Low-Altitude Risk Assessment Roadmap

October 30, 2020

NOTICE

This document is disseminated under the sponsorship of the U.S. Department of Transportation in the interest of information exchange. The U.S. Government assumes no liability for the contents or use thereof. The U.S. Government does not endorse products or manufacturers. Trade or manufacturers' names appear herein solely because they are considered essential to the objective of this report. The findings and conclusions in this report are those of the author(s) and do not necessarily represent the views of the funding agency. This document does not constitute FAA policy. Consult the FAA sponsoring organization listed on the Technical Documentation page as to its use.

Legal Disclaimer

Technical Report Documentation Page

1. Report No.	2. Government Accession No.	3. Recipient's Catalog No.
DOT/FAA/AR-xx/xx		
4. Title and Subtitle TITLE OF REPORT Develop Risk-Based Training and Standards for Waiver Review and Issuance: Literature Review: Task 1-3 (60) Day Roadmap		5. Report Date October 26, 2020 6. Performing Organization Code ASSURE: University of North Dakota, Kansas State University, University of Alaska - Fairbanks
7. Author(s) Catherine Cahill, PhD, Tom Haritos, PhD, Paul Snyder, Timothy Bruner, Kurt Carraway, Gary Ullrich, Marcos Fernandez Tous		8. Performing Organization Report No.
9. Performing Organization Name and Address Univ. of Alaska Fairbanks 1731 South Chandalar Dr Fairbanks, AK 99775 Kansas State Univ. Polytechnic 2310 Centennial Road Salina, KS 67401	Univ. of North Dakota 3980 Campus Rd Stop 9007 Grand Forks ND 58202-9007	10. Work Unit No. (TRAIS) 11. Contract or Grant No. 15-C-UAS
12. Sponsoring Agency Name and Address U.S. Department of Transportation Federal Aviation Administration Washington, DC 20591		13. Type of Report and Period Covered Roadmap 14. Sponsoring Agency Code
15. Supplementary Notes		

The purpose of this research is to develop a roadmap for obtaining the data required towards the development of a framework to conduct a low altitude airspace risk analysis. This research aims to identify the data categories required for the FAA to assess hazards and associated risk relative to a low-altitude airspace environment(s), to assess on-going or planned FAA research and standard-setting efforts with ASTM and RTCA, industry standards organizations, to determine what resulting data may be used to fill the data gaps for these categories, in addition to identifying hazards and mitigations that may lend towards the development of a framework to conduct a low-altitude airspace risk assessment. The roadmap will include: identifying the data categories required for the FAA to complete a low-altitude risk assessment, providing insight into what data exists and where it resides, determining what research applicable to this analysis is being conducted through current or upcoming FAA or industry standards efforts, identifying gaps in required data, and suggesting research to fill the gaps.

17. Key Words	18. Distribution Statement
Safety Risk Management Low Altitude Airspace UAS Integration	This document is available to the U.S. public through the National Technical Information Service (NTIS), Springfield, Virginia 22161. This document is also available from the Federal Aviation Administration William J. Hughes Technical Center at actlibrary.tc.faa.gov.

19. Security Classif. (of this report)	20. Security Classif. (of this page)	21. No. of Pages	22. Price
Unclassified	Unclassified	46	

Form DOT F 1700.7 (8-72) Reproduction of completed page authorized

Table of Contents

Contents

Table of Figures

List of Acronyms

Acronym	Meaning
ADS-B	Automatic Dependent Surveillance Broadcast
AGL	Above Ground Level
ARTCC	Air Route Traffic Control Center
ARTS	Automated Radar Terminal System
ATC	Air Traffic Control
ATO	Air Traffic Organization (FAA)
ASDE	Airport Surface Detection Equipment
ASSURE	Alliance for System Safety of UAS through Research Excellence
ASTM	American Society for Testing and Materials
BVLOS	Beyond Visual Line of Sight
CAASD	Centre for Advanced Aviation System Development (MITRE)
CFR	Code of Federal Regulations
CMS	Common Message Set
CONOPs	Concept of Operations
DEM	Data Elevation Models
DHS	Department of Homeland Security
DTED	Digital Terrain Elevation Data
EIA	Energy Information Administration
ERAM	En Route Automation Modernization
ETMS	Enhanced Traffic Management System
FAA	Federal Aviation Administration
GA	General Aviation
GIS	Geographic Information System
GNSS	Global Navigation Satellite System
GPS	Global Positioning System
HIFLD	Homeland Infrastructure Foundation Level Data
ICAO	International Civil Aviation Organization
IFR	Instrument Flight Rules
JARUS	Joint Authorities for Rulemaking on Unmanned Systems
LAANC	Low Altitude Authorization and Notification Capability
LTE	Long Term Evolution
METAR	Meteorological Aerodrome Report
NAS	National Airspace System
NASR	National Airspace Resources
NEXRAD	Next Generation Radar
NGA	National Geospatial Intelligence Agency
NOAA	National Oceanic and Atmospheric Administration
NOP	National Offload Program
NORAD	North American Aerospace Defense Command
NPRM	Notices of Proposed Rulemaking

OE	Obstruction Evaluation
OSM	Open Street Map
PDARS	Performance Data Analysis and Reporting System
PSAP	Public Safety Answering Points
RADES	Radar Evaluation Squadron
RMSE	Root Mean Square Error
RTCA	Radio Technical Commission for Aeronautics
SMS	Safety Management System
SORA	Specific Operations Risk Assessment
STARS	Standard Terminal Automation Replacement System
TAF	Terminal Area Forecast
TCL	Technical Capability Level
TDWR	Terminal Doppler Weather Radar
TFR	Temporary Flight Restrictions
TRACON	Terminal Radar Approach Control
UA	Unmanned Aircraft
UAS	Unmanned Aircraft System
UAT	Universal Access Transceiver
UPP	UTM Pilot Program
USDA	U.S. Department of Agriculture
USGS	U.S. Geological Survey
UTM	UAS Traffic Management
VFR	Visual Flight Rules
VLOS	Visual Line of Sight

Executive Summary

As part of the ASSURE A25 research project, the FAA sponsor tasked the research team to develop a roadmap that outlines key data categories required for a low-altitude risk assessment. The intent of this roadmap is to (1) identify data categories required for the FAA to complete a low-altitude risk assessment, (2) provide insight into what data exists and where it resides, (3) determine what research applicable to this analysis is being conducted through current or upcoming FAA or industry standards efforts, and (4) identify gaps in required data and suggest research to fill the gaps as able. Bearing this in mind, the scope of this roadmap focuses on segregated unmanned flight operations at altitudes at or below 400 feet above ground level (AGL). Follow-on work will build upon this roadmap to address larger components of the FAA's envisioned "scalable compliance review process" that is aimed at establishing a flexible mechanism for obtaining operational approval based upon operational risk associated with an unmanned aircraft system (UAS) and a given concept of operations (CONOPs).

The roadmap that follows was derived through a combination of subject matter expertise provided by the research team, targeted requests by the Commercial Drone Alliance (CDA), and knowledge gained from past and current research from the FAA's Center of Excellence (CoE) for UAS research, the Alliance for System Safety of UAS through Research Excellence (ASSURE). Therefore, this report includes a detailed overview of the past, present, and future research efforts through ASSURE that support low-altitude operations safety, informs the research team about what data is needed to conduct a rigorous low-altitude risk assessment, and provides relevant information for industry standards and initiatives.

This roadmap represents a starting point for exploring critical data categories and components for a low-altitude risk assessment, and it is intended that this roadmap serve as a foundational element for future efforts to establish risk-based standards for operational approvals for UAS operations in the NAS at altitudes of 400 feet AGL and below. The team identified four key types of data categories needed for such a low-altitude risk assessment: air risk data (e.g., airspace class data, airborne traffic density, ADS-B participation, etc.), ground risk data (e.g., terrain, land use and zoning, population density, No Fly Zones, etc.), navigation/command and control data (GNSS availability, cellular tower coverage, satellite communications availability), and weather considerations data (e.g., current and forecast weather data, weather radar coverage as a function of height, etc.).

This report includes representative data sets for each of the identified data categories and a visual representation to highlight key categories that have been captured through this work. Additionally, this report demonstrates where data can be obtained and data that may be difficult to obtain. Most importantly identifying specific data elements inside these data categories and establishing consistency among the data sets and data elements needed to create a working low-altitude risk assessment tool for any location in the United States is beyond the scope of this effort. However, the research team intends for this roadmap to inform follow-on research to expand these data categories into populated sets of information that can point towards (1) standards and practices for low-altitude risk assessment and (2) policy regarding low-altitude UAS operations. The environmental conditions described by the elements of the roadmap, when combined with a rigorous safety analysis of the aircraft and standardized training of airmen, will provide a

quantitative description of the potential risks of any CONOPs, allow for the mitigation of those identified risks, and result in safer, low-altitude UAS operations.

Introduction and Summary

The National Academies of Science, Engineering, and Medicine (NASEM, 2018) suggests the Federal Aviation Administration (FAA) should expand on quantitative data collection to address risk as it pertains to unmanned aircraft systems (UAS) integration as the qualitative nature of current risk management approaches implemented to address UAS risk initiates results that fail to be repeatable, predictable, scalable, and transparent. At present, the lack of empirical data in the UAS industry leads to qualitative and subjective risk assessment and analysis greatly reducing the probability for expanded and non-segregated operations in the National Airspace System (NAS). Additionally, NASEM (2018) ascertains an explicit need for the FAA to evolve away from the subjectivities presented in FAA order 8040.4B (Safety Risk Management Policy, 2017) related to UAS and migrate towards quantitative probabilistic risk practices based on acceptable safety risk utilizing well-quantified data that is relevant.

In 2016, the FAA amended its regulations to Title 14: Aeronautics and Space and added part 107: Small Unmanned Aircraft Systems. The passage of 14 CFR part 107 provided rules to conduct low-risk unmanned aircraft operations in the National Airspace System, greatly enabling commercial and the public sector. At that time, a large majority of UAS operations fell within the restrictions of part 107 (i.e. aircraft under 55 pounds, daylight, ops below 400 feet AGL). Although a noteworthy effort on the part of the FAA to implement sUAS regulations, further research is deemed necessary to address issues that remain unresolved. Issues hindering integration of larger systems as identified by the GAO (2012) include: (1) the inability for UAS to detect, sense, and avoid other aircraft and airborne obstacles, (2) vulnerabilities in the command and control paradigm, (3) limited human factors engineering incorporated in UAS technologies, (4) lack of standards to guide the safe integration of UAS, and (5) the lack of capability to transition UAS into the Next Generation Airspace System (NextGen). Resolution of these issues are key to the safe and effective full-scale integration of UAS into the NAS regardless of vehicle size and weight.

Fortunately for sUAS operations, 14 CFR part 107 provides opportunities for operators to apply for waivers to specific provisions of the basic regulation, such as flying beyond the visual line of sight (BVLOS) of the Pilot in Command or operating the UAS over people. These waiver provisions afford applicants the ability to petition the FAA for increased operational latitude, while providing the FAA with a mechanism to closely review all waiver requests to ensure that the proposed UAS flight operation does not compromise the safety of the NAS. The increasing level of risk associated with the advanced operations, such as BVLOS and operations over people, requires that the FAA carefully evaluate these operations to ensure the safety in the NAS as multiple operators and organizations conduct an increasing number and variety of advanced operation types.

According to 81 FR 50789 (Requests for Waivers and Authorizations Under 14 CFR part 107 System of Records Notice, 2016), the waiver application and review process depend on the complexity of the operation, the completeness of the applicant's waiver documentation, the justification for the operation, and the data needed for the waiver team to evaluate if the operation can be performed safely. The amount of documentation accompanying a waiver submission should be proportional to the scope and scale with which the applicant seeks relief from a given regulatory element of part 107. In the simplest terms, if an applicant seeks to waive more elements of part

107 that result in a greater level of operational risk, they must provide more substantial documentation and rationale behind their justification(s). The wide range of differences in operator experience, aircraft types, aviation knowledge, and organizational maturity add complexity to the problem. Therefore, the required documentation needs to include an analysis of the risks associated with the airspace (including air and ground risks), aircraft, and airmen and proposed methods for mitigating the identified risks. Obtaining sufficient data on all three aspects of the safety case is a challenge to many operators, so this requirement has been the downfall of many waiver requests.

