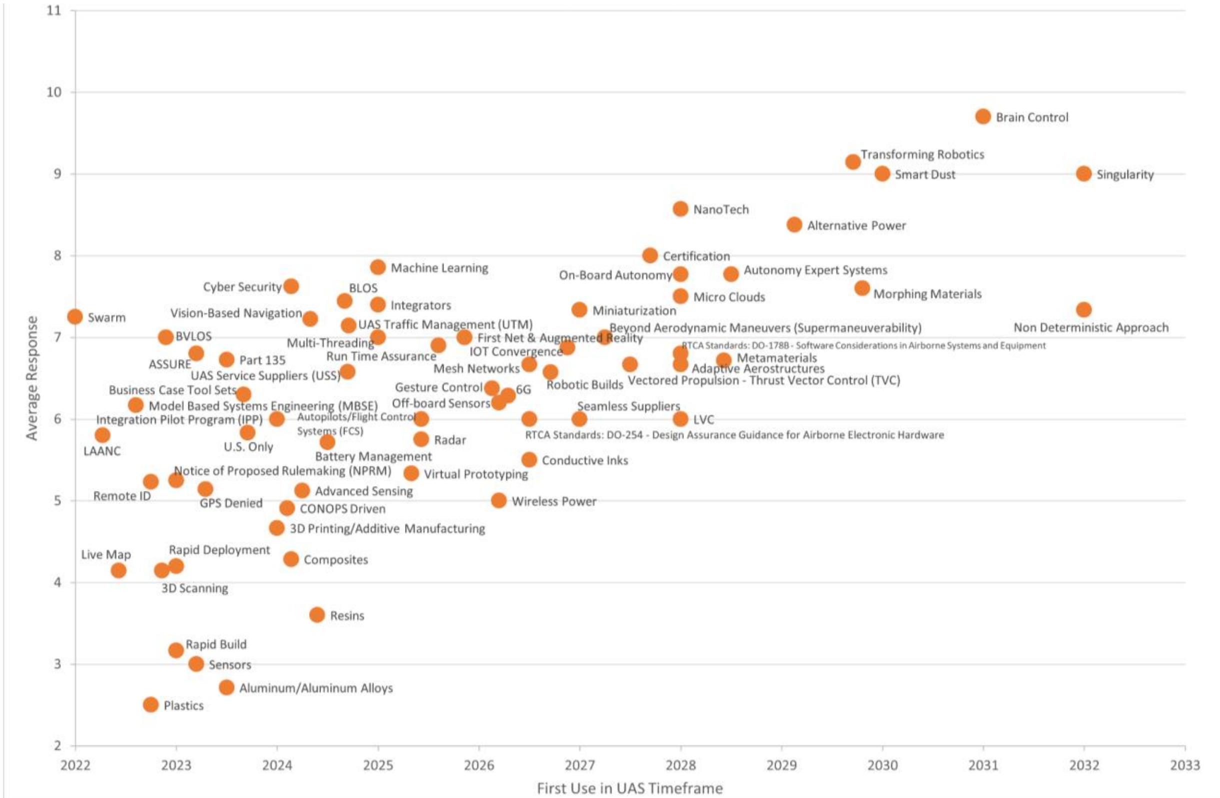

Figure 31. Difficulty of Development vs. Estimated First Use Scatter Chart.

Scale of Market Impact. Figure 32 indicates that there are many factors or hindrances that, once dealt with, will have a significant impact on the market. This suggests that the increase in sUAS activity will not be a simple linear increase over time but will be a series of step functions.

