FLIGHT SAFETY FOUNDATION

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IN-TIME AVIATION SAFETY MANAGEMENT SYSTEM

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IASMS Research Roadmap Version 1

2025–2045

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1 Introduction

Aviation safety is a fundamental requirement for public acceptance of air transportation, commerce and the other missions that aircraft serve. The current safety record is enviable, and the aviation community is committed to maintaining and improving this record. The International Civil Aviation Organization (ICAO) has described safety management systems as having four main pillars: safety policy, safety risk management, safety assurance, and safety promotion.

Figure 1-1 IASMS encompasses two of the four SMS pillars

In 2018, the National Academies of Science, Engineering and Maintenance looked at the evolution of risk management and safety assurance and defined a set of challenges and research priorities for an evolving suite of capabilities referred to as the In-Time Aviation Safety Management System (IASMS). The U.S. National Aeronautics and Space Administration (NASA), based on the recommendations from the National Academies, has since developed a concept of operations for IASMS and is conducting research on the different components that contribute to overall safety.

This document describes a long-term research roadmap for IASMS, looking at key research needs supporting the evolution of IASMS capabilities between now and 2045. It is a high-level roadmap, designed with the intent of providing readers with a broad understanding of the overall research landscape rather than any detailed research plans or maturation approaches. Recognizing the uncertainties with any long-term plan, Flight Safety Foundation expects to periodically update this document to reflect current community feedback as well as to incorporate changes in the status of research, development and implementation efforts. While IASMS is envisioned for the U.S. National Airspace System (NAS), much of its functionality may also be implemented outside of the United States. As such, the contents of this roadmap are not specific to the NAS.

1.1 Overview of IASMS

IASMS is a concept for a suite of "in-time" and real-time safety assurance services, operating both at the individual system level as well as the "system of systems" level. These services are aimed at supporting the safety of flight for a wide array of mission profiles and vehicles. IASMS is envisioned to contribute to the evolution of air traffic safety by continuously monitoring, assessing and identifying mitigations to hazards and risks.

The IASMS concept of operations (ConOps) envisions an in-time set of processes and tools that continuously monitors and assesses factors related to aviation safety, thereby providing an opportunity to apply interventions before safety levels degrade. The analysis performed is also expected to uncover new leading indicators for

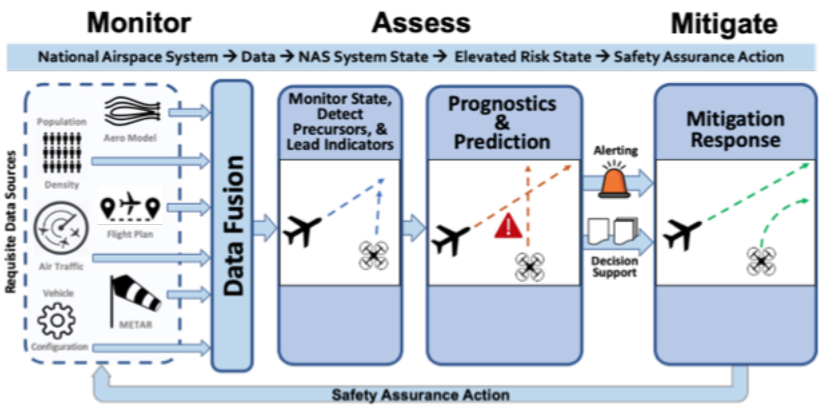

Figure 1-2 IASMS continually monitors the environment for changes in risk levels

emerging risks. IASMS capabilities will also identify mitigations that can either be provided to stakeholders or, in some cases, automatically implemented.

The IASMS is envisioned as a suite of federated capabilities, distributed among federal, state and local systems, that provides services to stakeholders operating in the NAS, including aircraft operators, the U.S. Federal Aviation Administration (FAA) and other organizations providing aviation-related services. The IASMS ConOps encompasses traditional crewed aircraft operations, uncrewed aircraft systems (UAS), and new entrant operations including advanced air mobility (AAM) services.

IASMS services, functions and capabilities may be resident across a broad set of systems, including those providing traditional air traffic management (ATM) services, UAS traffic management (UTM) services and other services, as well as within aircraft systems. Via this distributed data architecture, the IASMS capabilities will work together to identify and mitigate risks, both known and emerging, before safety is compromised.

1.2 Roadmap Purpose and Scope

This roadmap work is being performed under a grant from NASA to assist the System Wide Safety Project in identifying NASA safety research priorities and to foster partnerships with outside organizations performing complementary research. This roadmap is intended to provide readers with a broad understanding of the overall research landscape in five-year increments through 2045, the notional time frame when the IASMS concept would be realized.

The Roadmap was developed by reviewing multiple future concepts of operations and postulating the capabilities, technologies, standards and policies that would be needed to support those operations (See Appendix B for a detailed description of the methodology.) The Foundation reached out to a broad range of international stakeholders to understand their key concerns and expectations regarding safety and research needs (See Acknowledgements for the list of contributors). The document does not assume any specific architecture but does recognize the need for decisions that drive architecture choices. The document, further, does not assume any limitations in research assets or investments.

IASMS research will also need to be closely tied to capabilities supporting safety assurance. In addition, the IASMS system itself, and the associated automation, will need to undergo design and operational safety assurance processes before being used to inform or make operational decisions. Note that a research roadmap for safety assurance is being published separately by NASA.

1.3 IASMS Roadmap Overview

The National Academies report describes the evolution of IASMS capabilities in three phases that roughly correspond to the overall evolution of air traffic operations and ATM capabilities.

Chapters 2 through 5 of this document capture the overall evolution of IASMS in five-year increments. Each chapter provides a brief summary of the operational objectives that research would be addressing, and then describes the IASMS research needs with respect to the IASMS constructs of monitor, assess and mitigate.

The IASMS capabilities will need to be tuned to the evolution of broader operations and technologies. Thus, a broader view of the context for IASMS research is captured in Appendix A, which describes research along several different perspectives, or "swim lanes." Each of these swim lanes lays out, in five-year periods, the operations

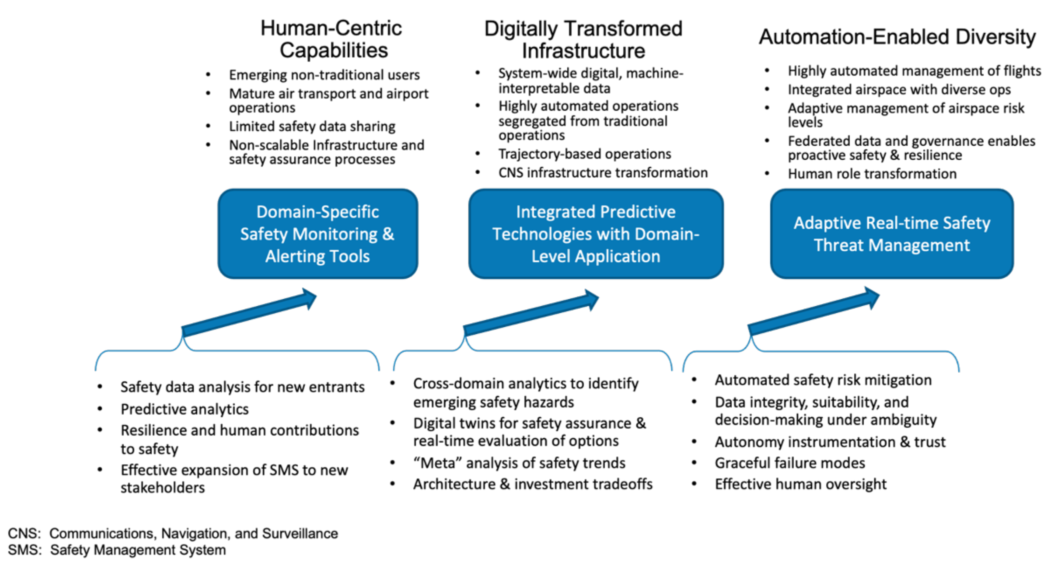

Figure 1-3 IASMS overall evolution and supporting research needs

and capabilities envisioned to be in place and derives a broad set of research, technology advancements and standards, and key policy needs.

Finally, Chapter 6 provides a brief discussion of proposed next steps.

2 IASMS Research Needs: 2020–2025

IASMS research in this period is primarily aimed at expanding the use of SMS and capabilities to more stakeholders and helping distribute safety data more widely for analysis and further risk mitigation. Additionally, by 2030, new entrants operating uncrewed, remotely piloted, or highly automated vehicles are expanding into airspace not typically in heavy use by traditional aviation, and third-party service providers are proliferating to meet these new needs.

Operators also have noted the importance of establishing repeatable, scalable processes for documenting due diligence of operational safety objectives to ensure that business cases for investment in new vehicles and operations are viable.

2.1 Monitor

It is increasingly important to understand the needs and means of monitoring the operations and impacts of uncrewed systems, and to begin identifying ways for relevant information to be shared appropriately. Similarly, "crowdsourcing" may be a viable source of new data that is not easily accessible today, such as urban terrain or obstacle data and low-altitude micro-weather measurements. Prototypes for collecting data, sharing data across service providers and analyzing data (including flight plan data that is specific to uncrewed systems) will be helpful in this time period to better understand these new ways of accessing this non-traditional data and establishing a common operating picture (COP). Additional research is needed to create international guidance for air navigation service provider (ANSP) safety data monitoring, as well as for other stakeholders that may not routinely participate in safety management systems.

2.2 Assess

Ensuring resilience and understanding minimum safety requirements become important areas of research in the near term. Understanding how individuals maintain their operations well within the safety envelope (e.g., through Learning From All Operations) will inform new entrants as well as established aviation stakeholders. Research to identify requirements for high-fidelity modeling will be important both for regulators and for those developing new vehicles or operational models. Research is also needed to inform standards related to qualifying third-party service providers and defining minimum information requirements (e.g., weather) supporting safe operations for new entrants.

2.3 Mitigate

With the introduction of uncrewed systems, regulators and operators need research that demonstrates how systems intended to reduce the likelihood of a collision can acceptably meet target levels of safety and be reflected in rulemaking.

Efforts to promote safety practices can include understanding how to effectively communicate the benefits of these practices to stakeholders. Mitigation efforts may include the evaluation of policy mechanisms that further encourage best practices to reduce the likelihood of unintended safety impacts from business continuity of operations (COO) decisions, in response to systemic disruptions (e.g., a pandemic).

3 IASMS Reseach Needs: 2025–2030

In the period leading up to the 2035 time frame, air traffic management and other related systems are evolving to a fully machine-readable environment with broader access to data in real-time. Commercial space and advanced air mobility operations in both low altitudes and upper altitudes drive the need for research supporting improved safety monitoring, more flexible separation protections, and coordination. Increasing complexity and interdependence in the airspace further drives research to evaluate safety trends and identify emerging hazards.

3.1 Monitor

During this time frame, a significant effort will be needed to research and define metrics that support safety analysis for a broader range of stakeholders. Expanding metrics definitions to better understand contributions to resiliency is another path to transforming safety practices. Research on tradeoffs and implications for the architecture necessary for this level of data sharing will need to address data governance issues as well as spectrum tradeoffs as they affect real-time wireless data exchange. Additional architecture studies will be needed to understand how IASMS monitors the overall safety performance of operational systems. Further, as highly automated systems are increasingly used, understanding both data integrity and the need for instrumentation of automation will be critical to inform future safety analysis.

3.2 Assess

Over this time frame, new operational concepts are being developed that will have implications on requirements for maintaining acceptable levels of safety. Safety requirements will need to be integrated with research on concepts such as flexible airspace, advanced air mobility operations and more nuanced integration of commercial spaceflight. IASMS research will need to address the evaluation of safety data trends and the use of predictive analytics that can identify emerging risks and hazards. Research to advance the use of highly capable simulations, such as digital twins, will enable improved impact evaluation on overall airspace operations as well as to evaluate new operations or vehicles. These models will also support evaluations of proposed real-time mitigations to ensure all impacts of a potential safety intervention are well understood. Equipage and spectrum requirements for airspace may also require further research to understand and assess trade-offs in safety and overall societal benefits.

3.3 Mitigate

As airspace operations become more complex, research into safety mitigation approaches will coincide with assessment of overall safety. Research will also need to differentiate how to implement safety mitigations, including recognizing that human response times and behaviors will be different in comparison to automated flight behaviors in integrated airspace. Design expectations for these highly automated operations will inform manufacturers developing suitable systems. Research for mitigating safety hazards will be needed to address the threat of unauthorized operations, including uncrewed systems that are not compliant with airspace or other operational constraints. Cyber hazards are also a growing concern, and mitigation of breaches will be critical as systems become increasingly automated.