Unfortunately, the evaluation of the safety case documentation for these waivers requests is subjective and requires enhanced subject matter expertise for the approval process, often which the FAA does not possess (NASEM, 2018). Additionally, many of the operators requesting waivers do not have the aeronautical expertise required to assemble a viable safety case. These factors present many challenges for the FAA and industry stakeholders seeking authorization for operational latitude outside the provisions established as 14 CFR part 107.

The most challenging part of developing a safety case is the characterization of risks associated with the UAS. Very few UAS are type certified, so the FAA personnel evaluating the UAS need data from the operator establishing the aircraft's durability and reliability, the robustness of the command and control links, the sense and avoid methods used to avoid other aircraft, the lost link procedures, the maintenance protocols, the ability to maintain continuity of flight after an engine failure, the potential damage due to the aircraft striking a human (for operations over people) or vehicle, the temperature and wind limits of the aircraft, and a multitude of other information. This information is difficult to obtain even for seasoned UAS operators, but is essential for evaluating the potential for safe flight during advanced operations.

UAS operators also need to demonstrate in their safety cases the training credentials and expertise of their crew and the policies and procedures that will limit human error during operations. NIST, universities, and other organizations are developing training and certification programs for UAS pilots; however, many operators requesting advanced operation waivers only possess a Remote Pilot Certification and never received hands-on training on how to safely plan flights, including implementing emergency procedures, maintain their aircraft, prevent fatigue from influencing their decisions, and other activities required by the airman to conduct safe operations. These operators need to demonstrate to the FAA waiver evaluators that they are professionals who understand the implications of flying a UAS in the NAS and will ensure the safety of their operations.

Lastly, the risk assessment must evaluate the risks associated with the UAS's operating environment. The waiver applicant must be able to demonstrate that the UAS can operate in a specific environment without increasing risk to the NAS. As operators want to conduct missions that are longer distance, BVLOS, and/or over people, they must show that they are minimizing the risk to everyone in that environment. It can be difficult to obtain the data needed to demonstrate that the population density is low over the entire flight path, that the aircraft is flying within 50 feet of high-tension powerlines so manned aircraft traffic should not be a risk, or that the weather should not be a factor during that season in that place. UAS operators can spend significant effort and resources to obtain the data needed to prove the safety of their operation in a specific environment; then they change environments and have to go through the process for the new location. As a result, there is a push from industry stakeholders for the FAA to develop a quantitative method for assessing the risk of an operation anywhere in the country. The initial request from industry representatives is that:

> "...the FAA and other relevant stakeholders conduct a sophisticated, national study of the operational risks associated with low-altitude UAS operations below 400 feet AGL. The risk analysis would consider factors such as traffic density, trajectories, weather, population density, terrain, land use and zoning, building heights, and other local factors for the entire United States. The federal government could conduct an airspace characterization effort leveraging nationwide radar and other surveillance assets (from the FAA, DOD, and other sources) to provide an assessment of the relative risk presented by UAS operations (including piloted urban air taxis) within this low-altitude airspace environment. The study would leverage available data to assess the level of risk on a probabilistic basis.
>
> Although useful for all UAS operations beyond visual line of sight (BVLOS), the study would be exceptionally helpful in unlocking low-altitude, low-risk operations masked by existing infrastructure and terrain features—operations that promise to provide significant utility to public safety and other enterprises facing staffing shortages and social distancing constraints. The study would also be extremely useful to enable UAS delivery operations more broadly, including for delivery of critical supplies to quarantined individuals."

A low-altitude risk assessment of this type would provide a much-needed way for a UAS operator to quickly obtain the data needed to quantifiably assess the risks associated with the environment in which their low-altitude UAS operations would occur. However, it is not sufficient on its own to guarantee the safety of the UAS operation. As stated above, the UAS operator would still need to assess the risks due to the UAS and the airmen associated with the operation to determine the risk of the operation, but it would provide a common basis for evaluating one part of the safety case needed for the FAA to evaluate and approve an advanced operations waiver.

The work described in this document outlines a roadmap for developing a low-altitude risk assessment for operations below 400' AGL in the NAS. The effort is not a thorough gap analysis and will not identify the specific data variables for each data category required to complete a low-altitude risk analysis, understanding, and mitigation. However, it will be a roadmap for obtaining the data required to conduct the risk analysis, understanding, and mitigation. The roadmap will include: identifying the data categories required for the FAA to complete a low-altitude risk assessment, providing insight into what data exists and where it resides, determining what research applicable to this analysis is being conducted through current or upcoming FAA or industry standards efforts, and identifying gaps in required data and suggesting research to fill the gaps.

This task is focused on segregated airspace (under 400' AGL), but the gaps and lessons learned during this effort may be applied to a follow-on studies and future effort may also be focused on the development of a 'scalable compliance review process' for low-level integrated airspace (400'-3000 'AGL).

The path to achieving a quantitative, low-altitude risk analysis, understanding, and mitigation is as follows:

- Identify the data categories required for the FAA to assess hazards and associated risk relative to low-altitude airspace environment(s) to assess safety case submissions more effectively.
  - Possible data categories would include traffic density, trajectories, weather, population density, terrain, land use and zoning, building heights, and other factors for the entire United States.
  - The safety risk assessment would be in accordance with FAA Safety Risk Management Policy 8040.4B, FAA Unmanned Aircraft Systems Safety Risk Management Policy 8040.6. The assessment would limit the data categories related to those under the jurisdiction of the FAA.
- Identify current, readily available sources of data related to these categories.
- Identify where data currently is unavailable for these categories.
- Assess on-going or planned FAA research and standard-setting efforts with American Society for Testing and Materials (ASTM) and Radio Technical Commission for Aeronautics (RTCA), industry standards organizations, to determine what resulting data may be used to fill the data gaps for these categories. Include dependencies between research activities.
- Identify remaining gaps between the current and expected data where no FAA research or industry standards efforts are identified and identify what data is needed for the FAA to complete safety risk assessment in relation to low-altitude airspace environment.
- Suggest research to fill the data gaps or, if research and testing is not feasible, the studies that should be conducted to assist the FAA in assessing the impact of specific risk.

This process, should, with enough time and support, provide a useful tool for UAS operators seeking to conduct advanced operations and FAA evaluators needing to evaluate advanced operation safety cases.

Low-Altitude Risk Assessment Roadmap

Research Background

The Consolidated Appropriations Act of 2014 served as a congressional mandate and directed the Federal Aviation Administration (FAA) to establish a Center of Excellence (COE) for unmanned aircraft systems (UAS). In May 2015, the FAA selected the Alliance for System Safety of UAS through Research Excellence (ASSURE) as the FAA's new UAS COE. Research conducted under the auspices of the COE is designed to address current gaps associated with UAS technologies and integration of UAS into the National Airspace System (NAS), as well as support the development of policy and standards required to address new and innovative aspects for expanded and non-segregated UAS flight operations. The following section of this roadmap highlights past, current, and future research initiatives that support low-altitude operations safety and forecasting.

<u>Past Research (ASSURE)</u>

Since research through the FAA's CoE began in 2015, there have been numerous research projects that have set the stage for current, ongoing research projects. This section provides a brief overview of past ASSURE research, providing a high-level discussion of research objectives and a brief discussion of outcomes. Individual reports and project discussion are available form ASSURE's website (assureuas.org).

FAA Research Requirement: Certification Test Case to Validate sUAS Industry Consensus Standards (**A1**)

UAS Research Focus Area: UAS Airworthiness and certification

ASSURE A1 sought to address the use of consensus standards from ASTM F38 for use in establishing a certification basis for sUAS through 14 CFR part 21.17(b). As such, research for A1 focused on an in-depth analysis of ASTM F2910-14: Standard Specification for Design and Construction of a Small Unmanned Aircraft System (sUAS). The focus of this research was to identify compliance issues and gaps within the standard and determine how these standards could inform a flight test program. Ultimately, this research helped to inform revisions to F2910 and the development of F3298: Standard Specification for Design, Construction, and Verification of Lightweight Unmanned Aircraft Systems (UAS).

FAA Research Requirement: Small UAS Detect and Avoid Requirements Necessary for Limited Beyond Visual Line of Sight (BVLOS) Operations (**A2**)

UAS Research Focus Area: BVLOS and Detect and Avoid (DAA)

ASSURE A2 explored requirements for BVLOS flight operations as they pertained to sUAS. This research included literature review of pilot and ground observer see and avoid performance, recommended performance measures for FAA, a survey of various technologies for DAA, general assessment for risk associated with the use of DAA technologies, and considerations for flight testing. This research enabled future operational testing of DAA systems by identifying key hazards associated with BVLOS flight operations, contributing to inputs for risk assessments for

BVLOS flight operations, and recommending additional controls. Flight tests served as a mechanism to validate preliminary data gathered as a result of this work. Outcomes of this research informed additional (ongoing) ASSURE research into the exploration of DAA performance measures.

FAA Research Requirement: UAS Airborne Collision Hazard Severity Evaluation (**A3**)

UAS Research Focus Area: Airborne collision and severity

Research through ASSURE A3 focused on determining the potential severity of UAS with manned aircraft to identify an Equivalent Level of Safety (ELOS) to manned aviation. This was accomplished by extensive use of complex simulations to explore the effects of the collisions of manned/unmanned aircraft of various types/configurations. The outcomes of this research provided data regarding damage that may occur as a result of a manned/unmanned aircraft collision. Additionally, it informed the need for future work – to include an exploration of engine ingestion.

FAA Research Requirement: UAS Maintenance, Modification, Repair, Inspection, Training, and Certification Considerations (**A5**)

FAA Research Focus Area: UAS maintenance and modification

ASSURE A5 explored requirements for UAS maintenance, modification, repair, inspection, and maintenance technician repair and certification. This research explored existing maintenance programs for commercial UAS, performed an analysis of current maintenance technician programs and made comparisons to existing aircraft maintenance paradigms for manned aviation. Outcomes of this research answered questions relating to existing maintenance practices for UAS, identified critical maintenance considerations for UAS with respect to technical qualifications, and proposed future research regarding the need for reliability data and the need to understand maintenance-induced failures.

FAA Research Requirement: UAS Surveillance Criticality (**A6**)

FAA Research Focus Area: Detect and Avoid (DAA)

This research focused on addressing UAS surveillance and sought to analyze UAS surveillance technologies and methodologies against industry standards. As part of this research, the team explored questions relating to how ADS-B (out) may impact UAS DAA functions, design assurance criteria for UAS DAA functions, and criteria for evaluating equivalent level of safety of UAS when compared to manned aircraft DAA functions. Outcomes of this research informed further research into FAA surveillance criticality analysis and provided a starting point for evaluating the performance of DAA technologies against standards and other systems.

FAA Research Requirement: UAS Noise Measurement (A8)

FAA Research Focus Area: UAS Noise certification

This research gathered noise data on a Tiger Shark UAS for the purpose of outlining standards for gathering noise data for UAS noise certification. As part of this research, The FAA's Office of Environment and Energy (AEE) carried out a test program at Griffiss International Airport in Rome, NY. Outcomes of this research were test data and methodologies for gathering noise data for UAS.

FAA Research Requirement: UAS Recommendations for Minimum UAS Control Station Standards and Guidelines (**A10**)

FAA Research Focus Area: Control Stations and Human Factors

ASSURE A10 focused on the development of recommendations for minimum control station requirements regarding controls station design and human factors. This research effort was divided into control station (CS) subtasks and pilot and crew (PC) subtasks with the goals of merging functional requirements and human factors considerations developed as part of the CS tasks with operational requirements and procedures for pilots that were developed as part of the PC tasks. Ultimately, the outcomes of each set of subtasks were intended to inform the design and operation of a UAS control station with human factors considerations – e.g. providing guidance for ergonomics required for the safe operations of a UAS.