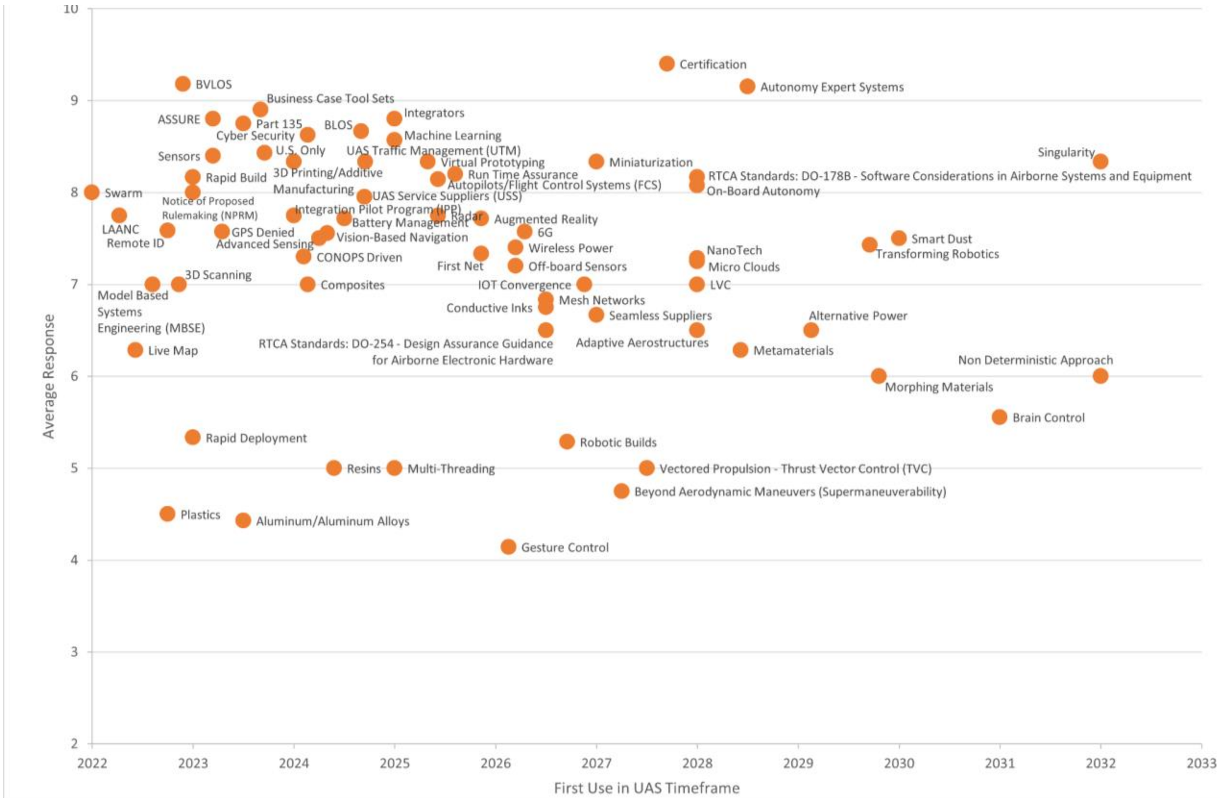

Figure 32. Market Impact vs. Estimated First Use Scatter Chart.

Similar graphs are provided the Phase 2 report in Supplement B for other broad dimensions.

4.5.3 Forecast of Market Impact

The results of this knowledge elicitation exercise also provide a qualitative estimate of break points when a critical factor has been adequately addressed, resulting in an increase in the rate of growth in sUAS activity. The knowledge elicitation data provide the following forecasts for the different critical factors in terms of the expected time frame for an impact on sUAS activity and the size of the market impact. Here the UAH team addresses each of the 68 UAS influencing technologies and concepts involved in the Maturation Forecast of Enabling Technologies and Standards. The expected year presented in Table 10 is either the estimated first use in UAS or estimate of initial technology availability (provided by SMEs in knowledge elicitation) depending on which date was the furthest in the future. A "two-year buffer" period was added to the final date selected. It is likely that widespread increase in sUAS activity as a result of the maturation of some hindrance will take some time once a critical factor has been addressed; therefore, the actual market impact may be seen closer to a couple of years after maturation. This assumption is congruent throughout the results presented in the subsequent sections. If an influencing technology or concept has already matured (i.e., ASSURE, LAANC, Part 135, USS, and IPP/BEYOND) the timeframe factor was dropped from the analysis.

4.5.3.1 Market Forecast for 68 Influencing Technologies and Concepts

Table 11 provides a market forecast for the 68 influencing technologies and concepts based on market impact and expected year of maturity. Out of the 22 influencing technologies and concepts that were scored as having a substantial effect on the UAS market, 10 or 45.45% were predicted to mature by the year 2027 and 20 or 90.9% were forecasted to have their critical factors addressed by 2030. Therefore, it can be reasonably assumed that an increased volume of UAS activity will occur in this timeframe.

Table 11. Market Forecast for 68 Influencing Technologies and Concepts.