4 IASMS Research Needs: 2030–2035

In the years 2035 and beyond, air traffic management will involve routine machine-to-machine communications and integrated airspace that includes both human-managed operations and operations managed by high levels of automation. Research through 2035 is aimed at enabling these increasingly complex operations and the transformation of human roles.

Airspace volumes become more flexible, and systems move away from direct human guidance of operations to a broader oversight role for humans. Further integration of highly automated flights and human-managed flights is occurring in some areas; these flights are supported by safety systems that consider this mix in evaluating and maintaining acceptable levels of safety. Flight management procedures supporting autonomous operations in integrated airspace, based on concepts such as digital flight, are in place by 2040. These will require new procedures and monitoring capabilities in airspace as well as on airports and other locations where there are shared arrival and departure facilities.

4.1 Monitor

With a significant digital infrastructure in place, research in this time period is focused on supporting the expansion of safety data shared across domains, including ways to share data across different regulators and service providers worldwide. The sheer volume of data drives the need to understand how to manage, share and validate it. This work becomes a major objective for researchers in this time frame, potentially driving architectures and new computing and communications technologies. Challenges will include the alignment across different metrics and the harmonization of data formats needed for international collaboration to ensure safety and resiliency of data.

4.2 Assess

Research in this time frame emphasizes the development of algorithms and techniques to more quickly identify (i.e., in "real-time") emerging risks in highly complex environments. Assessment of real-time and predicted risk levels in flexible airspace volumes involves new factors, such as autonomous management of operations. Such real-time assessment will need to ensure a constant level of resilience in the airspace so that unanticipated events can be managed safely. Research on predictive analytics will continue and operations and flight management methodologies will be refined for implementation by highly automated systems.

4.3 Mitigate

Research on safety assessment and safety risk mitigation techniques includes use of models to understand and mitigate downstream effects as well as real-time monitoring of operational conditions. This research assesses the effectiveness of proposed adjustments and interventions. Research on human roles in mitigating safety risk is essential to understand how humans effectively interact and maintain awareness of system behaviors, both with respect to managing operations in a volume of airspace (or an aerodrome environment) and in effectively managing a highly automated or autonomous vehicle's operations.

5 IASMS Research Needs: 2035–2040

Research in this time frame is designed to support a highly automated environment that accommodates, in most airspace and airport or airport-like environments, a mixture of autonomously managed and human-managed flights. In many locations, flights carrying large volumes of cargo or people are managed autonomously end-to-end through highly reliable distributed systems. Airspace, for the most part, is autonomously managed, and interventions for safety are routinely initiated without human approval.

5.1 Monitor

Research in this time frame helps to establish resilient techniques for appropriately fusing or integrating real-time and post-operational data while dealing with an unprecedented volume of historical reference data and disparate data qualities. Human means for monitoring system status are refined so that effective interventions can be in place when "soft" failure modes need to be initiated and communicated. Research continues to identify new system safety threats, including threats that could potentially cause system-wide outages.

5.2 Assess

Research on computing technologies and predictive analytics matures, enabling truly "in-time" identification of emerging safety hazards and associated mitigation strategies for all operations. Assessments include immediate operational factors and highlight when procedures may need adjustment to reflect the operational and technical environment. Research on managing the dynamic definition of airspace volumes optimizes the ability to safely support capacity, efficiency, environmental and other goals at both a system level and the individual operations level.

5.3 Mitigate

Research on mitigating safety risks includes automatic evaluation and identification of operational adjustments and broader procedural and technical elements that contribute to changes in safety risk levels. Research also significantly refines contingency management procedures to ensure that highly automated systems have "robust-failure" and "soft-failure" modes responding to a wide variety of stressors, including intentional acts by bad actors.

6 Next Steps

This document represents the initial version of a long-range roadmap for the needed research supporting the evolution of the capabilities that comprise an In-Time Aviation Safety Management System. The development of these capabilities will need to be integrated with the overall research and development for air traffic management capabilities, supporting technologies and associated policy decisions. This first version has significant detail on the broader evolution of air traffic management and safety research, as laid out in Appendix A. Future versions of this roadmap will focus more deeply on the IASMS needs for monitoring, assessing and mitigating safety risks and the research specifically needed for these capabilities to evolve, highlighting safety monitoring and mitigation needs for both airborne operations and surface operations.

Progress will depend not only on research but also on the ability to effectively implement new technologies and concepts that introduce innovation into the air traffic management system. Currently, stakeholders from the new entrants sector are concerned that safety assurance processes and lack of policy are hindering their ability to close the business case for nearer-term investments. Without the ability to move forward, there may be little aviation community interest in the planning needed to mature more advanced concepts, as timing is critical for business viability. For example, will certified vertiports be available when electric vertical takeoff and landing (eVTOL) vehicles are approved for operation?

At a the IASMS Roadmap Workshop, conducted at NASA Langley Research Center in January 2023 with aviation stakeholders, participants identified the need for a leadership body to establish consensus and commitments among key stakeholders on priority activities for ATM innovations, including IASMS, in order to accelerate the necessary changes when possible. Participants also expressed a need for a clear, concise and compelling problem statement for IASMS that would provide clarity for executive decision-makers on the importance of IASMS-related investments. The group articulated a concern that without a clear prioritization of activities needed to realize IASMS, there will be mismatches between community expectations and the corresponding necessary underlying capabilities.

In summary, the value of this roadmap can only be retained if the elements captured here are regularly reviewed and updated to support future decision-making, reflect ongoing changes in community priorities, and define the investments in advanced operations. Future versions of this roadmap can also be improved by integrating perspectives from a broader set of stakeholders, including additional stakeholders from traditional aviation perspectives, insurance providers, maintenance service providers, general community interests, etc.

We recommend that this Roadmap be updated on an annual or biannual basis so that it continues to be relevant by providing a high-level view of the elements involved in bringing envisioned safety innovations to fruition.

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Appendix A: Expanded IASMS Roadmap

1 Overview

This document postulates the critical capabilities necessary to safely enable envisioned future aviation operations that involve highly automated and autonomous vehicles and systems executing new operations, frequently in the same airspace as legacy crewed vehicles. We have identified key activities needed to support implementation of these capabilities and sequenced them in five-year time frames.

The roadmap, presented in this appendix, is divided into six major sections, or swim lanes, capturing different research areas associated with IASMS:

Section 2 — Safety Data and Resilience Analysis;
Section 3 — Strategic Conflict Management;
Section 4 — Tactical Separation Management;
Section 5 — Individual Vehicle Flight Management;
Section 6 — Aviation Weather; and,
Section 7 — Cross-Cutting Research and Development.

Each section captures a set of capabilities anticipated to be available within a given time frame. In addition, each section identifies activities, during that same time frame, that are postulated to be needed for a future five-year time frame. Sections are further divided into subsections, each focusing on a five-year period between now and 2045.

Figure A1-1, below, illustrates the structure of the information provided for each five-year period within a given section. The graphic presents the new capabilities postulated to be available by or during the current and subsequent five-year periods, grouped into sections or swim lanes. The activities expected to be ongoing during this five-year time frame in support of future capabilities are listed and are categorized as research, technology and standards or policy initiatives. Each subsection begins with a table in this format to provide an overview of the postulated capabilities and activities expected. Numbers associated with each item in the table correspond to a numbered subsection for easy reference.

Note that some research is expected to result in a capability in the next time frame, while other research may continue across multiple time frames, providing incremental results along the way. We recognize that many activities will have some impact outside the time frame and swim lane in which they are placed. Additionally, many broad research initiatives, technology and standards efforts, and policy initiatives are foundational to realizing IASMS and support multiple swim lanes. These types of activities have been placed together in the cross-cutting swim lane, Section 7.

<table>
<tr><th colspan="3">20XX–20XX+5</th><th>20XX+5–20XX+10</th></tr>
<tr><td colspan="3">New capabilities introduced by, or during, this period
• X.m.1 Capability</td><td rowspan="3">New capabilities introduced by, or during, this period
• X.n.1 Capability
• X.n.2 Capability</td></tr>
<tr><td>Research Completed</td><td>Technology & Standards</td><td>Policy Initiative</td></tr>
<tr><td>X.m.2 Research
X.m.3 Research</td><td>X.m.4 Standard for XY</td><td>X.m.5 Policy</td></tr>
</table>

Figure A1-1. The IASMS Roadmap structure

2 Safety Data and Resilience Analysis

Maintaining aviation's safety record will involve growing from a strictly forensic approach to safety, based on analysis of accidents and incidents, to one that increases overall safety through a combination of expanded data sharing, predictive analytics and increased knowledge of how routine actions during nominal operations affect safety margins. In an increasingly interconnected and complex aviation system, safety analysis will expand to focus beyond off-nominal events and undesired states (events that are rare) to include more analysis of events and operations that stay well within a safety envelope. Safety data collection will expand from a focus on hazardous events to analysis of routine operational data. Advanced computing capabilities will enable more effective identification of emerging hazards as well as the ability to expeditiously identify, and execute, appropriate interventions and mitigations. *(See Figure A2-1, below, illustrating this progression.)*

2040-2045	2.5.1 Autonomous identification and mitigation of emerging safety risks
2035-2040	2.4.1 In-time identification of emerging safety hazards and mitigation strategies
2030-2035	2.3.1 Expanded real-time critical safety data collection and aggregation 2.3.2 State Safety Programs to include monitoring of UAS SMS
2025-2030	2.2.1 Safety database and funded post-analysis capability for new entrants 2.2.2 State safety programs expand monitoring of SMSs 2.2.3 Sharing of safety data among regulators
2020-2025	2.1.1 Initial safety performance metrics for UAS 2.1.2 Integrated methodology to assess system risk and resilience 2.1.3 Broader ANSP adoption of internal safety data analysis

Figure A2-1 Postulated progression of safety data and analysis capabilities

IASMS will lead the expansion of safety management systems (SMS) by collecting safety data from an expanded set of aviation stakeholders, including new entrants, while evolving toward in-time analysis of all safety data. For the purposes of the roadmap, *Safety Data* will include all types of data and information that can help inform safety decision-making. This definition can be refined as the roadmap matures, and should be further developed by regulators, air navigation service providers (ANSPs) and other users of safety data.

Maintaining airspace system safety into the future will require broad sharing of critical safety data among users and service providers to ensure the rapid detection and timely mitigation of safety issues as they emerge, and before they become hazardous. Safety monitoring capabilities will need to exist at all levels of architecture of this distributed system. Development of data governance and a taxonomy related to collection and use of safety data will be necessary to support data collection efforts. Additionally, broad use of data analysis and predictive analytics will require ongoing research into human interface and management of information. (National Academies, 2020)

IASMS will increase resilience of airspace and vehicle systems through a combination of faster identification of unsafe conditions and the integration of continuous learning into risk management, as described in Learning From All Operations. (Flight Safety Foundation, 2022) *Resilience* is often considered the ability to mitigate hazardous conditions that may occur and to enable timely recovery from those that do occur, while maintaining as much system functionality as possible. (National Academies, 2020) Learning From All Operations considers that resilience, from a safety perspective, is focused on the different adaptive processes with the aim of sustaining purposeful operations under varying conditions and pressures, while maximizing the likelihood of an accident-free outcome and minimizing the undesired consequences of a potential or actual adverse event.

The progression of safety capabilities related to safety data and resilience that we postulated to be realized between now and 2045 are shown in Figure A2-1 and are described in further detail in the following sections.

2.1 Safety Data and Resilience Analysis: 2020–2025

The safety data and resilience analysis capabilities envisioned to be available in this time frame and the next, together with the research completed, technology and standards developed and policy initiatives established during this period are shown in Table A2-1.

2.1.1 Initial safety performance metrics for UAS

A set of required safety performance metrics for small UAS operations, especially for low-altitude beyond visual line of sight (BVLOS) operations, will be established by

<table>
<tr><th colspan="3">2020–2025</th><th>2025–2030</th></tr>
<tr><td colspan="3">2.1.1 Initial safety performance metrics for UAS
2.1.2 Integrated methodology to assess system risk and resilience
2.1.3 Broader ANSP adoption of internal safety data analysis</td><td rowspan="3">2.2.1 Safety database and funded post-analysis capability for new entrants
2.2.2 State safety programs expand monitoring of SMSs
2.2.3 Sharing of safety data among regulators</td></tr>
<tr><td>Research Completed</td><td>Technology & Standards</td><td>Policy Initiative</td></tr>
<tr><td>2.1.4 Prototype safety database and analysis capability with new entrants
2.1.5 Develop methodology to assess resilience practices
2.1.6 Explore policy mechanisms to mitigate safety impacts of significantly disruptive events</td><td>2.1.7 Develop international standards for ANSP safety data analysis</td><td>2.1.8 Ensure new entrant safety data is available and an analysis capability is funded
2.1.9 Pathway to expand and harmonize SMS for UAS programs</td></tr>
</table>

Table A2-1. Safety data and resilience analysis capabilities and activities, 2025–2030

2025. Once policy requiring safety data sharing is in effect (see activity 2.1.8), operators will routinely provide required data that can eventually be used to inform safety best practices and future decisions on risk management. Acceptable risk levels for each safety risk will be determined as part of this research.