It is important to note that this research emphasized UAS that were operated beyond "small" designation; with maximum takeoff weights greater than 55 pounds. Initial assumptions for the PC subtasks were as follows:

- The UA had a maximum takeoff weight greater than 55 pounds.
- The UA was a fixed-wing aircraft.
- The UA had a single power plant.
- A crew with a single pilot was required for flight.
- The pilot using the CS controlled a single unmanned aircraft.
- Flight operations were conducted under instrument flight rules (IFR).
- Flight operations were conducted day or night, as dictated by required equipage.
- Flight operations were conducted over people.
- Flight operations took place in airspace classifications D, E, and G, including both towered and non-towered airports.
- Flight operations may take place under varying levels of traffic conditions.

To link PC subtasks with those of the CS team, researchers for the PC tasks performed validations of PC tasks on representative control stations, documented the findings, and revised pilot procedures accordingly.

FAA Research Requirement: UAS Low Altitude Safety Case Study (**A11**)

UAS Research Focus Area: Operations over people and ground impact metrics

ASSURE A11 focused on exploring data requirements and analysis required for the submission of a waiver for operations over people for 14 CFR part 107. This research consisted of exercising the part 107 waiver process by investigating requirements to meet performance standards established by the UAS Micro-ARC. Outcomes of this research include the successful acquisition of a waiver to operation a DJI Phantom 3 over people as well as new methodologies for establishing safety thresholds for UAS operations over people.

FAA Research Requirement: UAS Ground Collision Severity Evaluation 2017-2019 (**A14**)

UAS Research Focus Area: Ground collision and severity

Research through ASSURE A14 emphasized the validation of earlier ASSURE research regarding ground impact severity through ASSURE A4 (not listed here) and ASSURE A11. This research included the evaluations of kinetic energy released through UAS ground impacts via impact testing and correlating that data with established injury metrics. Outcomes of this research provided recommendations for areas of additional testing, assessments of the efficacy of injury metrics, and recommendations for performance-based standards for securing components.

Current Research (ASSURE)

FAA Research Requirement: Small UAS Detect and Avoid Requirements Necessary for Limited Beyond Visual Line of Sight (BVLOS) Operations **(A18)**.

UAS Research Focus Area: Low Altitude Operations Safety

By 2014, even before the FAA had created rules for the operation of sUAS, there were numerous safety reports of close encounters between sUAS and manned aircraft. These encounters generally are occurring when manned aircraft are close to the ground during approach and landing. With the release of the 14 CFR part 107 sUAS rule, the number of UAS in the NAS has increased dramatically, increasing the probability of close encounters and midair collisions. DAA technology is not only necessary to help manage this risk, but also to allow BVLOS operations. Standards and rules for DAA that will allow UAS to conduct BLVOS operations in the future. Many sUAS operations, such as precision agriculture, crop and wildlife monitoring, search and rescue, and linear infrastructure inspection are currently restricted, limiting the potential of sUAS commercial operations and public benefit.

This research will help inform FAA regulations and industry standards addressing DAA and BVLOS operations. Some of the questions this research intends to answer are:

- What are the use cases requiring DAA for BVLOS operations?
- What DAA systems are available, what are their capabilities and limitations, and are they mature enough to support BVLOS operations?
- Is the SARP definition of "Well Clear" appropriate?
- What characteristics of DAA systems and UAS must be considered to ensure maintenance of well clear status?

- How should sUAS DAA systems be evaluated to ensure they provide safe separation services in the NAS?
- What is the recommended test method(s) to evaluate different DAA systems?

FAA Research Requirement: UAS Test Data Collection and Analysis **(A19)**.

FAA Research Focus Area: Low Altitude Operations Safety

This research relates to the development of the technical data requirements, test methods, risk assessments, safety risk management processes, data collection, and administrative processes/reporting used to inform safety cases in support of the UAS integration regulatory framework. It will develop a system to capture test objectives and categorize them consistent with the FAA's UAS Integration Research Plan functional areas and research domains. The analysis of this data will inform the development of regulatory products (i.e., rules, standards, policy, etc.) needed to reach UAS integration milestones. Finally, it will facilitate the query and reporting of data in a consistent format across the Test Sites.

To enable development of safety cases, this system must:

1. Provide a framework for developing/supporting UAS integration safety cases by utilizing test objectives and data.
2. Align UAS test objectives and data to:
    a. Research objectives in a manner that enables users to cross-check needs for UAS data/research with test data stored in the system.
    b. UAS operational capabilities.
    c. FAA research domains.
    d. FAA functional areas.
    e. Other UAS integration milestones
3. Have the following high-level characteristics:
    a. Leverage best practices currently used among the UAS Test Sites (data collection and categorization/classification).
    b. Provide solutions for potential proprietary issues related to data collection.
    c. Conform with FAA rules regarding software applications (e.g., documentation).
    d. Enable efficient data entry through utilization of the process developed through this effort.
4. Include the features:
    a. Keyword searchable in an interactive manner.
    b. Data mining.
    c. Data tagging.
    d. User friendly.
    e. Intuitive user interface.
    f. Ability to link to supporting reports.
    g. Have a standardized supporting project report template(s).
    h. Ability to incorporate preexisting data.
    i. Ability to export data into multiple formats (i.e., excel spreadsheets, CSV, comma delimited.

j. Ability to indicate whether test data stored in the system meets a research need or whether additional data/testing would be required.
k. Adaptability, expandability, and modifiability: It will have the ability to adapt as needs change and gaps are identified.

FAA Research Requirement: Integrating Expanded and Non-Segregated UAS Operations into the NAS: Impact on Traffic Trends and Safety **(A21)**.

UAS Research Focus Area: Operational Safety & Forecasting

This research will provide further insight into the safe integration of sUAS through forecasting of expanded and non-segregated sUAS operations and subsequently collecting data to inform the FAA on risk-based methodologies to safety rules, regulations and revised Safety Management System (SMS) protocols based on forecasted UAS operational needs and performance characteristics. The proposed research, by its design, supports two critical components of the UAS Integration Research Plan: (1) Expanded Operations and (2) Non-Segregated Operations. Expanded operations over people and non-segregated BVLOS operations are anticipated to enable future UAS interoperability in controlled airspace with manned aircraft at varying altitudes and under instrument flight rules. Under this premise, UAS must be properly equipped with technologies that harmoniously exchange data and flight information. This research will serve to examine the avionics equipage and procedures requirements for establishing UAS interoperability with manned aircraft in controlled airspace and stand as a pillar to the FAA's phased integration approach by developing a quantitative framework for risk-based decision making and waiver approvals to meet the growing operational needs and technological evolution of UAS.

Using data and knowledge from on-going integration activities such as the UAS Integration Pilot Program (IPP), Low Altitude Authorization and Notification Capability (LAANC), UAS Traffic Management (UTM), UAS Facility Maps (UASFM), Certificate of Authorizations (COA)/COA Application Process (CAPS), and Special Government Interest (SGI), the research is intended to:

- Understand the emerging usage patterns and missions leading to expanded operations.
- Scope out operations and characteristics of non-segregated operations and potential traffic patterns.
- Understand and describe likely conflict and safety risks.
- Describe risk profile in busy terminal areas and in lower altitudes elsewhere.
- Describe need for safety and certification regulations emanating from integrations.
- Underscore the revisions of SMS incorporating emerging needs of expanded and non-segregated operations.

Successful completion of this research is likely to shed important insights into interactions between human factors, technology, procedures, and further (de)regulations pertinent to UAS integration into the NAS.

FAA Research Requirement: Validation of Low-Altitude Detect and Avoid Standards – Safety Research Facility **(A23)**.

FAA Research Focus Area: UAS Detect and Avoid

The tasking for this work validates prior research in the performance of human pilots to detect other air traffic, assesses the potential for conflict, and analyzes potential maneuver options for avoidance against an intruder aircraft when a potential conflict exists. The results of data and analyses conducted during this effort will be used by the FAA to support a determination of whether the risk ratio safety performance thresholds defined in the ASTM Detect and Avoid standard are adequately safe by comparing them to the measured ability for onboard pilots flying at lower altitudes to see-and-avoid other aircraft.

The Unmanned Aircraft Systems Safety Research Facility's (UASSRF)'s work will be used exclusively by the FAA to determine adequate safety performance thresholds required by DAA Systems that serve as an alternate means of compliance to existing manned aviation see-and-avoid regulations listed in 14 CFR Part 91.113. This work will provide the FAA with information necessary to develop and validate certification standards for DAA systems. This work will be used to develop preliminary, internal, FAA documents to support standards development, policy decisions, and/or rulemaking. See-and-avoid performance metrics are needed that measure the ability of manned aircraft pilots to see and to then avoid conflicts with other aircraft. Different see-and-avoid performance metrics exist depending on whether the pilot uses assistive technologies that aid in visual detection and whether the separation goal being evaluated is to remain well clear of other aircraft or to avoid a near mid-air collision with other aircraft. The results of these assessments are expressed as see and-avoid risk ratios and are intended to inform the establishment of DAA risk ratios for unmanned systems that serve as an alternate means of compliance to see-and-avoid regulations used in manned aviation.

The establishment of safe DAA risk ratio values involves comparing the risk of low altitude UAS operations to the existing risk of low altitude manned aviation operations. This risk comparison necessitates measuring the ability of manned aircraft to see-and-avoid other air traffic.

FAA Research Requirement: UAS Safety Case Development, Process Improvement, and Data Collection **(A24)**.

UAS Research Focus Area: Low Altitude Operations Safety

This research is a follow-on to the UAS Test Data Collection and Analysis (A19) project. In this research, the test data collection and analysis system developed in A19 is exercised to determine how the system can be optimally utilized. The questions about the optimization of the system include:

- Who is best suited to be an applicant for a waiver or exemption and why? Should it be the UAS manufacturer or the individual using the UAS? It could be either depending on the applicant.

- How can prior testing on a vehicle which led to successful waiver/exemption be used in future applications?
- Can an applicant with a full review of a previously successful waiver, use that information for their application?
- Can prior testing on a vehicle which led to successful waiver/exemption be used or referenced by an applicant without any visibility or review by the applicant? (Note: The consideration is towards vehicle test and does not enable an applicant from bypassing the development of their operational procedures, and risk analysis for their specific operations.)
- Should the FAA develop a list and publish the list of approved vehicles for waiver/exemptions? If yes, what additional requirements should the applicant have, i.e., operating procedures, maintenance procedures, etc.?
- Could an applicant cite another waiver's tests without seeing or reviewing the data? Could an applicant buy an off the shelf drone and apply for a waiver without seeing the test results?
- How can safety cases for part 107 waivers be improved?

FAA Research Requirement: Develop Risk-Based Training and Standards for Waiver Review and Issuance **(A25)**.

FAA Research Focus Area: Low-Altitude Operations Safety

The purpose of this research is to provide tools and insight to the FAA to: (1) assist in the development of a more standardized reviewing process for part 107 waivers, and (2) address challenges faced by FAA reviewers when evaluating part 107 waivers using non-standard risk assessment methodologies. This is accomplished by (1) suggesting modifications to FAA orders 8040.4B, "Safety Risk Management Policy" (2017) and 8040.6, "Unmanned Aircraft Systems Safety Risk Management Policy" (2019) (2) developing a framework to modify existing part 107 waiver process, and enabling harmonization with alternative risk assessment methodologies (e.g. ASTM and JARUS SORA), and (3) validating the proposed framework through test cases. It is expected that the results of this research will provide guidance and a framework for FAA to review part 107 waivers in a consistent manner that preserves the safety of the NAS. This will ultimately benefit both the FAA and applicants, providing a more straightforward and objective process for waiver review and enable the FAA to provide additional guidance to applicants to ensure that sufficient information is provided in waiver submissions.

This research is intended to:

- Provide recommendations to the FAA on modification to 8040.4B and 8040.6 to incorporate a range of UAS operations.
- Take existing standards (ASTM and JARUS SORA) into consideration, develop a framework to assess various risk components to "feed into" revised UAS-specific tables in 8040.4B and 8040.6. This framework will help waiver proponents articulate the CONOP-dependent safety case for a range of waivered operations. This will, in turn, simplify the burden placed on FAA Flight Standards in determining risk acceptance of proposed operations and simplify the process to establish precedence for a range of UAS operations.