Category	# Participants	Market Impact	Expected Year	Uncertainty
3D Printing/Additive Manufacturing	3	Substantial	2026	± 9 Months
3D Scanning	7	Above Moderate	2025	± 7 Months
6G	7	Above Moderate	2028.29	± 9.86 Months
Adaptive Aerostructures	6	Above Moderate	2030	± 11 Months
Advanced Sensing	8	Above Moderate	2026.25	± 9.75 Months
Alternative Power	8	Above Moderate	2031.13	± 13.71 Months
Aluminum	7	Moderate	2025.5	± 8 Months
ASSURE	5	Substantial		
Augmented Reality	7	Above Moderate	2028.71	± 10.5 Months
Autonomy Expert Systems	13	Substantial	2031.5	± 12 Months
Autopilots/Flight Control Systems	7	Substantial	2029.14	± 10.2 Months
Battery Management	7	Above Moderate	2026.5	± 6 Months
Beyond Aerodynamic Maneuvers	4	Moderate	2029.25	± 12 Months
BLOS	9	Substantial	2027	± 12 Months
Brain Control	10	Moderate	2033	± 13 Months
Business Case Tool Sets	10	Substantial	2026.33	± 12.75 Months
BVLOS	11	Substantial	2026.1	± 9.67 Months
Certification	10	Substantial	2029.7	± 13.33 Months
Composites	7	Above Moderate	2026.14	± 7.2 Months
Conductive Inks	4	Above Moderate	2028.5	± 10.5 Months
CONOPS Driven	11	Above Moderate	2027.3	± 11.4 Months
Cyber Security	8	Substantial	2026.14	± 14 Months
First Net	7	Above Moderate	2027.86	± 11.5 Months
Gesture Control	8	Moderate	2029.25	± 10.5 Months
GPS Denied	7	Above Moderate	2026.14	± 9 Months
IPP/BEYOND	4	Above Moderate		
Integrators	5	Substantial	2027.75	± 14 Months
IOT Convergence	8	Above Moderate	2028.88	± 12.75 Months
LAANC	12	Above Moderate		
Live Map	7	Above Moderate	2026.57	± 8.14 Months
LVC	3	Above Moderate	2030	± 11 Months
Machine Learning	7	Substantial	2027.43	± 9.86 Months
Mesh Networks	6	Above Moderate	2028.5	± 9.5 Months
Metamaterials	7	Above Moderate	2030.43	± 13.71 Months

Micro Clouds	4	Above Moderate	2030	± 12 Months
Miniaturization	3	Substantial	2030	± 16 Months
MBSE	7	Above Moderate	2026.5	± 8.5 Months
Morphing Materials	5	Moderate	2031.8	± 14.4 Months
Multi-Threading	2	Moderate	2027	± 12 Months
Nano Tech	7	Above Moderate	2030	± 12.86 Months
Non-Deterministic Approach	3	Moderate	2034	± 15 Months
NPRM	5	Above Moderate		
Off-Board Sensors	5	Above Moderate	2030	± 10.2 Months
On-Board Autonomy	13	Substantial	2030	± 12 Months
Part 135	12	Substantial		
Plastics	8	Moderate	2024.86	± 5.4 Months
Radar	8	Above Moderate	2027.43	± 7 Months
Rapid Build	6	Substantial	2025	± 7.5 Months
Rapid Deployment	6	Moderate	2025	± 7.5 Months
Remote ID	12	Above Moderate		
Resins	5	Moderate	2026.4	± 8.25 Months
Robotic Builds	7	Moderate	2029.14	± 12 Months
DO178	6	Substantial	2030	± 12 Months
DO254	5	Above Moderate	2028.5	± 11.25 Months
Run Time Assurance	10	Substantial	2027.6	± 10.8 Months
Seamless Suppliers	6	Above Moderate	2029	± 14.4 Months
Sensors	5	Substantial	2025.2	± 4.8 Months
Singularity	3	Substantial	2034	± 5 Months
Smart Dust	4	Above Moderate	2031	± 16 Months
Swarm	4	Above Moderate	2029.25	± 10.5 Months
Transforming Robotics	7	Above Moderate	2032.14	± 17 Months
U.S. Only	7	Substantial	2027.86	± 11.57 Months
USS	20	Above Moderate		
UTM	21	Substantial	2026.86	± 11 Months
Vectored Propulsion	6	Moderate	2029.5	± 10.8 Months
Virtual Prototyping	9	Substantial	2027.33	± 9 Months
Vision-Based Navigation	9	Above Moderate	2027.33	± 9 Months
Wireless Power	5	Above Moderate	2028.2	± 16.8 Months

5.0 Phase 3. DEVELOPMENT OF A QUANTITATIVE FRAMEWORK FOR THE ASSESSMENT OF THE RISK ASSOCIATED WITH THE OPERATION OF SUAS

Phase 3 defines a quantitative risk-based framework for making risk-based decisions for inclusion in the SMS process that applies to the operation of sUAS. Below is a summary of the methods and key findings of Phase 3. Complete details are available in Supplements C-E along with cited references.