2.1.2 Integrated methodology to assess system risk and resilience

During this period, some organizations will implement the initial Learning From All Operations methodology once it has been completed (see activity 2.1.5). These organizations will collect broader safety data from their nominal operations, and the framework itself will be validated and ready for wider implementation.

2.1.3 Broader ANSP adoption of internal safety data analysis

More ANSPs will use internal safety data analysis and metrics to identify risks for surface safety, airborne safety, and safety around commercial space operations. This approach provides deeper insights into risks encountered even when procedures are followed and will eventually replace the practice of using only conformance monitoring for safety analysis. Safety data analysis in place of conformance monitoring will increase over the coming periods as it enables ANSPs to examine much larger data sets using automated forms of analysis. One example of such activity is FAA's Risk-Based Safety Assurance.

2.1.4 Prototype safety database and analysis capability with new entrants

Prototypes of safety databases will be developed in this time frame, along with analysis capabilities to identify safety hazards and trends involving new entrants and new operations, including commercial space operations. New entrants that are voluntarily sharing operational data contribute to validating and refining the value from these analytical tools. The benefits these early adopters receive from sharing data will provide additional motivation for others to participate.

With the introduction of BVLOS operations, there is a significant diversity in the safety performance data that is measured and recorded across different platforms and operations. Metrics based on safety data are defined and assessed to determine which are the most informative regarding UAS operations. The most salient factors affecting overall safety levels are determined, the major safety risks are identified, and this information will inform future standards on UAS performance measurement.

2.1.5 Develop methodology to assess resilience practices

A Learning From All Operations methodology to assess system risk and operational resilience by examining nominal operations will be developed in this time frame with a function to identify system pressures, resilience capabilities, resilience adaptive processes and resilience manifestations.

2.1.6 Explore policy mechanisms to mitigate safety impacts of significantly disruptive events

Drawing on lessons learned from operations during the COVID-19 crisis in 2019–2021, research is performed to identify policy mechanisms that could help ensure that the inevitable intense focus on financial viability during significantly disruptive events (such as pandemics and financial crises) does not include diversion of resources from key safety activities, especially when previous risk levels have increased or when new risks have become evident.

2.1.7 Develop international standards for ANSP safety data analysis

States develop international standards for their automated analysis of safety data and specify what safety data is required from traditional operators, new entrants, service providers, original equipment manufacturers (OEMs) and others. This data will be used to inform and improve their airborne safety procedures.

2.1.8 Ensure new entrant safety data is available and an analysis capability is funded

States develop a policy mechanism to ensure provision of necessary safety data associated with a key subset of uncrewed operations (e.g., long-range BVLOS, small package delivery and size and/or kinetic energy of UAS). Such mechanisms include a process for adding new operations and vehicles to this set. An ongoing funding source for the safety analysis necessary to support new entrants and new operations is identified.

2.1.9 Pathway to expand and harmonize SMS for UAS programs

International coordination is accomplished to ensure the global requirements and guidance for SMS are expanded to include UAS programs. These standards also enable national civil aviation authorities to implement their UAS programs' SMS in a standardized manner.

2.2 Safety Data and Resilience Analysis: 2025–2030

Table A2-2, below, shows the safety data and resilience analysis capabilities envisioned to be available in this time frame and the next, together with the research completed, technology and standards developed and policy initiatives established during this period.

<table>
<tr><th colspan="3">2025–2030</th><th>2030–2035</th></tr>
<tr><td colspan="3">2.2.1 Safety database and funded post-analysis capability for new entrants
2.2.2 State safety programs expand monitoring of SMSs
2.2.3 Sharing of safety data among regulators</td><td rowspan="3">2.3.1 Expanded real-time critical safety data collection and aggregation
2.3.2 State Safety Programs include monitoring of UAS SMS</td></tr>
<tr><td>Research Completed</td><td>Technology & Standards</td><td>Policy Initiative</td></tr>
<tr><td>2.2.4 Post-operational in-time analysis of safety data for traditional ops
2.2.5 Analysis of new entrant safety data
2.2.6 Identification of predictive techniques for risk analysis</td><td>2.2.7 Safety resilience metrics established
2.2.8 Initial common SPI definitions for UAS</td><td>2.2.9 Guidance on integrating business COO with SMS
2.2.10 Broader adoption of non-punitive safety practices
2.2.11 International standards for UAS SMS</td></tr>
</table>

Table A2-2. Safety Data and Resilience Analysis capabilities and activities for 2025–2030

2.2.1 Safety database and funded post-analysis capability for new entrants

Following the research and policy actions in the previous time period, the necessary safety data has been identified, is being collected and a fully funded analysis capability exists. As part of this capability, safety insights, priorities for safety analysis, and best practices are routinely discussed and shared among new entrants for broader implementation.

2.2.2 State safety programs expand monitoring of SMSs

Many international aviation regulatory bodies have implemented state safety programs (SSPs), to various degrees, that include both traditional operators, new entrants, service providers, OEMs and others. While there are recommendations for operators to document their SMS procedures, there may not be the feedback mechanisms to evaluate the effectiveness and actual level of implementation or monitor performance. States may also need to consider regulations that expand use of an appropriate SMS to additional operators or other stakeholders. Effective SSPs will have to collect information and effectively monitor performance of UAS operators.

2.2.3 Sharing of safety data among regulators

Policy mechanisms, safety data definitions and the needed interfaces are in place to allow broader sharing of critical safety data across international boundaries, enabling a richer set of data to be assessed to evaluate safety trends, to detect hazards or practices that affect overall safety, and to address safety concerns. A non-punitive approach to assessing data is in place across cooperating regulators.

2.2.4 Post-operational in-time analysis of safety data for traditional ops

Additional research on the "in-time" and "real-time" assessment of safety data to identify new hazards or conditions that compromise safety is matured for traditional operations. Research results, including new algorithms, interfaces for additional data sources and techniques, are applied to currently collected aviation safety data for both in-flight and surface operations (e.g., flight data recording and the FAA's Aviation Safety Information Analysis and Sharing (ASIAS) program) to assess the effectiveness of newly developed predictive analytics algorithms when used on near real-time safety data. Some research might examine how machine learning and artificial intelligence can support this effort.

2.2.5 Analysis of new entrants safety data

Following post-analysis assessment of advanced UAS operations and other new entrant data to understand safety hazards, research evaluating the application of predictive analytics is performed via a regional operational evaluation with a set of operators performing advanced operations. In addition to the algorithms, operational procedures associated with in-time identification of emerging safety hazards with new entrants and new operations will be operationally evaluated. The regional operational evaluation is performed with participants to validate the benefits and algorithms.

2.2.6 Identification of predictive techniques for risk analysis

Predictive analytics techniques are explored and developed to support in-time analysis of safety data and identify emerging safety hazards. This research can use existing safety data (e.g., airborne and ground surveillance information, ASIAS for traditional operations and flight data recorder (FDR) data) to develop the necessary predictive algorithms to identify emerging safety hazards.

2.2.7 Safety resiillence metrics established

Safety resilience metrics, e.g., those from initial Learning From All Operations analyses, will be established by 2030. These are a set of metrics that include system pressures, operational resilience capabilities, operational resilience adaptive processes, resilience manifestations and a comprehensive set of safety margins for use with the Learning From All Operations methodology.

2.2.8 Initial common SPI definitions for UAS

Consensus is reached on a set of initial definitions for safety performance indicators (SPIs), which is published for small UAS and for vehicles performing advanced operations. This set of definitions provides a means to correlate performance characteristics across a broad range of uncrewed systems to include heavier and very heavy UAS, and vehicles designed for very-high-altitude operations. In addition to providing additional harmonization across manufacturers, the definitions are used by organizations to collect and aggregate this safety data.

2.2.9 Guidance on intergrating business COO with SMSs

Based on analysis and aviation safety lessons learned across the industry following the COVID-19 pandemic (activity 2.1.5), regulators provide broad guidance on how continuity of operations (COO) plans should be integrated with safety management systems to avoid unintended reduction of operational safety.

2.2.10 Broader adoption of non-punitive safety practices

The International Civil Aviation Organization (ICAO) and other aviation stakeholders have long recognized that open reporting of safety issues is crucial to establishing and maintaining an effective SMS. Safety reporting is an important part of an effective safety program, and all people involved in any way with aviation safety need to be encouraged to report safety deficiencies without fear of punishment. This concept is accepted by an increased number of civil aviation authorities (CAAs) and is further defined in ICAO Annex 19.

2.2.11 International standards for UAS SMS

Following the pathway identified in the previous time period (activity 2.1.8), international standards are published for UAS SMS. This harmonization facilitates broad safety data sharing and performance monitoring of UAS.

2.3 Safety Data and Resilience Analysis: 2030–2035

Please see Table A2-3, below, for a summary of the safety data and resilience analysis capabilities envisioned to be available in this time frame and the next, together with the research completed, technology and standards developed and policy initiatives established during this period are shown in Table A2-3, below.

<table>
<tr><th colspan="3">2030–2035</th><th>2035–2040</th></tr>
<tr><td colspan="3">2.3.1 Expanded real-time critical safety data collection and aggregation
2.3.2 State safety programs include monitoring of UAS SMS</td><td rowspan="3">2.4.1 In-time identification of emerging safety hazards and mitigation strategies</td></tr>
<tr><td>Research Completed</td><td>Technology & Standards</td><td>Policy Initiative</td></tr>
<tr><td>2.3.3 Refined algorithms to identify emerging risks
2.3.4 Refined methods enabling a predictive SMS</td><td>2.3.5 International standard for safety information exchange
2.3.6 Testing and validating predictive management system methodologies</td><td></td></tr>
</table>

Table A2-3. Safety Data and Resilience Analysis capabilities and activities for 2030–2035

2.3.1 Expanded real-time critical safety data collection and aggregation

A funded system is in place that collects and aggregates safety data from an expanded set of stakeholders, including new entrants, advanced air mobility (AAM) operators, vertiport and other aerodrome operators, and traditional operations in real-time as the safety data is shared. Analysis of this aggregated data provides increased insights on safety best practices and previously unknown safety risks. This capability includes harmonization of data governance and ongoing development of an aviation safety data taxonomy to include UAS and AAM vehicles and thereby will continue to support identification of safety performance and gaps as new operations emerge.

2.3.2 State safety programs include monitoring of UAS SMS

International SMS standards (ICAO Annex 19), as well as supporting guidelines and procedures, are revised and developed to include monitoring the performance of UAS programs' SMSs. Guidelines would be further developed for states on how to monitor the performance of UAS programs' SMS as part of the states' SSPs.

2.3.3 Refined algorigthms to identify emerging risks

Based on outcomes from activities 2.2.4 and 2.2.5, research continues to mature algorithms and techniques that analyze post-operation data to identify real-time emerging risks and to alert humans, who are either in- or on-the-loop, to these flight risks. This research validates that all necessary safety data is available and develops algorithms to provide potential mitigations.

2.3.4 Refined methods enabling a predictive SMS

Existing prediction methods that are applicable to SMS, like those developed in activities 2.2.5 and 2.3.3, will be further analyzed by means of numerous inductive and deductive methods to establish a predictive SMS model. Some methods postulated include analysis, synthesis, generalization, specialization, the proving and deduction method, the analysis and synthesis, and many others. This effort includes testing and validating the predictive management methodologies as they are developed.

2.3.5 International standard for safety information exchange

In this time frame, an international standard for safety information exchange, Safety Information Exchange Model (SIXM), is established. The model is expected to standardize a formal language that reliably characterizes the performance of daily operations, including both risks and operational resilience. This standard will help the aviation industry move beyond event-based taxonomies to communicate safety issues, margins, margin distributions and the dynamics of those distributions, and will be used with the Learning From All Operations methodology.

2.3.6 Testing and validating predictive management system methodologies

Predicative management system methodologies developed in activity 2.3.4 are tested and validated on organizations' activities; these methodologies are provided as a standard for organizations to use as part of their overall assurance methodology. This work includes the verification and operation of predicative management systems.

2.4 Safety Data and Resilience Analysis: 2035–2040

The safety data and resilience analysis capabilities envisioned to be available during this five-year time frame, and the next, are shown in Table A2-4, along with the research completed, technology and standards developed and policy initiatives established during this epoch.