- Validate the proposed modification to 8040.4B, 8040.6, and risk assessment framework by submitting a range of waivers using this proposed system.

Successful completion of this research will provide the following benefits:

- Findings, recommendations, and lessons learned will create transparency between waiver proponents and FAA Flight Standards to streamline the Part 107 Certificate of Waiver process.
- Recommended standards proposed through this research will enable waiver evaluators to utilize a standardized approach for reviewing waivers.
- A standardized methodology for waiver review and issuance enables a precedent-based system in which the FAA reviews waivers consistently and objectively.

The added guidance for FAA waiver evaluators creates a more robust system for processing waivers that ensure consistent outcomes while maintaining safety. In addition, this guidance will assist in addressing issues of compatibility between alternative risk assessment methodologies, FAA Order 8040.4B, and 8040.6.

This research seeks to answer the following questions:

1. How can a modified 8040.4B and 8040.6 enhance the part 107 waiver review process?
2. Can existing industry standards (ASTM, JARUS SORA) inform a framework for proponents to articulate the risk components necessary for the FAA to consider part 107 waivers?
3. What are the minimum requirements for a framework for a risk-based standard for reviewing part 107 waivers?
4. How does a risk-based standard for reviewing part 107 waivers fit into the current waiver review process?

FAA Research Requirement: Establish Risk-based Thresholds for Approvals Needed to Certify UAS for Safe Operation **(A27)**.

FAA Research Focus Area: Operational Safety & Forecasting

This project will validate sUAS industry standards and support standards development and certification strategies for sUAS, necessary for their safe integration in the NAS. As part of the rulemaking effort surrounding the implementation of part 107, the FAA selected ASTM to establish a set of standards for airworthiness, maintenance, and operation in support of part 107. This project will identify weaknesses to make the standards more robust and increase the safety of sUAS operations in the NAS.

The primary tasks within this effort are:

1. Identify limitations associated with the current evaluation paradigm regarding sUAS pilot certification (14 CFR part 107) and report on the potential gaps towards expanded and non-segregated operations.
2. Develop a framework to capture the knowledge, skills, and abilities (KSAs) required for UAS pilots as they relate to classification and category of UAS.

3. Evaluate whether prerequisite levels of manned flight if any, should vary across the classification and category of UAS (i.e. group 2, 3, 4, 5) for expanded and non-segregated operations.
4. Evaluate to determine the constructs associated with pilot training requirements under the auspices of 14 CFR Parts 61 and 141 to determine the transfer of KSAs from manned to unmanned flight in complex UAS operations.
5. Establish a framework to adopt, adapt and exercise current regulatory requirements i.e. Parts 23, 25, 27, 29, 31, 33, and 35) towards performance-based type certification for sUAS (e.g. eBee X, Penguin C, FVR-90, or a similar unmanned aircraft) and a waiver to operate over people within visual line of sight as prescribed in 14 CFR part 107.31.
6. Expand the conceptualized framework to further exercise regulatory requirements associated with performance-based airworthiness criteria to achieve a consistent means of compliance.

FAA Research Requirement: Safety Risks and Mitigations for UAS Operations on and Around Airports **(A31)**.

FAA Research Focus Area: Risks around Airports

The research is intended to address gaps in knowledge that are currently a barrier to the safe, efficient, and timely integrations of UAS into the NAS. This safety and risk analysis will focus on evaluation of UAS operations on and around the airport surface. The research will identify the potential risks with regards to UAS operations on the ground at airports, near manned aircraft, communication with these UAS operators (if necessary), and Air Traffic (AT) services (if not provided). The research may inform potential changes to FAA regulations (such as 7110.65), industrial standards, and best practices.

The proposed research is intended to answer the following research questions and any related questions that may be developed through the research process:

- What are the representative use cases for UAS on and around airport surfaces?
- What level of communication/coordination is required between UAS operators, manned aircraft operators, airport managers, ATC, and other airport users/operators prior to and during UAS operations on and around airport surfaces?
- How do the varying size and capability of different UAS types impact these use cases? For example: 1) Do large UAS traversing the runway/taxiway surfaces require different AT services than smaller UAS? 2) How does UAS size impact the potential integration with or segregation of UAS operations from manned aircraft operations? and 3) How does the size of the UAS change how wake turbulence impacts its behavior?
- What are the impacts of different airspace classes and towered/non-towered airports on these use cases?
- What are the common risks for these representative use cases? What are the unique airspace-class/UAS-specific risks for each use case?
- What are the potential mitigations to identified risks to ensure safe operations for UAS?

- What airport infrastructure would assist in mitigating the hazards of operating UAS on and around airport surfaces?
- What airport policies and procedures would assist in mitigating the hazards of operating UAS on and around airport surfaces?
- How does FAA Order JO 7110.65 (ATC services are not provided to any UAS operating in the NAS at or below 500 ft AGL) impact the use cases and limit potential hazard mitigations for operations on and around airport surfaces?
- What issues identified during the application of the FAA’s ATO SMS and SRM processes to the selected use cases should be used to inform potential changes to FAA regulations and industry standards?
- What lessons were learned from these representative use case demonstrations?
- What recommendations from the literature review, use case analysis, SRM process, and flight testing should be highlighted to inform airport operations and design when integrating UAS on and around airport surfaces?

FAA Research Requirement: Urban Air Mobility: Safety Standards, Aircraft Certification and Impact on Market Feasibility and Growth Potentials **(A36)**.

FAA Research Focus Area: Safety Standards Aircraft Certification

In its core proposition and approach, the proposed research is "basic and early-stage applied research" in understanding UAM operations in the NAS. Designed as a short-term research project, the basic results will likely yield effective and "quantitative metrics" in evaluating UAM [Secy. Mulvaney memo, August 17, 2017], as a farther step towards UAS integration into the NAS. Understanding the volume and magnitude of UAM is essential in understanding safety implications and in prioritizing the FAA resources together with timing of allocating these scarce resources. Thus, the proposed research is designed to capture the following characteristics of the market potentials together with the implications on resources:

- Potential size and growth of the market at the local and/or at national level.
- Economic feasibility including price points at which individual market becomes viable.
- Anticipated cost to enter the market, considering factors such as vehicle acquisition and life cycle, operation liability, maintenance and replacement and upgrade schedules.
- Customer segments (e.g. regular business commuters, ad hoc travelers, etc.) for UAM viability.
- Characteristics of population density, traffic patterns including congestions, affordability, and preferred locations.
- Competition for UAM transportation or services (e.g. driverless cars and multi-modal transportation options, on-demand ride hailing services, virtual presence, etc.), providing cost comparisons where applicable.
- Ground infrastructure requirements, legal and management strategies consistent with the envisioned UAM network and connectivity to other transportation modalities as needed for efficient, "door-to-door" travel, and unplanned landing sites.

Furthermore, as part of the part 107 rulemaking effort, the FAA selected ASTM to establish a set of standards for airworthiness, maintenance, and operation in support of part 107. Understanding safety requirements for UAM, drawing upon the lessons learned from part 107, will require understanding barriers for additional demands on the NAS. While some of the existing constraints have been documented [see Thipphavong, et. al. (2018)], detailed analyses are presently unavailable and implications on UAM emergence and its penetration are not clear. For example, it is not evident how UAM:

- May impose demand on additional ATC infrastructure including airspace and workload on controllers?
- May require new paradigm to integrate with UTM and/or ATM?
- May impose demand on regulatory requirements including standards for airworthiness, certifications for design, maintenance and operations for vehicle-level and system-level safety and security?
- Will be resilient to a wide range of disruptions including weather and localized sub-system failures such as GPS?
- Will economically scale to high-demand operations with minimal fixed costs? and
- Will support user flexibility and decision-making including demands emanating from emerging UTM?

This research will identify weaknesses and develop a framework to make the standards more robust and increase the safety of potential UAM operations in the NAS. The projected benefits of this research include:

- Comprehensive analysis of market, feasibility, and projections of future demand together with their locations and timeline.
- Findings, recommendations, and lessons learned will the FAA understanding of Urban Air Mobility certification requirements.

This research also will explore:

- The role of autonomy in UAM vehicles.
- Air traffic management needs via UTM and/or ATM.

Future Research (ASSURE)

FAA Research Requirement: Investigate and Identify the Key Differences Between Commercial Air Carrier Operations and Unmanned Transport Operations **(A41)**.

FAA Research Focus Area: Unmanned Aircraft (UA) Crew Training and Certification, including pilots.

The passenger transportation network ecosystem and its associated technologies are likely to be among the most complex aviation has ever seen and the opportunities to facilitate the full integration of UAS into the NAS are significant. This research aims to characterize this ecosystem and analyze the differences between traditional manned and potential unmanned air transportation. These analyses along with timelines developed as a part of this research will enhance decision making and highlight the anticipated needs of the FAA to support further integration of UAS in air transportation operations in and across metropolitan areas including suburbs and exurbs.

This research seeks to answer the following questions:

- What is the potential for large UAS in carrying passengers in the US? Starting from road transportation and existing air transportation, it is expected that a potential market scope will be laid out.
- What are the likely locations of large UAS to meet demand and growth of air transportation over a period of 10 years?
- Will this change significantly follow the recovery from COVID-19?
- What interface characteristics are necessary for UAS passenger (e.g., UAM) to maintain awareness of aircraft system state with automated aircraft system and subsystem control?
- What are the envisioned characteristics of transition from piloted UAS to fully autonomous UAS in carrying passengers? What are the likely conditions that enable piloted UAS to transition into fully automated UAS and likely timeline?
- What interface characteristics are necessary for the UAS pilot to manage the aircraft's flight path with automated navigation?
- How can the autonomous systems be evaluated or certified such that safe integration of UAS in the existing ATM environment or emerging UTM is enabled?
- How will the UTM paradigm integrate with the large UAS environment? Or will a separate paradigm be needed? How these paradigms will be integrated with the NAS ATM that is already in place?
- How will strategic scheduling of large UAS occur?
- How will the non-scheduled large UAS be handled?
- What other resources and NAS investment may be necessary to facilitate growth of UAS in air passengers?
- What will be the aggregated economic benefits, i.e., direct, indirect, and induced, of integrating large UAS in transporting passengers on the overall economy?

In order to address these issues, an approach to predicting the larger (>55lb) commercial aircraft growth into the higher non-segregated altitudes (e.g., above 400ft AGL) is needed, with special emphasis on the use of these UAS in transportation of passengers. The approach (i.e., modeling and simulation of airspaces) along with near-term forecast is necessary to understand and prioritize NAS resources as these newer aircraft evolve in serving greater civilian and commercial needs such as air transportation. Finally, this research will inform future regulatory updates to UAS right-of-way rules, DAA performance standards, and collision avoidance standards.

FAA Research Requirement: From Manned Cargo to UAS Cargo Operations: Future Trends, Performance, Reliability, and Safety Characteristics Towards Integrations into the NAS **(A42)**.

FAA Research Focus Area: Unmanned Aircraft (UA) Crew Training and Certification including pilots.

This research is intended to address gaps in knowledge that are currently a barrier to the safe, efficient, and timely integration of UAS into the NAS. This includes the barriers to operating large UAS likely to be transporting cargo by air. This research will develop a framework for understanding and evaluating UAS commercial feasibility together with projected locational (i.e., specific areas) demand. Furthermore, an analytical framework detailing large UAS certification and explore the impact of autonomy on UAS with an emphasis on the cargo environment will be offered as well. Overall, this research has these projected benefits:

- Comprehensive analysis of market, feasibility, and projections of future demand together with their locations and likely network.
- Explicit accounting of effect of COVID-19 on likely adoption trends.
- Findings, recommendations, and lessons learned that will enhance the FAA understanding of Large UAS certification requirements beyond what is available.
- An exploration of the role of autonomy in UAS vehicles beginning with less risky areas (e.g., rural to exurbs) and then onto more populated areas of suburban and metro areas.