5.1 Summary of Phase 3 Findings

In June 2018, NASEM released its report "Assessing the Risks of Integrating Unmanned Aircraft Systems (UAS) into the National Airspace System." They concluded that the FAA approach to risk management is currently based on a qualitative, subjective risk assessment that should evolve to incorporate a quantitative probabilistic risk analysis to support decision making. The development of such a quantitative framework is further guided by Section 345 ("Small Unmanned Aircraft Safety Standards") of Public Law 115-254 (https://www.congress.gov/115/plaws/publ254/PLAW-115publ254.pdf).

The reports provided in Supplements C-E provide complete details on the accomplishments of Phase 3 executed in response to this need as indicated by the National Academies. In general terms, these reports describe a clear and consistent process for a quantitative risk-assessment framework to guide the development of applications for sUAS operations. This framework is presented as one component of a broader SRMP. The discussion further indicates that such a quantitative assessment based on flight operations should be considered one component of a broader SRMP and indicates that there are other components of the broader Safety Risk Management (SRM) process that also need to be considered:

- Compliance with Category 4 described within the NPRM RIN 2120–AK85. Operation of Small Unmanned Aircraft Systems Over People (amendment of Title 14 of the Code of Federal Regulations part 107 (14 CFR part 107) by permitting the routine operation of sUAS at night or over people under certain conditions).
- Verification and validation of hardware and software supporting the safety functions integrated into the automation in order to demonstrate compliance with FAA certification requirements for automated flight control in BVLOS operations over people, including human factors design requirements. (Such certification requirements need to be further defined.)
- Documentation of an effective safety management system as an additional safety net.
- Proof of insurance.
- Continued demonstration of safe operations once a flight operation has been approved and is ongoing.

The underlying logic and the computational methods used to define this risk-based framework for the assessment of the risk associated with the operation of sUAS are described in detail in these Supplements. Their use is further illustrated through application to a realistic scenario. This illustration focuses on the use of flights (actual operations and flight tests) to evaluate the risks associated with automated control of a sUAS BVLOS over people.

This risk-based framework incorporates a blend of classical and Bayesian statistical methods to assess safety risks associated with a proposed flight operation using sUAS. This is demonstrated in Supplement C illustrating application of this framework using the scenario summarized in Table 12.

Table 12. Scenario Specifications and Parameters.

Category	Value
UAS type	Rotorcraft
UAS weight	10 kg
UAS maximum speed	65 km/hour (no wind)
Mission	Package delivery
Package weight	2 kg
Start location	Launch pad in urban area
Launch mode	Vertical from pad
Destination	Landing pad in an urban area
Landing mode	Vertical to pad
Route distance	5 km
Route duration	13-14 min
Route average speed	25 km/hour
Route altitude (A to B)	350 feet
Route altitude (B to A)	250 feet
Terrain type	Urban environment
Flight restrictions	Flight canceled or diverted if surface winds greater than 6 m/sec

In this illustration, it is assumed that a set of relevant flight data and parachute test data has been previously collected and archived, and that the waiver applicant chooses the run the minimum required number of additional tests on his proposed sUAS model and parachute.

These data are used to calculate probabilities, expected values, and confidence intervals for the possible outcomes of interest. Note that, since the goal of this report is to illustrate the quantitative framework, a conservative simplification was used to estimate the probability of having a significant impact on a pedestrian if the sUAS falls to the ground. It is assumed that if the sUAS falls vertically within a 2 meter by 2 meter area containing a pedestrian at its center, there is a significant impact and that the density of pedestrians in the area traversed by the sUAS is categorized as uniformly distributed over an urban area with low pedestrian density (4050 people per square mile as estimated in MITRE, 2018). The JARUS SORA (2019) draft Supplement F provides a much more precise method for estimating the probability of a significant impact that could be applied for actual applications of this framework.

In this example, the framework is applied to calculate the resultant expected values for the probabilities *with no parachute* for the two possible outcomes of interest. In the example that is presented, these expected values for these probabilities are calculated to be:

Probability of impact on pedestrian:	0.0000311963
Probability of impact on built environment:	0.00103988

The remaining possibility, i.e., no impact, holds the balance of the probability, i.e., one minus the sum of the two impact probabilities.