<table>
<tr><th colspan="3">2035–2040</th><th>2040–2045</th></tr>
<tr><td colspan="3">2.4.1 In-time identification of emerging safety hazards and mitigation strategies</td><td rowspan="3">2.5.1 Autonomous identification and mitigation of emerging safety risks</td></tr>
<tr><td>Research Completed</td><td>Technology & Standards</td><td>Policy Initiative</td></tr>
<tr><td>2.4.2 Algorithms for analysis of integrated real time and post-operational safety data</td><td>2.4.3 International standard for safety information exchange</td><td></td></tr>
</table>

Table A2-4. Safety Data and Resilience Analysis capabilities and activities for 2035–2040

2.4.1 In-time identification of emerging safety hazards and mitigation strategies

Based on research across the preceding time periods, this capability is implemented for artificial intelligence (AI) to analyze safety data and identify emerging risks in-time, and to provide both an alert and potential mitigations to humans who are either in-the-loop or on-the-loop for the event. Mitigations may include tactical adjustments, technical changes or procedures, or they may prescribe training. These algorithms are applied to all UAS and traditional crewed operations, and the appropriate personnel are trained to understand how to respond to alerts for both airborne and ground operations.

To make this capability available, it is expected that the overall architecture, necessary computing power, and communications requirements to support the perceived magnitude of data processing is understood and available.

2.4.2 Algorithms for analysis of integrated real time and post-operational safety data

Research is conducted on integrated, real time and post-operational safety data to perform real-time analysis for the autonomous implementation of near real-time mitigations identified by predictive analytics algorithms. Mitigations that require policy, equipment or training procedures will be provided to personnel who can assess and execute the needed next steps.

2.4.3 International standard for safety information exchange

The international standard for the SIXM is published. The model will standardize a formal language to reliably characterize performance of daily operations, assessing both risk and operational resilience and going beyond event-based taxonomies to communicate safety issues, margins, margin distributions and distributions' dynamics, and will be used with the Learning From All Operations methodology.

2.5 Safety Data and Resilience Analysis: 2040–2045

2.5.1 Autonomous identification and mitigation of emerging safety risks

In this time period, risk management and safety assurance are merged to accommodate the high density and fast pace of advanced UAS operations. This level of responsiveness provides a quick identification of emergent risks and hazards, allowing the automated system to initiate an appropriate action to directly mitigate the risk. The vision for IASMS is to autonomously monitor the state of an airspace system, assess and identify an elevated risk state, and to mitigate emerging risks through safety assurance action. In this time frame, for some operations and airspace, this risk identification and mitigation happens autonomously. This capability is expected to assure safety, in-time, for both traditional operations and new entrants for both airspace operations and surface operations.

3 Strategic Conflict Management

Strategic conflict management includes airspace design, metering of aircraft arrivals into the airspace volume and use of trajectory-based operations (TBO) to resolve separation violations forecast to occur. Actions supporting strategic conflict management goals may be taken before a flight departs or while a flight is airborne. In airspace where tactical separation services are not available or where pilots and/or aircraft may not be able to visually "detect and avoid" one another, procedural separation techniques may be used to ensure safe separation.

With the expansion of traffic into areas not traditionally served by ANSPs, many of the capabilities and actions captured in this section are in support of strategic management services that serve new entrants. *(See Figure A3-1 for an illustration of* *the capability evolution.)* This includes the maturation of unmanned traffic management (UTM) services for low altitude airspaces, providers of services to UAM (PSU) and traffic management at very high altitudes, such as upper E airspace in the United States. In this document, the term *extensible traffic management*, or xTM will refer to any such service that is provided outside instrument flight rules (IFR)-managed airspace. Research steps include the development of flexible airspace volumes, including flexible corridors. Flexible, or dynamic, airspace concepts include the ability to adjust the boundaries of the airspace and may involve adjusting the operational, performance and equipage requirements to operate within the airspace for a specific time interval.

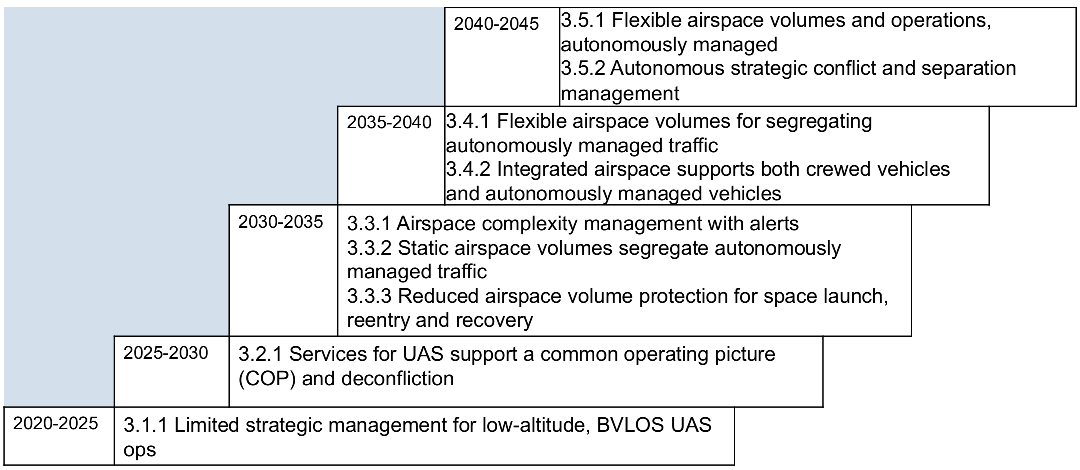

Figure A3-1. Evolution of Strategic Conflict Management Capabilities

Research will evaluate requirements for, and implications of, increasingly autonomous strategic conflict management as well as the need for procedures, equipage and other requirements associated with highly automated capabilities, regardless of where they are instantiated. Capabilities, such as digital flight, will be available for operators who find an advantage to a distributed capability for strategic conflict management. As automation functionality and applications increase, research efforts will need to address shifts in procedures that maintain safe margins and will examine the implications of automation on human roles, responsibilities and interfaces. Such research will also need to assess changes in overall capacity and other measures that capture the impact of increasingly autonomous services.

The progression of safety capabilities related to strategic conflict management that we postulated to be realized between now and 2045 are shown in Figure A3-1, above, and are described in further detail in the following sections.

3.1 Strategic Conflict Management: 2020–2025

Table A3-1 summarizes the strategic conflict management capabilities, research activities, standards and policy initiatives that are in place in 2020–2025, plus the strategic conflict management capabilities anticipated in the following five-year time frame.

3.1.1 Limited strategic management for low-risk, BVLOS UAS ops

Operators of small UAS have the ability to strategically manage potential airspace

2020–2025			2025–2030
3.1.1 Limited strategic management for low-altitude, BVLOS UAS ops			3.2.1 Services for UAS common operating picture (COP) and deconfliction
Research Completed	**Technology & Standards**	**Policy Initiative**	
3.1.2 Framework for pairwise vehicle separation requirements	3.1.3 Standards for xTM coordination across service providers and service boundaries		

Table A3-1. Strategic Conflict Management Capabilities and Activities, 2020–2025

conflicts for low-altitude BVLOS flights in some airspace. UTM service providers provide guidance to operators on any known UAS flights paths that would conflict with a proposed BVLOS flight path. There may also be awareness of potential conflicts using flight plans filed by traditional operators.

3.1.2 Framework for pairwise vehicle separation requirements

As the responsibility for managing airspace risk levels becomes increasingly automated, the approach for managing vehicle separation from other vehicles, obstacles or other hazardous conditions has the potential to become increasingly nuanced. An overall framework for separation management may help provide insights on questions such as whether to maintain the concept of vehicle classes, the level of complexity and downstream considerations to consider, and other factors.

3.1.3 Standards for xTM coordination across service providers and service boundaries

Organizations providing xTM services will need to be able to exchange information with ANSPs as well as other xTM providers in adjacent or overlapping service volumes. The data exchange may be within a state or across international boundaries. These standards will also include the requirements an xTM provider must meet to be qualified/approved by the state's approving authority (e.g., requirements for sharing or making available flight information to other ANSPs or xTM providers). Information exchanged will include information about both uncrewed and crewed operations that could affect operations or planning.

3.2 Strategic Conflict Management: 2025–2030

Table A3-2 summarizes the strategic conflict management capabilities, research activities, standards and policy initiatives that are in place in 2025–2030, plus the strategic management capabilities anticipated in the following five years.

3.2.1 Services for UAS common operating picture (COP) and deconfliction

2025–2030			**2030–2035**
3.2.1 Services for UAS common operating picture (COP) and deconfliction			3.3.1 Airspace volume complexity management with alerts 3.3.2 Static airspace volumes segregate autonomously managed traffic 3.3.3 Reduced airspace volume protection for space launch, re-entry, and recovery
Research Completed	**Technology & Standards**	**Policy Initiative**	
3.2.2 Requirements for dynamic debris field protection 3.2.3 Flexible airspace concepts and requirements 3.2.4 Airspace volume capacity and complexity management 3.2.5 Traffic management for very high-altitude operations	3.2.6 TBO strategic conflict management incorporating complexity and new entrants	3.2.7 Prioritization and separation requirements 3.2.8 BVLOS operator requirement to share flight plan information	

Table A3-2. Strategic Conflict Management Capabilities and Activities, 2025–2030

Services available to operators (e.g., those provided by USSs or PSUs) enable a common operating picture (COP) that allows all participants in the airspace to maintain safe operations, including BVLOS operations. Operators and/or the in-flight vehicles have access to reliable, complete information regarding other flights in the surrounding airspace. This allows operators to proactively adjust planned flight trajectories and if needed, to negotiate in advance with other operators before there are airspace conflicts.

When a conflict is identified or when another flight has higher priority, providers will offer an alternative path to the operator filing a proposed trajectory or they can provide the constraint information allowing the operator to assess options directly. They are also able to provide, in real-time, automated alerting to a UAS operator or directly to the vehicle if a separation conflict with another UAS or crewed aircraft is likely to occur, based on known information about other vehicles (crewed and uncrewed) in the airspace. Service providers are able to fully coordinate for overlapping jurisdiction areas and coordinate across service boundaries to assess whether a proposed flight has downstream conflicts that would need to be resolved.

3.2.2 Requirements for dynamic debris field protection

Space vehicle launches and re-entry operations are currently seen as relatively higher risk than traditional aviation operations; the potential for falling debris creates risk for both air traffic and for people and structures at ground level. Research on techniques that leverage TBO evaluates options to reduce the time that a given airspace volume is restricted for safety reasons. Airspace protections also include more differentiation of altitude based on likely debris patterns. This work also includes trade space analysis of risks associated with rerouting traffic around a potential debris field versus access to airspace that could be more quickly reopened.

3.2.3 Flexible airspace concepts and requirements

One of the concepts anticipated to address increased traffic, complexity and the introduction of autonomous vehicles is flexible airspace, which allows dynamic airspace configurations as needed. These concepts are matured, and requirements are developed that include appropriate safety margins.

3.2.4 Airspace volume capacity and complexity management

The ability for humans to manage a volume of airspace includes factors such as the similarity of performance of aircraft, the extent to which there are changes in altitude or direction, the number of potentially crossing paths, weather or other hazardous conditions, skill levels and well-being, the availability and reliability of automation, etc. How can these factors (and others) be addressed to ensure that needed safety margins are maintained in the face of off-nominal conditions?

Research is also needed to understand how changes in the available capabilities for operating in and managing airspace, in combination with complexity measures, may result in changes to the overall airspace capacity, and how these sorts of dynamic capacity fluctuations will drive operational safety margins. Further, as systems supporting strategic conflict management become more automated (or autonomous), the roles, responsibilities and means of people interacting with automated systems will need to adapt so that people can effectively maintain awareness of the relevant state of the air traffic system and have confidence that off-nominal conditions can be effectively handled through human-automation teaming.

"Soft-fail" modes, including how to handle unexpected conditions and equipment failures, self-healing and backup strategies, etc., will need to ensure that automation can minimize loss of safety margins without expecting people to "jump in" and resolve issues.

3.2.5 Traffic management for very-high-altitude operations

As the utility of very-high-altitude space operations increases, there will be increased complexity with the wide range of vehicle types and operations using the airspace, including military aircraft, commercial space ingress/egress and other high-altitude vehicles such as High-Altitude Long Endurance (HALE) and High-Altitude Pseudo-Satellites (HAPS) that loiter in the airspace for long durations. As a result, there will likely be a need to extend strategic conflict management services to this airspace. (In the United States, there is no controlled airspace above 60,000 ft above mean sea level (MSL); in other locations, the boundary may be different.) These services may include community coordination mechanisms, priority mechanisms, fee structures, etc. This research will also need to address how much information operators can access and minimum requirements, among other things.