Thus, the proposed research is designed to capture the following characteristics of the market potentials together with the implications on resources:

- Potential size and growth of the air cargo market at the local and at national level.
- Economic feasibility including price points and competitive alternative (e.g., traditional delivery by trucks; existing manned air cargo) at which individual market becomes viable.
- Effect of pandemics, such as COVID-19, on the adoption of larger UAS in cargo carrying operations.
- Anticipated cost to enter the market, considering factors such as vehicle acquisition and life cycle, operation liability, maintenance and replacement and upgrade schedules.
- Customer segments (e.g. warehouses, business locations, residential nodes, etc.) for UAS viability in air cargo.
- Characteristics of population density, traffic patterns including radius of feasible logistics, affordability, and preferred locations for cargo hubs (i.e., defined network) vis-à-vis point-to-point deliveries (i.e., open delivery network).
- Characteristics of resulting network: defined network (i.e., delivery between defined end points such as warehouse to homes) vs. open delivery network (i.e., delivery to any location).
- Competition for UAS transportation or services (e.g. cargo hauling by road transportation, traditional air cargo modes etc.), providing cost comparisons where applicable.
- Ground infrastructure requirements, legal and management strategies consistent with the envisioned UAS network for air cargo and connectivity to other transportation modalities

as needed for efficient, "door-to-door" supplies, "door-to-cargo hubs", and planned or unplanned landing sites.
- Direct and indirect economic benefits of integrating large UAS in air transport and induced economic benefits of this transformation.

FAA Research Requirement: Mitigating GPS and ADS-B risks for UAS **(A44)**.

FAA Research Focus Area: Detect and Avoid.

Unvalidated or unavailable GPS and “ADS-B In” data poses security and safety risks to automated UAS navigation and to Detect and Avoid operations. Erroneous, spoofed, jammed, or drop-outs of GPS data may result in unmanned aircraft position and navigation being incorrect. This may result in a fly away beyond radio control, flight into infrastructure, or flight into controlled airspace. Erroneous, spoofed, jammed, or drop-outs of “ADSB-In” data may result in automated unmanned aircraft being unable to detect and avoid other aircraft or result in detecting and avoiding illusionary aircraft. For automated Detect and Avoid, a false ADS-B track can potentially be used to corral the unmanned aircraft to fly towards controlled airspace, structures, terrain, and so on. This research is necessary to enable safe and secure automated sUAS navigation and safe and secure automated sUAS Detect and Avoid operations. Goals for the project include reports and recommendations useful for FAA policy development and UAS standards development. It is expected that this information will be used to better understand the risks, potential mitigations, and help the FAA to reassess and refine FAA policy with respect to validation of ADS-B data. The research may lead to new navigation requirements related to GPS as well.

The research requirement is intended to assess the safety and security risks of unvalidated GPS and ADS-B In data used to support a variety of UAS operations to include sUAS operations, unmanned cargo transport, and remotely piloted passenger transport operations. For sUAS operations, particular emphasis will be on low cost and easy to implement mitigations commensurate with their safety and security risks. The research will address the following research questions and any related questions that are developed through the research process:

- What are the potential security and safety risks associated with reliance on GPS and ADS- B In data for different categories of UAS operations to include: sUAS operations, unmanned cargo transport, and remotely piloted passenger transport operations?
- Are there effective, low cost, and easy to implement solutions to mitigate GPS and ADS- B risks for sUAS operations?
- What potential solutions exist for unmanned cargo transport and remotely piloted passenger transport operations?
- What policy recommendations should the FAA consider to better manage potential security and safety risks associated with reliance on GPS and ADS-B data for different categories of UAS and their operations?

FAA Research Requirement: Shielded UAS Operations: Detect and Avoid **(A45)**.

FAA Research Focus Area: Detect and Avoid.

Certain sUAS BVLOS operations, such as structural inspection, may be in close proximity to structures that are collision hazards for manned aircraft. These types of operations that are in close proximity to manned aviation flight obstacles such that they provide significant protection from conflicts and collisions with manned aircraft are termed “shielded” operations. Industry and the FAA believe that some reduction in DAA requirements (to avoid other aircraft) when shielded by flight obstacles may be appropriate. Currently there is no comprehensive analysis to determine the correct balance between mitigating UAS hazards with other nearby low altitude manned aircraft and enabling shielded operations. This work effort is intended to identify risks and recommend solutions to the FAA that enable shielded UAS operations. This effort will identify risks, determine whether shielded operations can be made safe, to what degree UAS Detect and Avoid requirements can be reduced, and recommend UAS standoff distances from manned aviation flight obstacles.

This project is intended to inform rulemaking and has applicability to BVLOS operations, DAA, and right-of-way rules. This effort is also intended to support the next phase of the ASTM DAA standard that is expected to include DAA shielding concepts.

The Massachusetts Institute of Technology Lincoln Laboratory has performed some initial analyses under a UAS Science and Research Panel (SARP) effort that evaluated how close helicopters get to buildings in the Boston area. Internally, the FAA has explored shielding concepts that mitigate conflicts with manned aircraft. These previous efforts will be leveraged to help provide a foundation for this effort.

The effort of this project will focus on the following research questions:

- What types of sUAS failures may increase collision risks when operating near obstacles, structures, and critical infrastructure? What are some recommended mitigations to address these risks? For instance, are obstacle avoidance capabilities needed for shielding operations near critical infrastructure?
- What are safe standoff distances (vertical and horizontal) from obstacles, structures, and critical infrastructure for sUAS BVLOS operations?
- What types of manned aircraft operate in close proximity to flight obstacles and structures? How often do they operate in close proximity? How close do they fly to these structures? What are their operational limitations (day only, special procedures, special pilot requirements, etc.)?
- What other mitigations should be coupled with shielding concepts in order to manage collision risks with manned aircraft and with obstacles?
- To what degree can DAA requirements to avoid other aircraft (manned and unmanned) be reduced during shielded sUAS operations?
- What regulatory, policy, and legal issues should the FAA consider for shielded sUAS operations?
    - Example topics include:
        - What should the FAA consider so as to not be negligent in their risk management responsibilities when issuing waivers involving shielding operations?

  - What are the potential implications if an accident with a manned aircraft occurs and the FAA waived DAA requirements?
  - What are the potential implications if the FAA does not require active obstacle avoidance capabilities and a collision with critical infrastructure occurs?

FAA Research Requirement: Small UAS (sUAS) Mid-Air Collision (MAC) Likelihood **(A47)**.

FAA Research Focus Area: Low Altitude Safety.

The primary goal of regulating UAS operations in the NAS is to assure an appropriate level of safety. This goal is quantified by national aviation agencies as an "Equivalent Level of Safety" (ELOS) with that of manned aviation. There are major key differences between manned and unmanned aviation that do not only lay in the separation of the pilot from the cockpit and the level of automation introduced but also in the variety of architectures and materials used for the construction of UAS. These differences could introduce new failure modes, and, as a result, and increased perceived risk that needs to be evaluated. In order to have an equivalent level of safety, according to the definition of the Range Commanders Council in its guidance on UAS operations it states that, any UAS operation or test must show a level of risk to human life no greater than that for an operation or test of a piloted aircraft.

The aforementioned metrics provide statistical probabilities of UAS mid-air collisions according to specific parameters defined for the evaluation. It should be noted that not all collisions lead to catastrophic accidents. The large variability of UAS sizes and the fact that not all the aircraft systems are critical for remaining airborne means that the aircraft involved may survive certain collisions.

The risk assessment to develop an Airborne Collision Unmanned Aircraft Systems Impact Severity Classification can be divided into three elements:

- Estimation of the probability of mid-air collision between UAS and manned aircraft. This will be a function of the operating airspace, aircraft operated within the airspace and the UAS configurations operating within the shared airspace.

- Evaluation of damage potential for typical UAS (classes based on weight, architecture, operational characteristics [altitude, velocity] mid-air collisions scenarios per manned aircraft class (commercial, general aviation, rotorcraft...) in order to assess the damage severity to manned aircraft. Several groups advocate to use simplified ballistic penetration models, similarity principles to existing bird strike requirement or kinetic energy thresholds. The objective of this project is to evaluate the severity of a typical quad and fixed wing UAS airborne collision. These results will be compared with current proposed penetration mechanics and energy-based criteria.

- Once the probability of an airborne collision is determined, the damage models can be combined with the probabilistic collision models to define appropriate Equivalent Level of Safety criteria.

To complement other collision severity research and produce a complete risk assessment of sUAS MAC with manned aircraft, MAC likelihood research needs to be completed. Because collision severity depends on where the collision occurred on a manned aircraft, this likelihood research will not only investigate overall MAC probabilities but also the MAC probabilities with different parts of manned aircraft. This likelihood assessment will investigate sUAS collisions with both General Aviation and Commercial aircraft.

The following research questions will guide this project:

- What is the probability of a UAS without a detect and avoid (DAA) system colliding with a manned aircraft?
- What is the probability of a UAS with a detect and avoid system colliding with a manned aircraft?
- What role does altitude play in collision likelihood?
- What is the overall risk of MAC with and without a detect and avoid system?
- How does UAS collision risk compare with the risk of a bird strike?

This research project has the following projected benefits:

- Unmitigated and Mitigated MAC probabilities models will be developed.
- Collision probabilities with individual parts of a manned aircraft will be considered.
- UAS Data from actual, real-world flight operations, will be used; it does not rely on Monte Carlo methods or other assumptive simulations.
- Manned Aircraft flight data is derived from ADS-B sources and provide measured improvements in accuracy and higher sampling rate than radar data.

The FAA's UAS Integration Research Plan contains identified research needs that will spawn additional requirements for ASSURE research. As the full integration of UAS into the NAS becomes closer to reality, the need to set the standards, rules, and regulations governing will require additional, more complex, safety analyses and testing by the ASSURE team in conjunction with industry consensus standards and FAA rulemaking.

ASSURE Relationship to Industry Consensus Standards

One of several avenues to bring the outputs of ASSURE research to industry is through participation in industry consensus groups, such as ASTM International. Participating in such groups provides a mechanism to bring lessons learned through research to industry by informing the development of standards. This approach enables a translation of research outcomes to industry and enables a means to validate findings.

The following past and current ASSURE research projects have involved participation in industry consensus standards groups, ASTM International in particular. While this list in not all-inclusive, it provides a snapshot of some of the contributions that ASSURE research has made to the standards development community. It also highlights some key focus areas where ASSURE has made significant contributions to the body of knowledge, helping to steer industry focus and inform solutions to various challenges facing the UAS industry as a whole.

ASSURE A1: Certification Test Case to Validate sUAS Industry Consensus Standards
This research involved the validation of ASTM standards for use in developing flight test plans for UAS type certification. As part of this research, the team generated a flight test program for as UAS. Outcomes of this research informed revisions to ASTM F2910 as well as the development of F3298 – Standard Specification for Design, Construction, and Verification of Lightweight Unmanned Aircraft Systems (UAS).

ASSURE A18: Small UAS Detect and Avoid Requirements Necessary for Limited Beyond Visual Line of Sight (BVLOS) Operations
ASSURE A18 addresses testing for small UAS detect and avoid systems for use in beyond visual line of sight (BVLOS) flight. At the time this report was drafted, research for ASSURE A18 is ongoing. The research team for ASSURE A18 has been actively engaged in the development of standards for use in setting performance and testing requirements for detect and avoid (DAA) systems. These standards include:

- ASTM F3442/F3442M – 20: Standard Specification for Detect and Avoid System Performance Requirements
- ASTM WK62669: New Test Method for Detect and Avoid

ASSURE A27: Establish risk-based thresholds for approvals needed to certify UAS for safe operation
Research through ASSURE A27 is ongoing at the time this report was drafted. ASSURE A27 revolves around determining thresholds and processes for risk-based approvals for type certification of UAS, to include requirements for pilot training. A key element of ASSURE A27 research is the participation in the ASTM WK70877 working group: New Practice for Showing Durability and Reliability Means of Compliance for Unmanned Aircraft Systems. This research also involves following an applicant through the type certification process and documenting procedures, challenges, and methodologies to provide additional insight to both the FAA and industry.

Continued engagement with industry consensus bodies is critical to translating ASSURE research to industry. It not only serves to assist regulators in translating research to industry, but it also serves as a means to validate findings. The same is true for the development of a low-altitude risk assessment roadmap. Engagement with industry will be critical in establishing sources of key data points and processes to build upon data categories identified through ASSURE A25 research.