The 99.99999% confidence intervals *with no parachute* are:

Probability of impact on pedestrian:	[0, 0.000785506] (0 to 0.000785506)
Probability of impact on built environment:	[0, 0.00517659] (0 to 0.00517659)

Based on the use of the decision matrix described in this example analysis (see Figure 33), using the expected values for these probabilities leads to the conclusion that the proposed operation is MEDIUM risk (Minor consequence) for the built environment, and MEDIUM risk (Major consequence) for its potential impact on pedestrians.

Based on the use of the decision matrix described in this example analysis (see Figure 33), using the 99.99999% confidence intervals leads to the conclusion that the proposed operation remains LOW risk (Minor consequence) for the built environment, and MEDIUM risk (Major consequence) for its potential impact on pedestrians.

Note that these decisions are dependent on the categorizations used in this table and the assignment of a consequence level to an outcome for a particular operation, as well as assumptions about the probability of impacting a person or the built environment if the sUAS falls to the ground. (Draft Supplement F of the JARUS SORA (2019) provides a detailed method for evaluating the probability of impacting a person that could be used within this framework.)

Using similar computations, *if the sUAS is equipped with a parachute,* the expected values for these probabilities become:

Probability of impact on pedestrian:	0.0000004812
Probability of impact on built environment:	0.0000160391

The 99.99999% confidence intervals *if the sUAS is equipped with a parachute* are:

Probability of impact on pedestrian:	[0,0.0000943007] (0 to 0.0000943007)
Probability of impact on built environment:	[0,0.000557299] (0 to 0.000557299)

Thus, with a parachute, based on the use of the decision matrix described in this example analysis (see Figure 33), using the expected values for these probabilities leads to the conclusion that the proposed operation is LOW risk (Minor consequence) for the built environment, and LOW risk (Major consequence) for its potential impact on pedestrians

Based on the use of the decision matrix described in this example analysis (see Figure 33), using the 99.99999% confidence intervals when the sUAS is equipped with a parachute leads to the conclusion that the proposed operation is LOW risk (Minor consequence) for the built environment, and MEDIUM risk (Major consequence) for its potential impact on pedestrians.

Note again that these decisions are dependent on the categorizations used in this table and the assignment of a consequence level to an outcome for a particular operation, as well as assumptions about the probability of impacting a person or the built environment if the sUAS falls to the ground. (Again, draft Appendix F of the JARUS SORA, 2019, provides a detailed method for evaluating the probability of impacting a person that could be used within this framework.)

Note also that this integration of a parachute into the risk assessment illustrates more generally how analysis of the risk associated with a cascading series of events can be incorporated into a safety assessment.

Details regarding the supporting computations are in Supplement C.

> 7: Extreme risk
– detailed treatment plan required
6,7: High risk
– needs senior management attention and treatment plan as appropriate
4,5: Medium risk
– manager level attention and monitoring as appropriate
< 4: Low risk
– manage by local level procedures

	→ Consequence →					
People	Injuries or ailments not requiring medical treatment.	Minor injury or First Aid Treatment Case.	Serious injury causing hospitalisation or multiple medical treatment cases.	Life threatening injury or multiple serious injuries causing hospitalisation.	Multiple life threatening injuries. Less than 10 fatalities.	Multiple fatalities, 10 or more
Reputation	Internal Review	Scrutiny required by internal committees or internal audit to prevent escalation.	Scrutiny required by external committees or Auditor General's Office, etc.	Intense public, political and media scrutiny. Eg: inquest, front page headlines, TV, etc.	Government inquiry or Commission of inquiry or adverse national media in excess of 1 week.	Government inquiry and ongoing adverse international exposure
Organisational / Client impact	Small delay, internal inconvenience only.	May threaten an element of the service delivery function. Business objective delayed. Easily remedied, some impact on external stakeholders.	Considerable remedial action required with disruption to a Group for period up to 1 month. Some business objectives not achieved.	Significant loss of critical information. Disruption to one or more Groups for up to 3 months. Some major objectives not achieved.	Permanent loss of critical information, substantial disruption to CASA or external intervention for over 3 months. Threatens existence of a Group within CASA. Major objectives not achieved	Threatens ongoing existence of CASA.