3.2.6 TBO strategic conflict management incorporating complexity and new entrants

Standards are in place for incorporating improved safety and efficiency improvements using TBO and detailed information regarding the aircraft operating within a given airspace volume, including pair-wise separation standards, complexity measures, weather, etc. These standards are defined for human-managed airspace, with the assumption that controllers and pilots maintain overall awareness and have final authority over any changes to an aircraft trajectory. Note that strategic conflict management functions may be defined for either operator-initiated or ANSP-initiated actions.

3.2.7 Prioritization and separation requirements

Changes to airspace regulations are formally put in place through mechanisms, such as notices of proposed rulemaking (NPRM), which capture changes in airspace policy believed to have net benefits for society as a whole. These changes include formal definitions of changes in right-of-way expectations, airspace access priorities and separation minima. This policy takes into account the breadth of operational modes and performance behaviors of vehicles that may be in close proximity. Pilots of crewed vehicles, for example, will need to become more familiar with the operating characteristics of AAM vehicles. AAM operators, similarly, will be required to understand the flight rules that crewed aircraft follow.

3.2.8 BVLOS operator requirement to share flight plan information

With the potential for UAS vehicles to be operating BVLOS, the airspace regulator may require, for certain criteria, that the operator provide information to a UTM or xTM provider regarding the flight in advance if the flight is not operating under IFR. Factors driving the requirement could include a certain overall density of operations, the likely presence of other crewed aircraft, etc. Required information elements could include, for example, the overall flight plan, the platform that is executing the flight, real-time updates on position information, operator identification, remote identification code and other items.

3.3 Strategic Conflict Management: 2030–2035

Table A3-3 summarizes the strategic conflict management capabilities, research activities, standards and policy initiatives that are in place in 2020–2025, plus the strategic management capabilities anticipated in the following five years.

<table>
<tr><th colspan="3">2030–2035</th><th>2035–2040</th></tr>
<tr><td colspan="3">3.3.1 Airspace volume complexity management with alerts
3.3.2 Static airspace volumes segregate autonomously managed traffic
3.3.3 Reduced airspace volume protection for space launch, re-entry, and recovery</td><td rowspan="3">3.4.1 Flexible airspace volumes for segregating autonomously managed traffic
3.4.2 Integrated airspace supports both crewed vehicles and autonomously managed vehicles</td></tr>
<tr><td>Research Completed</td><td>Technology and Standards</td><td>Policy Initiative</td></tr>
<tr><td>3.3.4 OpEvals for autonomous strategic conflict management</td><td>3.3.5 Airspace volume complexity monitoring, forecasting, and management requirements
3.3.6 Operator-to-operator conflict management standards</td><td>3.3.7 Policy capturing new flight rules and safety roles in autonomously managed airspace</td></tr>
</table>

Table A3-3. Strategic Conflict Management Capabilities and Activities, 2030–2035

3.3.1 Airspace volume complexity management with alerts

Automation for the strategic management of airspace incorporates more factors in assessing the overall level of airspace risk and continuously evaluates current and forecast levels of risk and potential mitigation strategies. Mitigation strategies, along with the likely impacts, are provided to humans for approval before execution.

As part of the complexity monitoring, systems will address airspace, such as Upper E airspace in the United States, that has a wide range of performance characteristics and speeds, and aircraft entering and exiting the airspace (such as commercial space vehicles).

In this time frame, this complexity management is autonomous only in limited areas and in certain types of airspace.

3.3.2 Static airspace volumes segregate autonomously managed traffic

Autonomously managed aircraft are authorized to operate in specific airspace volumes in all weather conditions (including zero visibility) without human oversight or intervention by the ANSP, other than the management of entry and exit from these airspace volumes. The locations of these airspace volumes that integrate autonomous operations is driven by risk analysis and feasibility assessments.

3.3.3 Reduced airspace volume protection for space launch, re-entry and recovery

The increased pace of space launches and returns is managed with reduced impacts to traditional aircraft due to the ability to better tailor the 4D space that is protected from potential space debris. ATC automation is able, in real time, to adjust trajectories of aircraft near a potential debris field using TBO based on assessment of current risk levels.

With the higher cadence of space launches and returns, policy will be in place to balance the allocation of airspace for space launches and re-entries with other operations.

3.3.4 OpEvals for autonomous strategic conflict management

Research is needed to understand options to establish appropriate roles, allocation of responsibilities and interfaces supporting human "over-the-loop" oversight of the performance and health of autonomous systems performing strategic conflict management. The research needs to include a significant emphasis on off-nominal conditions to understand the failure modes, the potential for effective human intervention and the mitigations and strategies to reduce behaviors that undermine overall system safety levels.

3.3.5 Airspace volume complexity monitoring, forecasting and management requirements

Technical requirements, performance needs and human oversight requirements are researched and evaluated in anticipation of autonomous strategic management of airspace, where humans are informed of overall airspace health without being directly involved in specific initiatives or strategies before they are executed.

3.3.6 Operator-to-operator conflict management standards

With a common operating picture available for operators with AAM missions and BVLOS UAS flights, operators have the opportunity to work directly with each other to resolve conflicts, both in a strategic and a tactical time frame. By this time, technical standards are in place that provide information exchange needs and algorithms for equitable conflict management negotiations.

3.3.7 Policy capturing new flight rules and safety roles in autonomously managed airspace

To fully implement autonomous management of air traffic and the associated safety practices, new policy will be needed addressing changes in flight rules and the change in roles and responsibilities of humans who have traditionally performed tasks that will be assigned to automation. This policy will need to address both technical considerations (benefits of the transition) as well as the impacts on people affected by this change.

3.4 Strategic Conflict Management: 2035–2040

Table A3-4 summarizes the strategic conflict management capabilities, research activities, standards and policy initiatives that are in place in the time period 2035–2040, plus the strategic conflict management capabilities anticipated in the following five years.

<table>
<tr><th colspan="3">2035–2040</th><th>2040–2045</th></tr>
<tr><td colspan="3">3.4.1 Flexible airspace volumes for segregating autonomously managed traffic

3.4.2 Integrated airspace supports both crewed vehicles and autonomously managed vehicles</td><td rowspan="3">3.5.1 Flexible airspace volumes and operations, autonomously managed

3.5.2 Autonomous strategic conflict and separation management</td></tr>
<tr><td>Research Completed</td><td>Technology and Standards</td><td>Policy Initiative</td></tr>
<tr><td>3.4.3 Autonomous management of arrivals and departures</td><td>3.4.4 Standards for facilities and capabilities enabling conflict management</td><td>3.4.5 Strategic conflict management and autonomous procedure harmonization</td></tr>
</table>

Table A3-4. Strategic Conflict Management Capabilities and Activities, 2035–2040

3.4.1 Flexible airspace volumes for segregating autonomously managed traffic

The boundaries of airspace reserved for autonomously managed aircraft are flexible, defined by automation based on known and forecast demand and conditions. Some of these volumes will serve as "corridors" for traffic to pass through airspace that includes crewed aircraft managed by humans. Automation also manages the interface across boundaries when autonomously capable aircraft cross into human-managed airspace.

3.4.2 Integrated airspace supports both crewed vehicles and autonomously managed vehicles

By this time frame, crewed vehicles and autonomously managed vehicles routinely operate in the same airspace. Autonomous vehicles are authorized to operate in all classes of airspace, including Class B. The "rules of the air" are documented for the interactions between crewed and autonomous vehicles.

3.4.3 Autonomous management of arrivals and departures

By this time frame, research has been completed on how to manage the convergence of vehicles into integrated airspace that includes both crewed and autonomous vehicles arriving to, or departing from, aerodromes.

3.4.4 Standards for facilities and capabilities enabling conflict management

As part of integrated airspace for crewed and autonomous operations, required standards for facilities that support these operations are mature and published. For example, standards will be developed for facilities supporting "last mile" deliveries, such as vertiport arrivals and departures.

3.4.5 Strategic conflict management and autonomous procedure harmonization

Internationally, the standards for managing conflicts associated with flights crossing international borders or flight information regions (FIRs) are harmonized among CAAs and ANSPs, providing improved coordination and predictability for highly automated and autonomous flights.

3.5 Strategic Conflict Management: 2040–2045

3.5.1 Flexible airspace volumes and operations, autonomously managed

Airspace safety levels and margins are autonomously managed. Airspace boundaries are less focused on human considerations and instead are driven by assessed performance requirements for aircraft to ensure that acceptable safety levels are maintained. There is a mixture of autonomously managed and human-managed operations, and operators that implement autonomous capabilities (such as digital flight) are able to operate seamlessly in airspace that also includes human-managed operations.

Space launches and re-entries are managed autonomously. TBOs and TBO management are used to ensure that airspace safety levels remain acceptable while minimizing the disruption to air traffic that is affected by the potential, or real, hazard.

3.5.2 Autonomous strategic conflict and separation management

Safety is continuously monitored and potential changes to safety levels are forecast, along with the evaluation of potential mitigation strategies. Overall levels of traffic and complexity are managed to ensure that, under various failure conditions, adjustments to traffic levels can be made.

4 Tactical Separation Management

Tactical separation management is the process of ensuring that aircraft maintain separation from other aircraft, obstacles and other hazards to maintain a target level of safety. Traditionally, this function has been performed by pilots using visual acquisition (supplemented by charting information or cockpit displays of traffic) to avoid loss of separation, or when under IFR, air traffic controllers have used radar or other surveillance sources to monitor traffic under their jurisdiction, providing instructions to pilots when needed that resolve the situation.

2040-2045	4.5.1 Autonomous tactical separation management for large transport and AAM operations
2035-2040	4.4.1 Performance-based adaptive separation
2030-2035	4.3.1 Conflict advisory alert and routing guidance for UAS 4.3.2 UAM & larger UAS autonomous tactical separation 4.3.3 Limited autonomous cargo operations
2025-2030	4.2.1 DAA for UAS self-separation and VFR enhanced safety 4.2.2 BVLOS operators have real-time surveillance information 4.2.3 Semi-autonomous small package delivery with human oversight
2020-2025	4.1.1 UAS ability to avoid static obstacles for low altitude BVLOS Operations

Figure A4-1. Evolution of Tactical Separation Management Capabilities

Safety research in this section addresses the need to adapt to increasingly diverse operations and vehicles and the increased availability of information through new channels. The evolution of tactical separation management capabilities is illustrated in Figure A4-1. Factors driving research, development, and policy include the following:

- New information sources and capabilities to increase the overall safety of traditional VFR operations will be needed;
- Separation standards will evolve as airspace complexity and density increase;
- Increased traffic volumes, especially of small and light UAS, will drive the need to revisit how vehicle positions are tracked and separation is managed; and,
- Regulators will need to address any airspace that will include users operating under different regimes (e.g., flight rules or airspace requirements) through either equipage requirements, segregation of operators or some other means.

In particular, highly automated or autonomous tactical separation management, whether performed on the aircraft itself or by a highly reliable system managing multiple aircraft, is anticipated to address safety needs in instances in which human oversight may not be effective or when the operator chooses to implement autonomous operations.

For this document, the term *autonomous tactical separation management* is defined to mean a capability for an automated system to monitor an airspace environment including all relevant information (traffic, hazards, weather information, etc.) to identify and predict loss of safe separation with a vehicle under its jurisdiction, and to either execute or communicate to the vehicle the appropriate adjustment to the flight path to maintain safe separation without a human oversight function. If this function resides on the vehicle, it is defined as *autonomous self-separation.*

The progression of safety capabilities related to tactical separation management that we postulated to be realized between now and 2045 is shown in Figure A4-1 below and described in further detail in the following sections.

4.1 Tactical Separation Management: 2020–2025

The tactical separation management capabilities envisioned to be available in this time frame and the next, and the research completed, technology and standards developed and policy initiatives established during this period are shown in Table A4-1, below.