Low-Altitude Risk Assessment Roadmap – Outline

What follows is an outline of the low-altitude risk assessment roadmap that resulted from ASSURE A25 Task 1-3. This roadmap represents a selection of data categories that the ASSURE A25 research team derived through input from subject matter experts (SMEs), ongoing ASSURE research, and knowledge of risk assessment practices and methodologies. As such, it represents the research team's best effort to identify data categories required to characterize low-altitude airspace environments and associated gaps in information. With the apparent need to understand and characterize a vast array of low-altitude operating environments, the research team intends for this roadmap to inform follow-on research to expand these data categories into populated sets of information that can point towards (1) standards and practices for low-altitude risk assessment and (2) policy regarding low-altitude UAS operations.

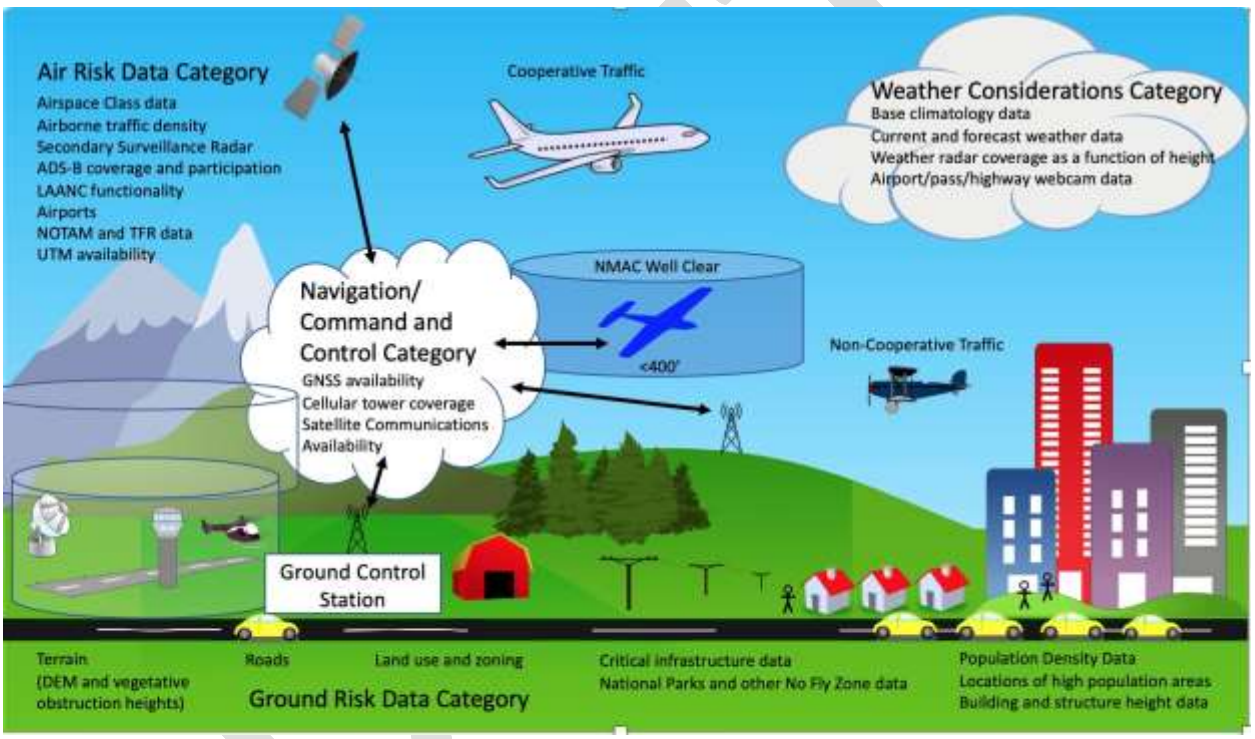

Figure 1. Representation of data categories for low-altitude risk assessment.

1.1. Air Risk Data Categories

Data categories in this section have relevance in determining air risk components required for a low-altitude risk assessment. While this list is not exhaustive, it provides a starting point for variables to consider when developing methodologies for quantifying the level of air risk associated with a given UAS flight operation. As such, data categories and variables highlighted in this section rely heavily on the work performed by the Massachusetts Institute of Technology Lincoln Labs (MIT LL) to develop a series of probabilistic models for airspace encounters – e.g. airspace encounter models. These models were developed using various sources of openly available geospatial information, map data, and aircraft characteristics and rely on extensive use of Monte Carlo simulation to provide probabilistic collision models to cover a large number of encounter scenarios.

Work performed by the MIT LL yielded five sets of encounter models that are useful for providing a starting point for baseline low-altitude air risk. These models, as highlighted in Weinert et al. (2020), are:

1. Uncorrelated Encounter Model – Applicable for non-cooperative aircraft without ATC services

2. Correlated Encounter Model – Applicable for cooperative aircraft with ATC services

3. Encounter Models for Unconventional Aircraft – Applicable for unconventional aircraft without a transponder equipped

4. Due Regard Encounter Model – Applicable for UAS flying in oceanic airspace flying with due regard

5. Helicopter Air Ambulance Model – Applicable for evaluating system performance for helicopter air ambulance encounters.

More detailed descriptions of these encounter models are out of scope for this research. However, detailed descriptions of these encounter models and their baseline assumptions and constraints may be found in Weinert et. al (2020).

While an in-depth assessment of the encounter models is out of scope for this research, the models do include important data categories and variables that are essential for establishing a clear picture of air risk. As such, the data categories that follow rely heavily from literature regarding the development and application of these encounter models.

1.2. Airspace Class

The different national airspace classes can be grouped into controlled and uncontrolled airspaces. For small UAS under part 107, the primary airspace available is uncontrolled airspace (class G) below 400 ft AGL. This does not mean however that all this volume of airspace is available to small UAS operators. This data category supports the identification of risks associated with inadvertent incursion into prohibited areas. Flight plans should be checked against data sources indicating the airspace class. Airspace features and aviation infrastructure can be accessed through the National Airspace Resources (NASR) database (FAA, 2020k). Every risk of incursion into unauthorized areas should be properly mitigated. Data information is considered stable through time. However, the information in this data category should be complemented with other data categories, such as "Zoning" or "National Parks and other no fly zones." The following figure illustrates where a UAS is allowed to fly, and where it needs ATC authorization and/or waiver.

Figure 2. Airspace Guidance for sUAS Operators.

1.3. Airborne Traffic Density

This category also includes traffic type, speed, and trajectory information. Traffic type is broken down into manned/unmanned, and cooperative/non-cooperative traffic.

MITRE (2017) identifies the UAS Accidents Report Database, owned by the FAA, as an information source related to this data category. The data years range between 2010 and 2014, when 105 occurrences were reported. The following information is downloadable at FAA (n.d.): Sponsor category, Sponsor, Event Date, Event Location, Event Type, and Aircraft Type. However, the reports themselves are not publicly available.

Alternatively, some of the following sources could provide more information:

- NTSB Aviation Accident and Incident Database (NTSB, n.d.).
- FAA Aviation Safety Reporting System NASA, (FAA, n.d.a).

- SkyWatch is a data source owned and managed by the FAA, with restricted access. (FAA, n.d.b).
- UAS Sightings reported to the FAA since November 2014 can also be accessed at FAA (2020g).
- Finally, the Near Mid-Air Collision System (NMACS) allows textual search across a wide range of data fields and is available at FAA (n.d.c).

MITRE's Centre for Advanced Aviation System Development (CAASD) has been developing Threaded Track since 2011. It consists of a compilation of several surveillance sources into a synthetic trajectory (Ahmed et al., 2017). Each of these data sources (which are radar-based) has different coverage and quality aspects associated, which may be considered during the integration process. Position reports from Terminal Radar Approach Control (TRACON) facilities, Air Route Traffic Control Centers (ARTCC) Airport Surface Detection Equipment, model X (ASDE-X), Enhanced Traffic Management System (ETMS) and Automatic Dependent Surveillance (ADS-B) are combined using the callsign as a unique identifier for each flight, thus avoiding ghost flights and data duplication. Unassociated data (flights not associated with a specific callsign) are also included in Threaded Track. This last group is made of VFR and General Aviation (GA) traffic, IFR over-flights and redundant coverage, and noise. Radar information in ARTCCs and TRACONs is obtained through the National Offload Program (NOP) that the FAA established in 2010. The information is complemented with ETMS from the same Common Message Set (CMS) data provided by the NOP as provided by ARTCC. Threaded Track data is archived in MITRE's Center for Advanced Aviation System Development (CAASD) with FAA Air Traffic Organization's (ATO) permission. They are only accessible by MITRE staff working in FAA projects.

FAA also owns the Performance Data Analysis and Reporting System (PDARS). PDARS is a specialized software to collect ATM data from the NAS. It is available in 20 ARTCCs (En-Route Automation Modernization, ERAM data), 28 TRACONS (through the Automated Radar Terminal System, ARTS and Standard Terminal Automation Replacement System, STARS) and airports (35 ASDE-X sources). It is intended for government use only. PDARS shares with Threaded Track compatibility issues among sources used. PDARS is only for government use, and commercial and academic exploitation is prohibited.

Finally, radar data from the 84th Radar Evaluation Squadron (RADES) located at Hill AFB, UT provide information on VFR flights (A-coded 1200). RADES receives radar data from FAA and DoD sites. They maintain continuous real-time feeds from a network of sensors with radar ranges spanning from 60 to 250 NM. Weinert et al. used 229 VFR reports from 84 RADES in 2013 to develop a model for aircraft close encounters, in which at least one of the aircraft is under VFR rules (Weinert et al., 2013).

1.4. Secondary Surveillance Radar

The 84th Radar Evaluation Squadron (RADES) monitors, evaluates, optimizes, and integrates fixed and mobile long-range radars for both the operational and federal communities. RADES capabilities include:

- Performance monitoring (480 sensors from the four military sectors),
- Sensor evaluation/optimization (211 sensors), and
- Radar obstruction evaluation (OE): Evaluation of radar impact caused by various obstructions (building constructions, wind turbine, etc.)

The data is forwarded to the North American Aerospace Defense Command (NORAD) and Air Combat Command (ACC) HQ.

1.5. ADS-B Coverage

The FAA currently maintains an interactive map that can be displayed in Google Earth, which highlights ADS-B coverage at various altitudes, equipage requirements for various spaces classes, and radar coverage. Challenges related to uncertainties on temporal resolution of this data set makes it unsuitable for navigation and flight planning. However, this tool is useful to identify areas where ADS-B coverage may not be guaranteed, and it provides a starting point to identify airspace volumes where ADS-B equipage and usage may become an important factor in a low-altitude risk assessment. A link to the FAA's Google Earth ADS-B plugin is downloadable at FAA (2020a).

1.6. ADS-B Participation

OpenSky collects worldwide data via a network of crowdsource ADS-B receivers. The network began operations in 2012 using 12 European sensors, but since then it has grown to over a thousand of them distributed around the globe. In the U.S., ADS-B equipped aircraft use Mode-S (the ICAO standard) or Universal Access Transceiver (UAT) links to automatically self-report their position to ground stations and other equipped aircraft.

In order to analyze ADS-B participation in low altitude operations, one must consider ADS-B coverage. Fewer ADS-B communication messages below 400 ft than above do not mean less ADS-B messaging in that portion of airspace, but its use might be impaired by VLOS obstructions.

1.7. LAANC Functionality

The FAA UAS Data Exchange is a collaborative approach between government and private industry facilitating the sharing of airspace data between the two parties. Under the FAA UAS Data Exchange umbrella, the agency will support multiple partnerships, the first of which is the Low Altitude Authorization and Notification Capability (LAANC). As of September 2020, 726 airports and 537 air traffic facilities participate in LAANC (FAA, 2020j).

LAANC offers the following information:

- Awareness of where pilots can and cannot fly.
- Air Traffic Professionals with visibility into where and when UAS are operating. It is noteworthy the remark of certain sources on the fact that some manned aviators do not have visibility on UAS operations (Aviators Code Initiative, 2019).

1.8. Airports

FAA definition of airport is: “[An] area on land or water intended to be used either wholly or in part for the arrival; departure and surface movement of aircraft/helicopters.” FAA airports information can be found at FAA (2020k).