Probability ↑	Numerical	Historical
	>1 in 10	Is expected to occur in most circumstances
	1 in 10 – 100	Will probably occur
	1 in 100 – 1000	Might occur at some time in the future
	1 in 1000 – 10000	Could occur but considered unlikely or doubtful
	1 in 10000 - 100000	May occur in exceptional circumstances
	< 1 in 100000	Could only occur under specific conditions and extraordinary circumstances

	Insignificant 0	Minor 1	Moderate 2	Major 3	Severe 4	Catastrophic 5
Almost Certain (5)	5	6	7	8	9	10
Likely (4)	4	5	6	7	8	9
Possible (3)	3	4	5	6	7	8
Unlikely (2)	2	3	4	5	6	7
Rare (1)	1	2	3	4	5	6
Extremely Rare (0)	0	1	2	3	4	5

Figure 33. Decision Matrix (from Ahn and Chang, 2016).

Regarding the conclusion that such a quantitative assessment based on flight operations should be considered to be one component of a broader SRMP, the report further illustrates how one of these components, the continued demonstration of safe operations once a flight operation has been approved and is ongoing, can be accomplished using a combination of UAS detection data and Automatic Dependent Surveillance-Broadcast-Out (ADSB-Out) data for manned aircraft.

This illustration shows how an extension of the Phase 1 analysis conducted for Phase 3 evaluated 47 sighting reports in the DFW area for which complete Aeroscope data was available for sUAS along with ADSB-Out data for manned aircraft. This analysis evaluated the proximity of sUAS with manned aircraft. Of those 47 cases with complete data, an sUAS was found to be in proximity to a manned aircraft in only 4 cases. Furthermore, in all 4 of those cases, none of sUAS presented a threat to the reporting aircraft because of altitude or lateral separations.

Using for estimation the fact that DJI UAS platforms make up approximately 77% of the U.S. UAS sales, since the Aeroscope only detects DJI sUAS, out of the 47 cases, if the sightings were valid indications of a threat of an sUAS to a manned aircraft, approximately 36 of the 47 sightings should have been identified as cases where an sUAS was actually in close proximity to a manned aircraft as contrasted with the 0 actually identified. If combined with LAANC data in the future, such analyses could be extended to identify sUAS infringing upon arrival and departure airspace and other restricted areas. Such analyses could in turn be used to provide insights into the performance of approved operations and provide guidance on how to improve the regulatory process if needed.

In summary, Supplement C contains the final version of the Task 3-3 report. *It is recommended that readers review the report provided in Supplement C before referring to additional assumptions regarding the underlying conceptual framework as provided in the report in Supplement D, as the report in Supplement C alone provides a complete description and illustration of the framework.* Additional details on the logic underlying the framework can then be reviewed as desired by reading the report provided in Supplement D.

Supplement E then contains the results of an additional subtask which describes a methodology/framework based on classical decision analysis for evaluating the trade-offs between the *costs and benefits* associated with a proposed sUAS operation.

6.0 CONCLUSION

To help meet the needs identified by the FAA, the National Academies of Science, Engineering, and Medicine, and Congress, this project completed work in three phases:

- Phase 1. Evaluation of Data and Establishment of Quantitative Impact of Expanded Operations
- Phase 2. Forecast of the Future Scope of sUAS Operations
- Phase 3. Development of a Quantitative Framework for the Assessment of the Risk Associated with the Operation of sUAS

Phase 1. This effort cataloged, analyzed, and provided visualizations of data sets collected by the FAA and its partners, including CONOPS trends and data needs based upon interviews of Test Site and IPP/Beyond lead participants, sUAS registrations, remote pilot examinations and certificates issued, flight waivers issued, sighting reports, and operational data (2015-2020). The catalog identified each data set and the properties of its data attributes such as completeness, consistency, etc., providing insights into trends and gaps in current data collection practices relevant to proposed operational risk assessment, indicating a need for future rulemaking to include clear guidance on safety risk management data collection requirements, and providing insights relevant to sUAS rulemaking.

In addition, third party UAS detection data in the vicinity of a large urban airport terminal was evaluated to determine the validity of sUAS sighting reports and UAS operator compliance with current FAA Part 107 sUAS rules. UAS detection data collected in the vicinity of the DFW Airport over an 18-month period (August 2018 – January 2020) censused 12,520 unique DJI sUAS across more than 162,000 separate operations. This survey identified key Part 107 potential compliance issues including 4,700+ operations above 500ft AGL, over 200 flights within 0.5 miles of DFW, and nearly 1,100 flights within 0.5 miles of a heliport.