4.1.1 UAS ability to avoid static obstacles for low altitude BVOS operations

By 2025, there will be routine BVLOS operations in low-altitude airspace in "shielded" areas. (A shielded airspace is within the horizontal and vertical boundaries that crewed aircraft are directed to in order to avoid airspace regulations.) In segregated

<table>
<tr><th colspan="3">2020-2025</th><th>2025-2030</th></tr>
<tr><td colspan="3">4.1.1 UAS ability to avoid static obstacles for low-altitude BVLOS operations</td><td rowspan="3">4.2.1 DAA for UAS self-separation and VFR enhanced safety
4.2.2 Real-time surveillance information for BVLOS operators
4.2.3 Routine semi-autonomous small package delivery with human oversight</td></tr>
<tr><td>Research Completed</td><td>Technology & Standards</td><td>Policy Initiative</td></tr>
<tr><td>4.1.2 Test suite for DAA
4.1.3 Lightweight technology for surveillance supporting DAA
4.1.4 Pair-wise separation and collision avoidance
4.1.5 Simultaneous management of multiple BVLOS vehicles
4.1.6 Right-of-way and prioritization approach</td><td>4.1.7 Operational requirements for performance-based separation management</td><td>4.1.8 Broad rulemaking for BVLOS operations</td></tr>
</table>

Table A4-1. Tactical Separation Management Capabilities and Activities, 2020–2025

airspace (where crewed aircraft flights have been restricted), BVLOS UAS will be able to avoid fixed obstacles through a combination of obstacle database information and reliable obstacle sense-and-avoid technologies resident on the aircraft. BVLOS UAS will also be able to operate in other relatively low-density airspace through compliance with rulemaking.

4.1.2 Test suite for DAA

A major requirement for an uncrewed vehicle operating BVLOS will be to ensure that it can safely avoid, and maintain separation from, both ground obstacles (static or moving) and in-flight aircraft (both crewed and uncrewed) via an approved detect and avoid (DAA) capability. Safety approvals for UAS can be facilitated by the ability of the manufacturer to demonstrate that the vehicle performs acceptably against a standard suite of encounters. (This is similar to the development of the encounter suites that were developed for traffic-alert and collision avoidance systems.)

4.1.3 Lightweight technology for surveillance supporting DAA

UAS conducting BVLOS operations will likely need a reliable DAA capability that can operate reliably within size, weight and power (SWAP) constraints, along with tradeoffs for flight time and payload. There may also need to be a capability to tactically avoid other small and light UAS, in addition to detecting traditional aircraft not equipped with cooperative surveillance. This capability will be a critical enabler for wide-spread BVLOS operations at low altitudes to support awareness of both aircraft equipped with some kind of cooperative surveillance capability and those that are not equipped.

4.1.4 Pair-wise separation and collision avoidance

As the management of airspace risk levels becomes increasingly automated, the approach for managing vehicle separation from other vehicles, obstacles or hazardous conditions has the potential to become increasingly nuanced. An overall framework for separation management may be helpful in providing insights on questions such as whether to maintain the concept of vehicle classes, the level of complexity and downstream considerations to consider, and other factors.

Associated with changes in vehicle separation standards, the behaviors of different vehicle types will need to be incorporated into future airborne collision avoidance systems (ACAS). ACAS algorithms may need to be revised, for example, depending on whether a vehicle is uncrewed and on the level of automation or autonomy it is employing.

4.1.5 Simultaneous management of multiple BVLOS vehicles

For many BVLOS operations, operators desire to have capabilities that allow an individual to oversee the flights of multiple, simultaneous UAS flights. Research in this area provides insights on the needed automation capabilities to support human oversight, performance requirements, and how to handle off-nominal conditions in a multi-flight configuration. These requirements may differ depending on airspace, vehicle, and operation.

4.1.6 Right-of-way and prioritization approach

With the introduction of uncrewed operations, there may be a need to evaluate means to implement, and the impacts of alternative approaches to prioritization of resources (e.g., airspace access, spectrum) and right-of-way expectations.[1] As uncontrolled airspace sees denser operations of BVLOS UAS, there may also be a need to implement priorities consistently across UTM or XTM providers, or to assess changing the airspace rules and classification associated with a specific airspace.

[1] The BVLOS ARC, for example, has proposed that BVLOS UAS, operating in airspace without ATC services, have right-of-way over traditional aircraft that do not have operating ADS-B or TABS equipment.

4.1.7 Operational requirements for performance-based separation management

With the routine introduction of BVLOS operations, including multiple, proximate operations to other UAS and crewed aircraft, standards will be needed that define appropriate separation distances drone-to-drone, drone-to-obstacles (if not under inspection), and drone-to-crewed vehicle. These are likely to be different than IFR separation standards and will supplement the current requirement of staying "well clear." These performance-based requirements will also consider the overall characteristics of the UAS (e.g., kinetic energy, frangibility).

4.1.8 Broad rulemaking for BVLOS operations

Much of the economic value of UAS is expected to derive from the ability to operate these vehicles in a BVLOS mode, and for one human, or a human team, to manage multiple simultaneous flights (m:N operations). Without a pilot on board the UAS to "see and avoid," regulators will need to create performance-based rules that allow UAS to operate BVLOS in a manner that is consistent with the anticipated economic and social benefits of these operations.

Because of the lack of a pilot on board, most regulators will need to adapt airspace rules that lay out performance requirements and other adjustments to airspace operations to maintain safe separation. These rules will also support some instances of semi-autonomous small package delivery and m:N operations. In some cases, regulators may impose requirements on other operators (of crewed aircraft) within certain airspaces as well.[2] Regulations will also address performance-based requirements associated with delivery of packages and overall safety needs for UAS in takeoff and landing situations.

4.2 Tactical Separation Management: 2025–2030

The tactical separation management capabilities expected to be available during this time frame are shown in Table A4-2, along with the research completed, technology and standards developed, and policy initiatives established in this period.

4.2.1 DAA for UAS self-separation and VFR enhanced safety

Between 2025 and 2030, DAA capabilities, standards and procedures will need to be in place to meet safety requirements for tactical separation of UAS from other vehicles. These capabilities will be offered by one or more manufacturers for use by

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[2] In the United States, a major enabler of BVLOS operations will be updates to the Federal Aviation Regulations (FARs), codifying a set of rules that operators can comply with to maintain an acceptable level of risk. A BVLOS NPRM (and subsequent updates to FARs) is expected to be issued before 2025 for an initial class of BVLOS operations.

<table>
<tr><th colspan="3">2025–2030</th><th>2030–2035</th></tr>
<tr><td colspan="3">4.2.1 DAA for UAS self-separation and VFR enhanced safety
4.2.2 Real-time surveillance information for BVLOS operators
4.2.3 Routine semi-autonomous small package delivery with human oversight</td><td rowspan="3">4.3.1 Conflict advisory alert and routing guidance for UAS
4.3.2 UAM and larger UAS autonomous tactical separation
4.3.3 Limited autonomous cargo operations</td></tr>
<tr><td>Research Completed</td><td>Technology and Standards</td><td>Policy Initiative</td></tr>
<tr><td>4.2.4 Operational and safety performance needs for advanced operations
4.2.5 Adaptative separation in TBO operations
4.2.6 Deconfliction between human and autonomously managed traffic
4.2.7 Collision avoidance addressing AAM vehicle characteristics</td><td></td><td>4.2.8 Equipage policy for integrated airspace operations
4.2.9 Right-of-way requirements</td></tr>
</table>

Table A4-2. Tactical Separation Management capabilities and activities for 2025–2030

small or light UAS. Such a capability may include a ground-based sense and avoid (GBSAA) service or stand-alone airborne equipment.

DAA technologies are available to enhance the safety of VFR operations through electronic flight bag (EFB) capability provision of DAA services for VFR pilots (using supplemental safety service regulatory framework).

4.2.2 Real-time surveillance information for BVLOS operators

As more new entrants operate outside of airspace managed by an ANSP, UAS operating BVLOS will need to have full awareness of traditional (crewed) aircraft and other UAS that may be operating in the same airspace. Maneuvers to avoid loss of acceptable separation can be avoided by providing to the UAS position information for traditional aircraft, as well as the planned route of flight (if available) in advance, to allow strategic updates to the UAS flight path to avoid potential conflicts. By this period, standards for service providers to collect and distribute (as appropriate) surveillance information will be established as one means of ensuring operators have this real-time information.

Such a capability will also need to be captured as performance and interface requirements for PSUs, USSs, and xTM providers serving vehicles in very-high-altitude (e.g., Upper E) airspace.

4.2.3 Routine semi-autonomous small package delivery with human oversight

While there are pockets of BVLOS capability before 2025, by 2030, the needed rulemaking, technologies and support infrastructure will be in place to enable safe, routine delivery of small packages (and mapping/data services) in densely populated areas. Individual UAS flights will be semi-autonomous, with an individual human overseeing multiple simultaneous flights. Human oversight will also include the capability to abort or suspend flights as safety needs dictate. The introduction of this capability will include resolution of local community control considerations, drop-off safety, etc.

Experience from implementing this capability supports implementation of capabilities associated with operations for larger cargo and human occupants, such as 4.3.2, 4.3.7.

4.2.4 Operational and safety performance needs for advanced operations

Internationally, there are a number of operators and manufacturers interested in enabling routine regional air mobility (RAM) and UAM operations for short- to medium-haul operations carrying cargo and human passengers. Individual vehicle capabilities will be increasingly autonomous, and new requirements will likely be needed for operation of these vehicles, especially in urban environments. This research will provide needed insights on the safety functions and procedures needed to ensure that the associated vehicles and operations comply with social expectations of safety.

This research will also address the safety considerations that would need to be in place to adjust pilot requirements for certain commercial operations, such as allowing a pilot on the ground to serve as backup for a flight.

4.2.5 Adaptative separation in TBO operations

With the increased focus on TBO and use of automation to more accurately forecast and coordinate aircraft movements, adaptive separation algorithms can be used to increase efficiency while maintaining acceptable levels of risk. This is expected to be accomplished by evaluating, on a pairwise basis, expected separations between aircraft (both traditional and new entrants) and potential hazards. Using known aircraft characteristics (e.g., speed, vertical profiles, turn characteristics), the distance needed to maintain safety can be tailored and small adjustments to flight paths can be made taking the aircraft capabilities into account.

4.2.6 Deconfliction between human and autonomously managed traffic

While there is likely to be segregated airspace for initial AAM operations, there will probably also be a need to integrate UAS, operating autonomously, in the same airspace as crewed vehicles being served by an ANSP. Such operations (e.g., sometimes referred to as "digital flight rules") will involve the need to understand human factors and the technical and performance requirements for AAM vehicles, ANSP automation supporting controllers, potential equipage needs and supporting ground systems that allow these operations to coexist.

The airspace management approach for controlled airspace will be a particular challenge. For example, in Class B airspace, what are the human roles in the presence of both piloted and uncrewed, autonomous aircraft? How should highly automated or autonomous systems operate when sharing airspace with crewed aircraft? This research will almost certainly begin before this time period and will need to be mature to enable integrated operations by 2035.

4.2.7 Collision avoidance addressing AAM vehicle characteristics

Research examining collision avoidance for very different vehicle characteristics and separation requirements will support capability 4.3.1, Conflict Advisory Alert, and routing guidance for UAS introduced during the next time period, 2030–2035. For AAM vehicles (including small UAS), collision avoidance algorithms will address AAM maneuverability and differing needs for uninhabited versus inhabited vehicles, and will also address the appropriate margins for initiating the execution of collision avoidance maneuvers.

4.2.8 Equipage policy for integrated airspace operations

With increasing complexity of operations and the introduction of autonomy, there may be a need to revisit minimum requirements for all aircraft to operate. There may be increased requirements for secondary surveillance, for example, or for updated radio-communications equipment that will meet new interoperability requirements. This policy will need to be informed by factors such as the anticipated traffic mix in 2040, costs and benefits to those affected by potential new requirements, the value of new operations that are enabled by additional equipage requirements, etc. The policy will also need to address a phased approach to timing, including forward-fit requirements and retro-fit requirements. Due to the long lead time for equipage mandates, any equipage policy that is to be widely in place by 2045 will likely need to be put in place by 2030.

4.2.9 Right-of-way requirements

Formal definitions to any changes in right-of-way expectations will be approved. There is a requirement for increased awareness of different operational modes and behaviors for vehicles that may all be found operating in the same airspace. Pilots of crewed vehicles, for example, will need to become more familiar with the operating characteristics of AAM vehicles. AAM operators, similarly, will be required to understand the flight rules that crewed aircraft follow.

4.3 Tactical Separation Management: 2030–2035

Table A4-3 contains the tactical separation management capabilities envisioned to support tactical separation management in this time frame and the next, together with the key research completed, technology and standards developed and policy initiatives established in this epoch.