1.9. NOTAM and TFR

Notice to Airmen (NOTAMs) and Temporary Flight Restrictions (TFR) can be accessed through FAA (2020d).

1.10. UTM Availability

Unmanned Aircraft System Traffic Management (UTM) is a separate management system for UAS but complementary to FAA Air Traffic Management (ATM) system. The research team that leads the transition towards full UTM integration into the NAS is composed of NASA, FAA, and industry participants. It aims at identifying airspace operations requirements for visual line of sight (VLOS) and beyond visual line of sight (BVLOS) operations for UAS. NASA and FAA have jointly collaborated in the development of the UTM Research Plan. Recent activity in UTM comprises:

- The second version of UTM Concept of Operations (CONOPS) was released on March 2, 2020 (FAA, 2020e).
- Technical Capability Level (TCL) 4 was completed in August 2019 with tests in Reno, NV and Corpus Christi, TX. (NASA, 2020).
- The FAA set up the UTM Pilot Program (UPP) to define a set of capabilities to support UTM operations (FAA, 2020h).

Following the FAA modernization and Reform Act of 2012 and the FAA Extension, Safety and Security Act of 2016, the FAA established seven UAS Test Sites around the country. Their main objective is to “provide verification of the safety of public and civil UAS, [*sic.*] operations, and related navigation procedures before their integration into the NAS.” (FAA, 2020f).

1.11. Ground Risk Data Categories

Data categories under this label cover population distribution, terrain geography, as well as man-made structures.

1.12. Population Density

An area's current population density is an ideal data point to help understand the risks that an aircraft operation poses to people on the ground. However, short of real-time location monitoring of cell phone location data, there may be large inaccuracies in population density data. Population density varies by time of day, specific days of the year, and scheduled and unplanned events such as concerts and sports. A potential compromise that comes short of real-time location monitoring is using anonymized historical location data from cell phones. This type of data is commercially available through providers like AirSage (AirSage, n.d.). Also, population density data is normally available through local administrations.

1.13. Locations of High Population Areas

The Next Generation 911 system's implantation has improved the quality of Geographic Information System (GIS) data available to dispatchers. This data includes the identification of high-population areas. Although it is decentralized to local dispatch offices, there could be an effort to consolidate information from the Next Generation 911 system relevant to quantifying the risk of aircraft operations to a particular environment. Next Generation 911 GIS data can be supported with different business solutions, one of them being ArcGIS (ArcGIS, n.d.). Public Safety Answering Points (PSAP), designated centers to receive and route 911 calls, are in the process of being upgraded to a digital environment. GIS maps provide road centerlines names and location.

1.14. Terrain (DEMs and Vegetative Obstruction Heights)

The 3D Elevation Program (3DEP) will provide a nation-wide, lidar-based Digital Elevation Model (DEM) by 2021. This program is managed by the U.S. Geological Survey (USGS) National Geospatial Program (USGS, n.d.a). Other DEMs exist, although with less resolution as that offered by 3DEP. These are:

Digital Terrain Elevation Data (DTED) standards DTED2 and DTED1 from the National Geospatial-Intelligence Agency (NGI) with 1-arc second and 3-arc seconds resolution respectively are only available to the Department of Defense (DOD), DOD contractors, and U.S. Government agencies supporting DOD functions. DTED0 shares 30-arc seconds resolution with other models such as GLOBE, GTOPO30 and its enhancement GMTED2010. GLOBE data is available through the National Oceanic and Atmospheric Administration (NOAA) website (National Centers for Environmental Information, n.d.a). Its cost is $25. GTOPO30 is available through EarthExplorer. GMTDE2010 can be visualized in GMTED2010 Viewer (n.d.). GTOPO30’s root mean square error (RMSE) is 66 m, whereas GMTDE2010’s ranges between 26 and 30 m.

1.15. Land Use and Zoning

Land use and zoning data are decentralized to local municipalities. There are also some municipalities that are not zoned. Therefore, the data quality can vary, and it would take an extensive consolidation effort to integrate this data.

1.16. Building & Structure Heights

Building and structure heights are another decentralized data category. One location where this data is found is in local airport master plans. Although this data source would not cover all possible building and structure heights, it would provide heights of buildings and structures close to airports infrastructures. Another potential data source is the FAA's Digital Obstacle File, which is updated every 56 days and can be accessed at the FAA's website (2020c).

1.17. National Parks and Other No-Fly Zones

A data source that can help identify national parks and determine if a property is privately or publicly owned is OnX Hunt app. (OnX 2020). This data source is an application that has been conceived to help hunters identify hunting locations and contact information. The data could be used to help to characterize the risk posed on a protected environment by a UAS operation. Another nation-wide data set that may have applicability to aid the characterization of environmental risk is the Landfire program (n.d.). This program contains publicly available information.

Partnered with the FAA, Kittyhawk has developed the B4UFLY app for UAS users to gather information on safe areas to fly (Kittyhawk, 2020). Examples of areas where operations are restricted include: Special Flight Rule Area around Washington D.C., critical infrastructure, airports, military training routes and temporary flight restrictions. The B4UFLY app is available for free at the App Store for iOS and Google Play Store for Android.

1.18. Critical Infrastructure

There are several open source databases of geospatial information relating to critical infrastructure that are available for free. While not exhaustive, this section provides a brief list of commonly available information related to power lines, rail lines, roads, and pipelines. These sources were identified by Weinert (2020) for the purpose of defining UAS use cases as inputs for encounter models. Examples of information locating critical infrastructure are shown below:

- Linear infrastructure
    - Power transmission lines: U.S. Department of Homeland Security (DHS) Homeland Infrastructure Foundation Level Data (HIFLD) (Homeland Infrastructure Foundation-Level Data, 2020).
    - Railway tracks: Geofabrik OpenStreetMap (OSM) (Geofabrik, 2018). A German product, full metadata is available to Geofabrik OSM contributors only.
    - Pipelines: U.S. Energy Information Administration (EIA) provide information on pipelines locations for crude oil, hydrocarbon gas liquids, natural gas, and petroleum products (Energy Information Administration, n.d.). In particular, crude oil pipelines location can be downloaded directly here: https://www.eia.gov /maps/map_data/CrudeOil_Pipelines_US_EIA.zip
    - Roads: There are several sources that provide information on roads. Among others, the Natural Earth data has 10 m accuracy and have been extracted from the CEC North America Environmental Atlas (Natural Earth, 2020).

- Aviation obstacles: The FAA provides information nearby airports (FAA, 2020b).

These open data sources are publicly available. However, Weinert (2020) notes that, "A challenge is that many datasets do not guarantee complete coverage of all features. This issue exists for both federally managed and open sourced datasets. The information available across datasets vary too and correlating datasets can be challenging" (A. Weinert, 2020, p. 11). This implies that while these data sources may be useful, their accuracy may be difficult to determine.

In addition to the sources listed above, the B4UFLY app may also provide additional information relating to critical infrastructure.

1.19. Roads

Road data are decentralized to local municipalities. Although a nation-wide data does exist, it can be limited in scope and quality. It would take an extensive consolidation effort to integrate the higher quality data housed by local communities. For more information, see "Critical Infrastructure" subsection above.

1.20. Navigation/Command and Control

Data categories under this group are related to navigation satellite systems, and communications platforms for command and control (C2), either satellite- or ground-based.

1.21. GNSS Availability

To date, DoD maintains the Global Positioning System (GPS) without selective availability. The complete GALILEO deployment (24 satellites + 6 active spares) is expected by the end of 2020.

1.22. Satellite Communication Coverage

Two satellite constellations provide services to cell phone companies: Iridium and Globalstar. Iridium NEXT satellites number 66, distributed in six rings (i.e., 11 satellites per ring) located at 485 miles above the Earth. Each satellite has an orbital period of 100 min and travels at a speed of 17,000 mph on average. Iridium satellites add a latency to the system of about 40-50 ms. A coverage map can be found at GroundControl (n.d.).

Globalstar constellation consists of 24 satellites in LEO orbit, distributed in eight orbital planes of six satellites each. With an orbit inclination of 52^o, they provide full coverage between 70^oN and 70^oS. Their orbital period ranges from 114 to 130 min. A coverage map of Globalstar can be found at GlobalCom (2019).

1.23. Cellular Coverage

Several websites provide information on cellular coverage. By introducing a zip code or address, a map can be zoomed in a specific area within the U.S. It is also noteworthy that the U.S. Department of Agriculture (USDA) is currently working on several programs to make broadband connectivity available in rural areas around the country. Cellular coverage data is provided in the form of maps. Depending on the website used, information on different network providers and standards can be retrieved:

- US Cellular (USCellular, n.d.): Coverage on 5G, 4G Long Term Evolution (LTE), 3G Data and 4G LTE roaming.
- T-Mobile (T-Mobile, n.d.a) It provides a comparison between T-Mobile, AT&T and Verizon coverage.
- Verizon (Verizon, 2020): 5G ultra wideband, 5G nationwide, 4G LTE and 3G coverage.
- AT&T (ATT, n.d.): 5G and 4G LTE coverage.
- Sprint (merged with T-Mobile in 2020) (T-Mobile, n.d.b): 4G LTE coverage.

A compatible device is required to connect to a specific network. The following issues should also be considered when using each of the sources above:

- US Cellular: The map shows an approximation of service coverage. Actual coverage may vary. Service may be interrupted or limited due to weather, terrain, customer equipment, or network limitations. Coverage indoors may also vary. US Cellular does not guarantee coverage.
- T-Mobile: The website does not present any restrictions to the data.
- Verizon: A coverage disclaimer is included. Among other things, they are not a guarantee of coverage, and wireless service subject to network and transmission limitations. Also, customer equipment, weather, topography, and other environmental considerations associated with radio technology also affect service and service may vary significantly within buildings. The accuracy of the data is not guaranteed.
- Sprint: A disclaimer is presented with similar aspects highlighted in US Cellular or Verizon.

1.24. Weather Considerations

A broad spectrum of weather information tools exists. Only some of them are aviation specific. For those that are not, the National Oceanic and Atmospheric Administration (NOAA) provides a good starting point of weather data information, although the industry has also developed useful tools for weather assessment.

1.25. Base Climatology

The National Oceanic and Atmospheric Administration's (NOAA) National Centers for Environmental Information provide a broad range of historical weather products. Temperature and precipitation values, and weather anomalies can be retrieved with different granularity (daily, monthly, seasonal, and annual), for the CONUS and Alaska. This data can be retrieved from NOAA (National Centers for Environmental Information, n.d.b).

1.26. Current Conditions

UAS operators should consider the accessibility to and use of sources for weather current conditions in their area, previous to the intended flight. Meteorological Aerodrome Reports (METAR) are the international standard code format to provide weather information at airports. Information included in METARs reports include current wind direction and speed, visibility, cloud cover, temperature, and dewpoint. However, METARs are limited to geographical regions at or on airport surroundings. They are updated hourly, unless significant weather changes occur, in which case the frequency is adapted to the specific phenomenon. In this last case, the report is called SPECI. METAR data can be retrieved from the Aviation Weather Center (n.d.a).

1.27. Forecast Conditions

As with current weather conditions, UAS operators should consider the accessibility and use of sources for weather forecast conditions in their area, previous to operations. Terminal Area Forecast (TAF) are the international standard code format to provide weather forecast at terminal areas (5 miles from the Airport Reference Point, ARP). On a broader range, the NOAA also has a broad range of forecast products.

TAF uses the same descriptors as METAR. NOAA uses two information ranges, short range (up to 48 hr) and medium range (up to six days) forecasts for pressure patterns, circulation centers and fronts. Maps on temperature, dewpoint, sky cover and amount of precipitation are also available. TAF reports are valid for 24 hr. and are updated every six hours. NOAA maps provide forecast for every 3hr. range. TAF data can be retrieved at Aviation Weather Center (n.d.b).

A broad set of weather graphical information can be retrieved at the National Oceanic and Atmospheric Administration (n.d.a).