Phase 1. Future Extensions. An extension of this analysis conducted for Phase 3 evaluated 47 sighting reports in the DFW area for which complete UAS detection data was available for sUAS along with ADSB-Out data for manned aircraft. This analysis evaluated the proximity of sUAS with manned aircraft. Of those 47 cases with complete data, an sUAS was found to be in proximity to a manned aircraft in only 4 cases. Furthermore, in all 4 of those cases, none of sUAS presented a threat to the reporting aircraft because of altitude or lateral separations. (Using for estimation the fact that DJI UAS platforms make up approximately 77% of the U.S. UAS sales, since the Aeroscope only detects DJI sUAS, out of the 47 cases, if the sightings were valid indications of a threat of an sUAS to a manned aircraft, approximately 36 of the 47 sightings should have been identified as cases where an sUAS was actually in close proximity to a manned aircraft, as contrasted with the 0 actually identified.)

An important future extension of this Phase 1 work would be to study sUAS detection data along with ADSB-Out data for manned aircraft and with LAANC data on a national scale, making it possible extend the Phase 1 analyses. This could include a focus on sUAS infringing upon arrival and departure airspace and other restricted areas, as well as assessment of compliance with LAANC approvals.

Phase 2. The primary purpose of the research provided by Phase 2 was to forecast the growth of the sUAS market and gain insights into the hindering factors that need to be addressed in order to enable this growth. To support this forecast and associated insights, two knowledge elicitation studies were conducted. In the first interview study, four SMEs were prompted to provide their predictions regarding the growth of sUAS operations from 2024-2032. The SMEs predicted that on average the number of commercial sUAS flights per day will increase to 1,019,200 flights per day in 2024 and increase to 2,730,000 flights per day by 2032. Given this small sample size, however, additional data collection is recommended in order to increase precision.

In the second knowledge elicitation study, 68 technologies and influencing concepts (such as regulatory items, standards, and FAA initiatives) that could affect the integration of UAS into the NAS were identified. These 68 areas were categorized into 9 categories: aerodynamics/performance, data/communications/security, materials, operations/flight management, power, regulation, research/ design/systems, sensors/imagery, and supply chain/manufacturing.

Using an online interview tool, sixty-six experts in these areas including sUAS pilots, developers, researchers, and regulators were asked to evaluate technical, enabling/hindering, and timeframe factors for each area. The answers received from these interviews indicated the urgency of need for the different areas as related to the average rating for the estimated first use/availability in sUAS (on a scale for 1-10 with 1 indicating the highest level of urgency and 10 indicating the lowest). Of the 22 influencing technologies and concepts that were scored as having a substantial effect on the UAS market, 10 or 45.45% were predicted to mature by the year 2027, while along with 20 others, 90.9% were forecasted to have their critical factors addressed by 2030.

Phase 2. Future Extensions. Overall, such results as provided by Phase 2 provide considerable insight into the future. An extension of this research to increase the number of participants in the first knowledge elicitaton study could provide greater precision in the estimates, and an extension of the second knowledge elicitation study may provide guidance on decisions about where to focus efforts in order to speed up the timelines for development in certain areas.

Phase 3. This phase of the work included the development of a risk-based framework for evaluating proposed sUAS operations and illustrated its application with a case study based on flight operations with automated control of an sUAS Beyond Visual Line of Sight (BVLOS) over people. The findings conclude that such a quantitative assessment based on flight operations should be considered as an important component of a broader SRMP.

The Phase 3 results further indicate that such a quantitative assessment based on flight operations should be considered one component of a broader SRMP and indicates that there are other components of the broader SRM process that also need to be considered:

- Compliance with Category 4 of RIN 2120–AK85. Operation of Small Unmanned Aircraft Systems Over People (amendment of Title 14 of the Code of Federal Regulations part 107 (14 CFR part 107) by permitting the routine operation of sUAS at night or over people under certain conditions).
- Verification and validation of hardware and software supporting the safety functions integrated into the automation in order to demonstrate compliance with FAA certification requirements for automated flight control in BVLOS operations over people, including human factors design requirements. (Such certification requirements need to be further defined.)
- Documentation of an effective safety management system as an additional safety net.
- Proof of insurance.
- Continued demonstration of safe operations once a flight operation has been approved and is ongoing.

This risk-based framework incorporates a blend of statistical methods to assess safety risks associated with a proposed flight operation using sUAS. The Phase 3 report defines and illustrates the application of this framework. In the illustration, it is assumed that a set of relevant flight data and parachute test data has been previously collected and archived, and that the waiver applicant chooses to run the minimum required number of additional tests on a proposed sUAS model and parachute. The illustration demonstrates how this framework can be applied to consider a possible cascading of events leading to an incident or accident. Data are used to calculate probabilities and expected values for possible outcomes of interest.