4.3.1 Conflict advisory alert and routing guidance for UAS

2030-2035			2035-2040
4.3.1 Conflict advisory alert and routing guidance for UAS 4.3.2 UAM and larger UAS autonomous tactical separation 4.3.3 Limited autonomous cargo operations			4.4.1 Performance-Based, Adaptive Separation
Research Completed	**Technology & Standards**	**Policy Initiative**	
4.3.4 Roles for autonomous separation of human-carrying vehicles 4.3.5 Oversight of multiple AAM vehicle flights by a single individual	4.3.6 Adaptive Buffer Zone requirements	4.3.7 Integration of segregated airspaces 4.3.8 Regulations allowing ground-based back-up pilots for some commercial ops	

Table A4-3. Tactical Separation Management capabilities and activities for 2030–2035

For operators of uncrewed vehicles that are using UTM or PSU service, the operator will need to receive guidance from the separation management service to reduce the likelihood of a separation violation or a collision. Service providers will have access to filed flight plan data from traditional crewed aircraft and access to any available real-time surveillance information, as well as being able to fully exchange UAS intent information with other service providers that have adjoining or overlapping service areas.

Based on the information available, these service providers will inform operators when their flight does not meet required separation parameters. In addition, service providers will either propose re-routes or they will provide information on constraints that the operator must conform to before updating a planned route of flight.

4.3.2 UAM and larger UAS autonomous tactical separation

AAM vehicles designed to be operated without a pilot performing tactical control will need a DAA capability that maintains appropriate separation from other airborne vehicles, obstacles, other airspace restrictions or aerodrome obstacles and vehicles. Many of these vehicles will be carrying human passengers and may be operating over populated areas, and the DAA functionality for these vehicles will likely have more stringent requirements than those for other uncrewed vehicles.

4.3.3 Limited autonomous cargo operations

Delivery of medium cargo loads is performed semi-autonomously (with remote pilots) in limited situations. Such operations may be used for humanitarian needs (e.g., food delivery) or to validate operations of larger autonomous vehicles. These operations are initially conducted in Class E or other low-density airspace. Initial operations are enabled via waivers or other agreements with regulators as a means of informing future regulations.

4.3.4 Roles for autonomous separation of human-carrying vehicles

Clarity in human roles and responsibilities will be needed in airspace where humans (e.g., pilots, controllers or other safety service providers) will not have direct authority to affect the operation of autonomous vehicles in the same airspace as crewed vehicles. This includes human factors such as what information is available to humans, issues of authority and accountability, and how to manage hazards and failure modes. Significant research is needed on understanding autonomy functions, including self-monitoring of failure conditions, "soft-fail" modes and means to communicate status to operational personnel who have responsibility for oversight. Operational acceptability to humans who have some level of responsibility will be critical if there is to be any set of mixed operations within a given airspace. Research topics include functional requirements, performance requirements, and operational evaluations to validate nominal and off-nominal situations.

4.3.5 Oversight of multiple AAM vehicle flights by a single individual

Research examines how multiple AAM vehicles can be safely managed by a single individual on the ground. Different configurations of operations are evaluated to test the ability of a ground-based pilot to monitor multiple flights through takeoff, arrival and landing, while allowing the ability to take an active role in a flight if needed.

4.3.6 Adaptive buffer zone requirements

Technical and performance requirements for adaptive separation zones are available for implementation in ANSP automation, xTM service provider automation, and/or vehicles with DAA or self-separation capabilities. Included in these requirements are default behaviors, definition of aircraft flight performance and other parameters that are relevant, and a means by which the system determining the appropriate separation distances can access characteristics of proximate aircraft and other relevant data.

4.3.7 Integration of segregated airspaces

Depending on the assessment of the operational suitability and practicality of having human-managed and autonomously managed vehicles within the same airspace, a policy decision will be needed on whether segregation of these two modes of operation should be continued. Along with this policy decision may be guidance on required equipage, performance expectations and accountability measures.

4.3.8 Regulations allowing ground-based back-up pilots for some commercial ops

Regulations are published that provide the basis for a change in roles and responsibilities for pilots in some types of commercial operations, such as cargo operations.

4.4 Tactical Separation Management: 2035–2040

The tactical separation management capabilities anticipated to exist in this time frame to support tactical separation management are shown in Table A4-4 below, together with the research completed, technology and Standards developed, and policy initiatives established in this time period.

4.4.1 Performance-based adaptive separation

Highly automated systems evaluate aircraft configurations and trajectories in airspace to identify any need to adjust aircraft separations from obstacles or other aircraft to maintain an acceptable level of safety. These systems may or may not be installed on individual aircraft. Any needed aircraft maneuvers are calculated based on the environmental conditions as well as the characteristics of any aircraft involved. The needed separation, and the extent of the maneuver, is determined by factors such as aircraft speeds, turning and climb/descent performance, presence of hazardous

<table>
<tr><th colspan="3">2035-2040</th><th>2040-2045</th></tr>
<tr><td colspan="3">4.4.1 Performance-Based, Adaptive Separation</td><td rowspan="2">4.5.1 Autonomous tactical separation management for large transport and AAM operations</td></tr>
<tr><td>Research Completed</td><td>Technology & Standards</td><td>Policy Initiative</td></tr>
<tr><td>4.4.2 OpEval of autonomous self-separation of large vehicles in lower-density airspace</td><td>4.4.3 Standards for autonomous vehicles crossing FIRs</td><td></td><td></td></tr>
</table>

Table A4-4. Tactical Separation Management capabilities and activities for 2035–2040

cargo, etc. Greater efficiencies are achieved as some aircraft can safely be in closer proximity while maintaining desired safety levels. Additional separations may be imposed in cases of factors such as wake turbulence, unstable weather or lack of maneuverability.

4.4.2 OpEval of autonomous self-separation of large vehicles in lower-density airspace

The operational suitability of fully autonomous aircraft separation and strategic conflict management operations is validated through long-term operational trials, initially performed in lower-density airspace (such as Upper E airspace, or airspace above FL 600). Vehicles in this airspace and their supporting automation are able to complete missions without human intervention, including maintaining safe separation from airspace hazards and other vehicles in that airspace.

4.4.3 Standards for autonomous vehicles crossing FIRs

Standards are developed for autonomous vehicles to ensure that their behavior is consistent with requirements in each FIR encountered. The algorithms will have to be harmonized to guarantee that behaviors are compatible with the regulations of each FIR within which an uncrewed vehicle operates.

4.5 Tactical Separation Management: 2040–2045

4.5.1 Autonomous tactical separation management for large transport and AAM operations

In the 2045 time frame, safety gains will have been achieved through the use of reliable, trusted automation that autonomously handles tactical separation management among most aircraft, including large transport aircraft that carry cargo or human passengers. The autonomous functions operate over a robust, distributed communications network, allowing systems to automatically update the scope of control if a system failure in another part of the network is detected. Piloted aircraft have systems that complement human decision-making while ensuring that safety is maintained if an unsafe condition is detected.

In this time frame, some autonomous systems will operate without the ability for humans to directly intervene (i.e., human out-of-the-loop).

5 Individual Vehicle Flight Management

To accomplish individual vehicle management, vehicles will monitor and exchange information about their health, flight paths, proximity to obstacles, real-time risk assessment and other characteristics of their state and operation. In an autonomy-rich environment, the management of airborne vehicles will be accomplished by a variety of support services operating in conjunction with onboard functions. As operations become more complex and airspaces become more densely populated, higher levels of automation will be needed to maintain an expectable level of risk. Optimizing the system for individual vehicle flight management will play a large role in enabling higher levels of automation.

This section discusses the development of the following capabilities, shown in Figure A5-1, needed for autonomous real-time flight path management:

- Flight planning services;
- Vehicle health monitoring and self-healing;
- Nonparticipating or cUAS strategies;
- Transition to single pilot and uncrewed large vehicle transport operations;
- Vehicle risk assessment; and,
- Vehicle flight plan management and contingency management.

In this section, we postulate incremental activities necessary to develop, enable and validate autonomous real-time flight path management. The progression of safety capabilities related to individual vehicle flight management that we postulated to be realized between now and 2045 are shown in the table below and are described in further detail in the following sections.

Epoch	Capabilities
2040-2045	5.5.1 Autonomous aircraft operations end-to-end
2035-2040	5.4.1 Single pilot operations with self-separation for large transport/cargo with ground-based backup pilots 5.4.2 Limited remotely piloted commercial operations
2030-2035	5.3.1 Vehicle self-monitoring and healing 5.3.2 Limited autonomous cargo operations 5.3.3 DAA capability for cUAS per national strategy 5.3.4 Remotely piloted AAM-like passenger operations
2025-2030	5.2.1 BVLOS Ground risk assessment capability 5.2.2 Expanded terrain and obstacle information 5.2.3 Real-time vehicle risk assessment
2020-2025	5.1.1 Unsheltered population mapping tools 5.1.2 UAS Flight Planning Service

Figure A5-1. Evolution of vehicle flight management capabilities

5.1 Individual Vehicle Flight Management: 2020–2025

Table A5-1 shows the individual vehicle flight management capabilities anticipated to exist by or during this time frame, as well as those postulated for the following time frame. The table also shows the research completed, technology and standards developed and policy initiatives established in this epoch.

<table>
<tr><th colspan="3">2020-2025</th><th>2025-2030</th></tr>
<tr><td colspan="3">5.1.1 Unsheltered population mapping tools
5.1.2 UAS Flight Planning Service</td><td rowspan="3">5.2.1 BVLOS Ground risk assessment capability
5.2.2 Expanded terrain and obstacle information
5.2.3 Real-time vehicle risk assessment</td></tr>
<tr><td>Research Completed</td><td>Technology & Standards</td><td>Policy Initiative</td></tr>
<tr><td>5.1.3 Crowdsourcing of terrain and obstacle information
5.1.4 Criteria for requiring specific USS safety services
5.1.5 Safety margins for AAM operations
5.1.6 Common Operating Picture</td><td>5.1.7 Definition for UAS flight plan</td><td></td></tr>
</table>

Table A5-1. Individual Vehicle Flight Management capabilities and activities for 2020–2025

5.1.1 Unsheltered population mapping tools

With a growing use of BVLOS for autonomous aircraft operations over people, it will be critical to manage the risk to those on the ground. During different times of the day, certain routes, areas of gathering and places of residency experience varying volumes of people, creating a challenging dynamic ground risk. Applying a mapping tool or aid to help account for this population traffic can allow for more accurate assessment of risk levels.

5.1.2 UAS flight planning service

As with the crewed aviation counterpart, UAS will require a flight planning service early in the integration process. A UAS flight planning service must enable intent sharing, altitude, route and arrival and departure times. This step is one of the first levels of safety for mixed volumes of traffic.

5.1.3 Crowdsourcing of terrain and obstacle information

Urban terrain databases are often incomplete and out of data due to rapid population growth and expansion. Including crowdsourcing for terrain map development aids operators in creating safe flight plans while providing them with the most current data about ground risks. Research will include methods for crowdsourcing and requirements for accuracy, resolution and frequency.

5.1.4 Criteria for requiring specific USS safety services

Research in this time frame will identify conditions in which a UAS or AAM operation has the potential to introduce a significant safety risk without the assurance that the operation is informed by essential services, such as weather information. The outcome of this research will be used to inform future policy initiatives.

5.1.5 Safety margins for AAM operations

As BVLOS AAM vehicles become a greater part of the air traffic mix, the expectations for safety margins will need to be clarified, especially as UAS with larger loads of cargo or human passengers are introduced.

For electric/battery powered vehicles, how much additional energy should be in reserve past the planned flight to a given destination? For traditional (av-fuel) vehicles, there are IFR requirements; do these requirements make sense for these vehicles? For vehicles that have the ability to safely land in locations that are not aerodromes, are there looser requirements?

5.1.6 Common operating picture

The needs associated with a common operating picture (COP) for UAS (BVLOS) operators are defined and support improved definition of underlying third-party services, including intent, notices to air missions (NOTAMs, previously known as notices to airmen) and other information. The COP includes minimum requirements for AAM and BVLOS UAS traffic, crewed traffic (both vehicles equipped with cooperative surveillance or unequipped), weather and other meteorological conditions, etc.

5.1.7 Definition for UAS flight plan

To support needed UTM functions, the minimum requirements for a UAS flight plan will be defined. These may add elements that are not present in current flight plans for traditional piloted aircraft. The UAS flight plan, for example, may include additional information regarding flight performance characteristics, mission criticality, airspace volume being used and 4D trajectory (4DT) data, as well as other information related to the operator or the ground control system.

5.2 Individual Vehicle Flight Management: 2025–2030

Table A5-2 shows the individual vehicle flight management capabilities anticipated to exist by or during this time frame, as well as those postulated for the following time frame. The table also shows the research completed, technology and standards developed and policy initiatives established in this time period.

5.2.1 BVLOS ground risk assessment capability

By this time period, UAS operators will have routine, broad access to ground risk assessment tools that allow them to assess the potential risks to infrastructure, people and property. Ground risk services may provide a range of assessments, from an overview of the risks along a flight path to an integrated risk assessment that considers multiple factors.