1.28. Weather Radar Coverage as a Function of Height

NOAA uses the Next Generation Weather Radar (NEXRAD) and the Terminal Doppler Weather Radar (TDWR) to obtain precipitation and wind information in a given area. NEXRAD is a network composed of 159 radars which uses S-band doppler technology. It is managed by

NOAA, the FAA, and the U.S. Air Force. TDWR is a radar network operated by the FAA which is used primarily for the detection of hazardous wind shear conditions, precipitation, and winds aloft on and near major airports situated in climates with great exposure to thunderstorms in the United States. Data coverage products come in a map form. NEXRAD and TDWR coverage is available for 3,000 ft, 6,000 ft and 10,000 ft AGL (National Oceanic and Atmospheric Administration, n.d.b).

1.29. Airport/Pass/Highway Webcams

Helios® is an image-based, real time system operated by L3Harris, which feeds on a network of thousands of public and private sensors and apply built-in analytics from which to extract information. Weather validation can assist go-no-go decisions (L3Harris, 2020). A potential data source to validate localized real-time, Helios uses machine vision to automatically categorize the weather, particularly precipitation, based on public and private video cameras. Weather validation can assist go/no-go decisions as well as inform the weather context after an operation. Helios® access requests are submitted through their website (L3Harris, n.d.).

1.30. Morning and Evening (Civil Twilight Times as a Function of Time of Year)

Sunrise and sunset times updated every day for most locations around the country. Information provided also includes civil twilight (when the geometric center of the Sun's disk is between 0° and 6° below the horizon), nautical twilight (6°-12°) and astronomical twilight (12°-18°). Both dawn and dusk times are available.

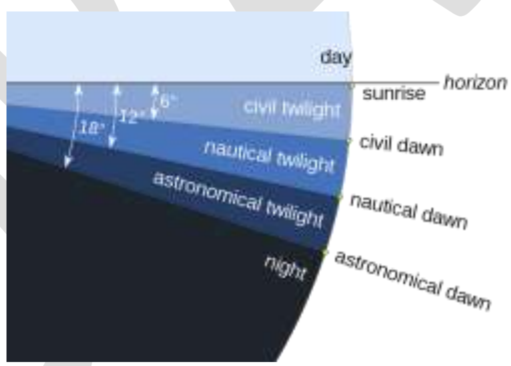

Figure 3. Morning twilight.

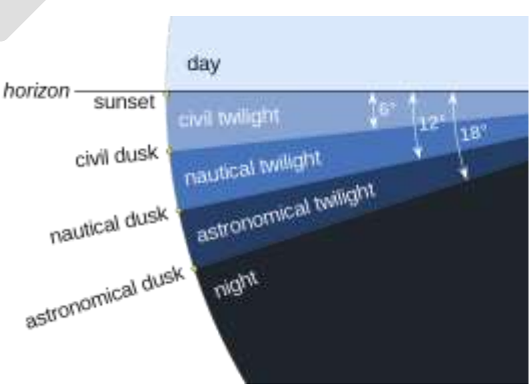

Figure 4. Evening twilight.

Information relating to morning, evening, and civil twilight times may be found at Time and Date (n.d.).

CONCLUSION AND RECOMMENDATIONS

The data categories and example data sets outlined above provide a roadmap for collecting and merging the data required to develop a comprehensive low-altitude risk assessment tool. Identifying specific data elements inside of these data categories and establishing consistency among the data sets and data elements needed to create a working low-altitude risk assessment tool for any location in the United States is beyond the scope of this effort. However, the effort outlined above could lead to research requirements for the ASSURE team and industry partners that would provide the missing data categories and elements needed to create improved safety cases for low-altitude operations or the development of low-altitude risk assessment tool. The information collected through these efforts and ASSURE research will inform: (1) standards and practices for low-altitude risk assessment and (2) policy regarding low-altitude UAS operations. The environmental conditions described by the elements of the roadmap, when combined with a rigorous safety analysis of the aircraft and standardized training of airmen, will provide a quantitative description of the potential risks of any CONOPs, allow for the mitigation of those identified risks, and result in safer, low-altitude UAS operations.

REFERENCES

Ahmed, S., Harback, K. T., Hechtman, D. M., Maroney, D. R. & Tsao, S. (March 2017). Unmanned Aircraft Systems data catalog. MITRE.

AirSage (n.d.). *Location storytelling through anonymous mobile-based data*. https://www.airsage.com/?gclid=Cj0KCQjw28T8BRDbARIsAEOMBcxJqkDgIlU4MspqNXuTobH3yz805-Pqj7B7nwIRniVJctPQrDAjmkEaAtQKEALw_wcB

ArcGIS (n.d.). *Developing and Maintaining Next Generation 9-1-1 GIS Data in Rural Areas*. https://www.arcgis.com/apps/Cascade/index.html?appid=5344beb51d394d838338c0cfccdc568f

ATT (n.d.). *Wireless coverage*. https://www.att.com/maps/wireless-coverage.html

Aviation Weather Center. (n.d.a). *METARs*. https://www.aviationweather.gov/metar

Aviation Weather Center. (n.d.b). *TAFs*. https://www.aviationweather.gov/taf

Aviators Code Initiative. (March 8, 2019). *Improving cockpit awareness of Unmanned Aircraft Systems near airports*. ACI. https://www.secureav.com/UAS-Awareness-WP-v1.0.pdf

Carlson, T. W. (2017). *Evening twilight*. Wikipedia. https://en.wikipedia.org/wiki/Twilight#/media/File:Twilight-dawn_subcategories.svg

Carlson, T. W. (2017). *Morning twilight*. Wikipedia. Wikipedia. https://en.wikipedia.org/wiki/Twilight#/media/File:Twilight-dawn_subcategories.svg

Energy Information Administration. (n.d.). *Maps*. https://www.eia.gov/maps/

Federal Aviation Administration (n.d.a). *FAA UAS Accident and Incident Preliminary Reports*. https://www.asias.faa.gov/apex/f?p=100:446:::NO:446::

Federal Aviation Administration (n.d.b). *SkyWatch*. https://skywatch.faa.gov/

Federal Aviation Administration (n.d.c). NMACS System Information. https://www.asias.faa.gov/apex/f?p=100:35:::NO::P35_REGION_VAR:1

Federal Aviation Administration (2018, October 30). *Airspace 101- Rules of the sky*. https://www.faa.gov/uas/recreational_fliers/where_can_i_fly/airspace_101/

Federal Aviation Administration (2020a, January 28). *Airspace*. https://www.faa.gov/nextgen/equipadsb/research/airspace/

Federal Aviation Administration (2020b, February 7). *Digital Obstacle File (DOF)*. https://www.faa.gov/air_traffic/flight_info/aeronav/digital_products/dof/

Federal Aviation Administration (2020c, February 8). *Digital Obstacle File (DOF)*. https://www.faa.gov/air_traffic/flight_info/aeronav/digital_products/dof/

Federal Aviation Administration (2020d, February 18). *NOTAMs, TFRs and Aircraft Safety Alerts*. https://www.faa.gov/pilots/safety/notams_tfr/

Federal Aviation Administration (2020e, March 2). *Unmanned Aircraft Systems (UAS) Traffic Management (UTM) Concept of Operations v2.0*. https://www.faa.gov/uas/research_development/traffic_management/media/UTM_ConOps_v2.pdf

Federal Aviation Administration (2020f, May 6). *UAS Test Site Program*. https://www.faa.gov/uas/programs_partnerships/test_sites/

Federal Aviation Administration (2020g, July 28). *UAS Sightings Report*. https://www.faa.gov/uas/resources/public_records/uas_sightings_report/

Federal Aviation Administration (2020h, July 30). *UTM Pilot Program (UPP)*. https://www.faa.gov/uas/research_development/traffic_management/utm_pilot_program/

Federal Aviation Administration (2020i, September 10). *Airports*. https://ais-faa.opendata.arcgis.com/datasets/e747ab91a11045e8b3f8a3efd093d3b5_0

Federal Aviation Administration (2020j, September 23). *Air Traffic Facilities Participating in LAANC*. https://www.faa.gov/uas/programs_partnerships/data_exchange/laanc_facilities/

Federal Aviation Administration (2020k, October 8). *28 day NASR subscription*. https://www.faa.gov/air_traffic/flight_info/aeronav/aero_data/NASR_Subscription/

Geofabrik. (2018). *OSM for North America*. https://download.geofabrik.de/north-america.html

GlobalCom. (2019). *GlobalStar Satellite Phone World Wide Coverage Map*. https://globalcomsatphone.com/support6/

GroundControl. (n.d.). *Iridium Coverage Map. Real time*. https://www.groundcontrol.com/Iridium_Coverage_Map.htm

Homeland Infrastructure Foundation-Level Data (HIFLD). (2020). *Electric Power Transmission Lines*. https://hifld-geoplatform.opendata.arcgis.com/datasets/electric-power-transmission-lines

Kittyhawk. (2020). *B4UFLY*. https://kittyhawk.io/b4ufly/

LandFire. (n.d.). *LandFire (LF)*. https://landfire.gov/

L3Harris. (n.d.). *Helios*. https://www.l3harrisgeospatial.com/Software-Technology/Helios

MITRE (2017, March). *Unmanned Aircraft Systems Data Catalogue*.

National Aeronautics and Space Administration (n.d.). *Aviation Safety Reporting System*. https://asrs.arc.nasa.gov/

National Aeronautics and Space Administration (2020, August 10). *UTM*. https://utm .arc.nasa.gov/index.shtml

National Centers for Environmental Information (n.d.a). *GLOBE version 1.0 Digital Elevation Data, 1999*. https://www.ncdc.noaa.gov/nespls/olstore.prodspecific?prodnum=G01180-CDR-A0001

National Centers for Environmental Information (n.d.b). *Temperature, Precipitation and Drought*. https://www.ncdc.noaa.gov/temp-and-precip/

National Oceanic and Atmospheric Administration. (n.d.a). *National Weather Service*. https:// graphical.weather.gov/

National Oceanic and Atmospheric Administration. (n.d.b). *Radar Operations Center*. https://roc.noaa.gov/WSR88D/Maps.aspx

National Transportation Safety Board. (n.d.). *Aviation Accident Database & Synopses*. https://www.ntsb.gov/_layouts/ntsb.aviation/index.aspx

Natural Earth (2020). *Roads*. https://www.naturalearthdata.com/downloads/10m-cultural-vectors/roads/

OnX (2020). *OnX Hunt App*. https://www.onxmaps.com/

Radar Evaluation Squadron. (July 15, 2020). *84th Radar Evaluation Squadron*. https://www.505ccw.acc.af.mil/About-Us/Fact-Sheets/Display/Article/376111/84th-radar-evaluation-squadron/

Time and Date. (n.d.). *Sunrise and Sunset in the United States*. https://www.timeanddate.com /astronomy/usa

T-Mobile. (n.d.a). *Compare LTE coverage*. https://www.t-mobile.com/coverage/lte-comparison-map

T-Mobile (n.d.b). *Sprint coverage*. https://coverage.sprint.com/IMPACT.jsp?

United States Geological Survey (n.d.a). *3D Elevation Program*. https://www.usgs.gov/core-science-systems/ngp/3dep

United States Geological Survey (n.d.b). *GMTED2010 Viewer*. https://topotools.cr.usgs.gov

/gmted_viewer/viewer.htm

USCellular. (n.d.). *Coverage Map*. https://www.uscellular.com/coverage-map

Verizon (2020). *Expore 4G LTE and 5G network coverage in your area*. https://www.verizon.com/coverage-map/

Weinert, A. (2020). "Method to Characterize Potential UAS Encounters Using Open Source Data." Retrieved from https://arxiv.org/ftp/arxiv/papers/1911/1911.00110.pdf

Weinert, A. J., Edwards, M., Alvarez, L., & Michelle Katz, S. (2020). "Representative small UAS trajectories for encounter modeling." *AIAA SciTech 2020 Forum*. https://doi.org/10.2514/6.2020-0741

Weinert, A. J., Harkleroad, E. P., Griffith, J. D., Edwards, M. W. & Kochenderfer, M. J. (August 19, 2013). *Uncorrelated encounter model of the National Airspace System version 2.0*. Lincoln Laboratory. https://www.researchgate.net/publication/285407021_Uncorrelated_Encounter_Model_of_the_National_Airspace_System_Version_20