Based on these data, the framework is applied to calculate the resultant expected values for the probabilities with and without a parachute for two possible outcomes of interest. In the example that is presented in the final Task 3-3 report, *if the sUAS is equipped with a parachute,* the expected values for these probabilities are:

Probability of impact on pedestrian:	0.00000481172416910775
with a 99.99999% confidence interval of:	[0,0.0000943007] (0 to 0.0000943007)
Probability of impact on built environment:	0.0000160391

with a 99.99999% confidence interval of: [0,0.000557299] (0 to 0.000557299)

Thus, with a parachute, based on the use of the decision matrix described in the example analysis, using the expected values for these probabilities leads to the conclusion that the proposed operation is LOW risk (Minor consequence) for the built environment, and LOW risk (Major consequence) for its potential impact on pedestrians.

The goal of the Phase 3 report was to describe a quantitative *framework* for assessing the risk associated with sUAS operations. For the FAA to apply the quantitative risk assessments provided by this framework as part of its regulatory functions, the FAA and/or the operator would need to specify a number of things, including:

- A definition of equivalence classes that allows the pooling of data from multiple sources instead of limiting analyses to data collected only by the operator requesting a variance.
- A decision regarding whether decisions should be based on expected values for outcome probabilities or confidence intervals.
- A definition indicating the category boundaries and risk assessments for the decision matrix.
- Assignment of a specific proposed sUAS operation to one of the categories defining consequences in the decision matrix.
- Specification of the conditional probability of impacting a person if the sUAS in a proposed operation falls to the ground (based on a definition of "impacting a person").
- Specification of the conditional probability of impacting the built environment if the sUAS in a proposed operation if the sUAS falls to the ground (based on a definition of "impacting the built environment").

In addition, while the decision matrix used in this example supports a concrete illustration of the application of this risk-based decision process, the categorizations used for Probability and for Consequences may or may not be appropriate for decisions focused on sUAS operations. Thus, while the use of the decision matrix is an important part of the framework, the definition of the categories within that matrix merit investigation.

<u>Phase 3. Future Extensions</u>. In addition, future research needs to address:

- Understanding the advantages and disadvantages of using of a Bayesian framework vs. using a framework based on classical statistics (or using both to provide converging evidence).
- Determining how to calculate the number of samples (both the number of flight tests and the number parachute tests) that the waiver applicant should collect in order to achieve a desired level of statistical power.
- Defining the data that should be collected and the statistics that should be calculated in order to monitor the actual flight performances of approved operations (data analytics) as a reactive safety net to determine that operation by a particular RPIC needs to be suspended, that the approval of a specific operation using a particular set of hardware and/or software needs to be suspended, or that some aspect of the approval framework illustrated earlier needs to be revised. This latter response could involve modifying the framework itself, or

it could involve reassessing the quality of the data used for approval of a particular operation or collection of operations.

- Determining reasonable assumptions for defining equivalence classes, considering the significance of such factors as winds, UAS speed, Global Positioning Service (GPS) reliability and the verification and validation of USS service reliability.
- Designing an effective and easy to use a dashboard to inform decision makers regarding the results of the reactive data analyses described in the bullet above.
- Defining a methodology for combining data from flights traveling different enroute distances.
- Providing a "cookbook" description of how an applicant can easily apply this quantitative analysis of safety risk based on flight operations and parachute tests, perhaps in the form of a website that supports incorporation of this quantitative framework for risk assessment into the development of a proposal for a specific operation.

Finally, it should be noted that a possible variation on the example provided in the Phase 3 case study would be one where:

- An sUAS manufacturer has done the work to gather the necessary data (from the pooled data source providing data on previous flights and from additional flight tests).
- This manufacturer has completed the necessary computations to specify the data-driven estimation of the probability that this specific sUAS model could experience one of the 4 hazard causes and fall toward the ground.
- The manufacturer has packaged these results for inclusion in a request for a specific operation.

The manufacturer could similarly pre-package the results of an analysis of data based on a parachute tests when the parachute is used in association with a specific sUAS model.

In conclusion, the findings of Phases 1-3 provide a detailed quantitative description of current sUAS operations and insights into how future technology developments and regulatory actions are forecast to impact future UAS operations. They further provide detailed specification and illustration of a quantitative framework for assessing the risk associated with sUAS operations.

Additional details regarding the methods, results and implications are provided in Supplements A-F.

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