5.2.2 Expanded terrain and obstacle information

BVLOS operations must consider potential terrain and obstacles, especially for low-altitude flights. While airports generally provide accurate information, the availability of this information in other areas is needed for safe, reliable, BVLOS operations. In this time period, such information is available. It may be consolidated via crowdsourcing from appropriately equipped UAS, or individual localities and organizations may create databases for specific service volumes.

2025-2030			2030-2035
5.2.1 BVLOS Ground risk assessment capability 5.2.2 Expanded terrain and obstacle information 5.2.3 Real-time vehicle risk assessment			5.3.1 Vehicle self-monitoring and healing 5.3.2 Limited autonomous cargo operations 5.3.3 DAA capability for cUAS per national strategy 5.3.4 Remotely piloted AAM-like passenger operations
Research Completed	**Technology & Standards**	**Policy Initiative**	
5.2.4 Vehicle self-monitoring, healing and SPIs 5.2.5 Counter-UAS (cUAS) strategies for intervention 5.2.6 Remotely piloted AAM-like operations		5.2.7 Regulations for UAS flight planning safety margins 5.2.8 Policy to allow cUAS intervention 5.2.9 Policy to define conditions for mandatory participation in USS	

Table A5-2. Individual Vehicle Flight Management capabilities and activities for 2025–2030

5.2.3 Real-time vehicle risk assessment

Some vehicles have an on-board risk-assessment capability that can integrate known environmental conditions, the status of proximate traffic, current weather conditions, etc., to maintain a real-time assessment of risks. Based on the level of risk calculated, these vehicles may adjust their flight paths automatically to ensure that the overall risk stays within acceptable safety levels.

5.2.4 Vehicle self-monitoring, healing and SPIs

Research is matured to identify the needed instrumentation for highly automated or autonomous aircraft flight management. The instrumentation and the associated SPIs will be input to on-board or off-board vehicle health monitoring and real-time system repair functions. The SPIs generated will also be part of the routine safety data that is assessed for overall safety trends and vehicle health. The research will analyze performance of different architectures to compare strengths and weaknesses of each.

5.2.5 Counter UAS (cUAS) strategies for intervention

UAS operating in unauthorized modes or locations have the capacity to do significant harm and to disrupt other air traffic that is compliant with local requirements. Research in this time frame is matured to assess alternative ways to mitigate the harm that could be caused by an unauthorized UAS. This research includes additional intervention techniques to address both the vehicle and the operator of the rogue UAS.

5.2.6 Remotely piloted AAM-like operations

Research is conducted to develop requirements for remotely piloted advanced operations like those envisioned by AAM. Operational evaluations will be performed in low-density airspace.

5.2.7 Regualtions for UAS flight planning safety margins

As UAS perform more advanced operations, increased cargo loads and, potentially, the presence of human passengers will require regulations that specify clear safety margins, such as needed energy reserves for alternative fuel/power sources, requirements for flight paths to have emergency landing options, etc. These regulations will likely be performance-based, looking both at the ground risks involved and the characteristics of the UAS performing the operation.

5.2.8 Policy to allow cUAS intervention

Based on research and assessments of potential harm, policies are updated that allow effective and appropriate interventions when a UAS is operating in an unauthorized manner. Authorized interventions will need to include both remotely piloted and autonomous UAS.

5.2.9 Policy to define conditions for mandatory participation in USS

Although some UAS operate BVLOS without any support of a third-party service provider or in-house capabilities for some functions, a policy is published that defines the conditions for when an operator must implement certain services or use a qualified third-party service provider. This could include conditions such as a minimum traffic density or complexity level, certain risk or hazard conditions in place, etc. Examples of third-party services include strategic deconfliction provider, operational planning, and command and control (C2) communications link provision.

Along with the policy specifying required services in place, there is also policy that identifies the minimum set of capabilities for a given safety service, the required performance and requirements for collecting safety data.

5.3 Individual Vehicle Flight Management: 2030–2035

Table A5-3 shows the individual vehicle flight management capabilities anticipated to exist by or during this time frame, as well as those postulated for the following time

<table>
<tr><th colspan="3">2030-2035</th><th>2035-2040</th></tr>
<tr><td colspan="3">5.3.1 Vehicle self-monitoring and healing
5.3.2 Limited autonomous cargo operations
5.3.3 DAA capability for cUAS per national strategy
5.3.4 Remotely piloted AAM-like passenger operations</td><td rowspan="3">5.4.1 Single pilot operations with self-separation for large transport/cargo with ground-based backup pilots
5.4.2 Limited remotely piloted commercial operations</td></tr>
<tr><td>Research Completed</td><td>Technology & Standards</td><td>Policy Initiative</td></tr>
<tr><td>5.3.5 Operational evaluations of single-pilot large transport ops with back-up pilot on ground (monitoring multiple vehicles)
5.3.6 Research for autonomous contingency management</td><td></td><td>5.3.7 Regulation allowing ground-based back-up pilots for some commercial ops</td></tr>
</table>

Table A5-3. Individual Vehicle Flight Management capabilities and activities for 2030–2035

frame. The table also shows the research completed, technology and standards developed and policy initiatives established in this period.

5.3.1 Vehicle self-monitoring and healing

Some vehicles are now certified with the capability for onboard vehicle self-monitoring (via instrumentation) and healing, providing additional reliability and the ability to assess the performance of highly automated and autonomous functions. Outputs from these vehicles provide additional insights for the design and testing of newer autonomous functions.

5.3.2 Limited autonomous cargo operations

Uncrewed aircraft carrying significant levels of cargo are now authorized to operate in low-density airspace, such as Class E, where risk levels are lower. These initial operations allow more reliable autonomous cargo operations and provide valuable data on the operation of vehicles performing autonomous flight management.

5.3.3 DAA capability for cUAS per national strategy

Following completion of research and policy developed in the previous time period, UAS now have a DAA capability to avoid vehicles operating in the airspace without participating, as required by the local ANSP and policy, to support effective interventions, as appropriate.

5.3.4 Remotely piloted AAM-like passenger operations

Remotely piloted AAM-like operations are allowed following research and OpEvals completed in the previous time period. These vehicles carry human passengers between airports and vertiports.

5.3.5 Operational evaluation of single-pilot large transport ops with backup pilot on ground (monitoring multiple vehicles)

Highly reliable flight management capabilities are implemented on large aircraft that are capable of advanced operations or can carry significant amounts of cargo, and eventually, people. Operational evaluations are conducted to verify the suitability of the avionics enabling single-pilot operations, including the capability for a ground-based pilot to monitor flight progress and to provide operational instructions.

5.3.6 Research for autonomous contingency management

Research is conducted to develop standards for autonomous contingency management, which is the capability to manage, reduce or eliminate unanticipated risk to people, property or other aircraft due to off-nominal events associated with vehicle operations. (National Academies, 2020) Much of this work examines dynamic decision-making and real-time perception of systems during off-nominal conditions. To support autonomous contingency management, it will be necessary to migrate safety critical communications from voice to data link.

5.3.7 Regulation allowing ground-based backup pilots for some commercial operations

Regulations will be introduced that allow some conditional commercial operations to transition from two pilots on board the aircraft to a single pilot on board, with the ability for a ground-based backup pilot to manage the aircraft if the on-board pilot is incapacitated or is otherwise unable to maintain control of the aircraft.

This activity will enable capability 5.4.1, Single-pilot operations with self-separation for large transport/cargo vehicles with ground-based backup pilots.

5.4 Individual Vehicle Flight Management: 2035–2040

Table A5-4 summarizes the individual vehicle flight management capabilities, research activities, standards and policy initiatives that will be in place in the time period 2035–2040, plus the strategic management capabilities anticipated in the following five-year time frame.

<table>
<tr><th colspan="3">2035-2040</th><th>2040-2045</th></tr>
<tr><td colspan="3">5.4.1 Single pilot operations with self-separation for large transport/cargo with ground-based backup pilots

5.4.2 Limited remotely piloted commercial operations</td><td rowspan="3">5.5.1 Autonomous aircraft operations end-to-end</td></tr>
<tr><td>Research Completed</td><td>Technology & Standards</td><td>Policy Initiative</td></tr>
<tr><td>5.4.3 OpEvals for autonomous large cargo operations</td><td>5.4.4 Contingency management standards</td><td>5.4.5 Safety critical communications using datalink</td></tr>
</table>

Table A5-4. Individual Vehicle Flight Management capabilities and activities for 2035–2040

5.4.1 Single-pilot operations with self-separation for large transport/cargo with ground-based backup pilots

Large commercial transport aircraft are now crewed with a single pilot on board, instead of two. Additional safety levels are achieved through a combination of advanced automation on board and potentially a ground-based backup pilot who is able to oversee the flight in the rare case that the on-board pilot is unable to complete the flight. These aircraft are able to operate in airspace designated for autonomous operations.

5.4.2 Limited remotely piloted commercial operations

Remotely piloted commercial operations are allowed in low-risk areas, and ANSPs gather data for wider implementation in the future. The criteria for an area to be considered "low risk" (for this purpose) have been defined prior to approving any such operation.

5.4.3 OpEvals for autonomous large cargo operations

Operational evaluations are conducted in low-density airspace for autonomous large cargo operations to validate how to safely enable these operations.

5.4.4 Contingency management standards

To enable assurance of contingency management automation, standards are developed for highly automated responses to off-nominal conditions. These standards consider automation making real-time decisions in off-nominal conditions while communicating safety-critical information via datalink.

5.4.5 Safety-critical communications using datalink

Policy is developed for migration of safety-critical voice communications to datalink to support autonomous contingency management, as described in 5.3.5. This policy decision will reflect the spectrum made available by policy decision 8.2.7, Spectrum policy for AAM and UAS vehicle communications.

5.5 Individual Vehicle Flight Management: 2040–2045

5.5.1 Autonomous aircraft operations end-to-end

Certified aircraft (e.g., those carrying people and/or cargo, or performing advanced operations) can now perform a complete flight gate-to-gate without a pilot on board. We expect, as a safety measure, there is a pilot or operator on the ground, monitoring the flight, who can intervene in certain error conditions.

These aircraft automatically adjust flight paths to ensure safe separations from other proximate aircraft or hazards and coordinate as appropriate with ATM service providers (e.g., for strategic conflict management coordination). These vehicles are also able to operate either in human-managed airspace or in airspace designated for autonomous operations.

6 Aviation Weather

Weather information, at the resolution, accuracy, refresh rate, and precision needed for any given operation and vehicle, is necessary to ensure operational safety for aviation. For new entrants, weather conditions at low altitudes and in urban areas are major concerns, and weather information providers will need to refine existing aviation weather products to address differences between manned and unmanned operations. Weather measurement, now-casting algorithms, and forecasting methodologies to ensure the safety of high density, complex, UAS operations will require more weather infrastructure than currently exists. Weather models and data, decision support tools, weather dissemination capability, and policy will all need to be researched and adapted to support UAS operations.

Timeframe	Capabilities
2040-2045	*(no major capabilities added this timeframe)*
2035-2040	*(no major capabilities added this timeframe)*
2030-2035	6.3.1 Qualified microclimate forecasting for urban weather 6.3.2 Upper atmosphere enhanced weather forecasts
2025-2030	6.2.1 Qualified third-party weather service providers 6.2.2 Qualified microclimate now-casting for urban weather
2020-2025	*(no major capabilities added this timeframe)*

Figure A6-1. Evolution of aviation weather safety-related capabilities

These weather capabilities, as shown in Figure A6-1, and activities are focused solely on the capability gaps that currently exist for UAS operations and do not address aviation weather infrastructure improvements being planned for traditional aviation. The progression of safety capabilities related to aviation weather that we postulated to be realized between now and 2045 are shown in the table below and are described in further detail in the following sections.

In future versions of this document, the relevant weather infrastructure, research, standards and policy will be integrated into the cross-cutting information.

6.1 Aviation Weather: 2020–2025

Table A6-1 summarizes the aviation weather capabilities postulated to exist by or during this time frame and the next, along with research completed, technology and standards developed, and policy initiatives established in this time period.

6.1.1 Weather needs for new entrants

Initial research is conducted to determine requirements (quality, refresh rate, uncertainty, etc.) for additional weather and microclimate information needed for advanced operations to support safety during UTM and AAM operations. This work includes understanding how weather data from various sources, and of differing quality and resolution, affects the useability of a now-cast or forecast.

6.1.2 Collection of weather data for urban areas and now-casting methodologies

New urban and low-altitude weather sensing and distribution capabilities are needed for microclimate monitoring and reporting to support safety of advanced urban UAS operations. Drawing from the results of research activity 6.1.1, this research seeks to develop methodologies for weather data collection to meet those requirements, and

<table>
<tr><th colspan="3">2020 - 2025</th><th>2025 - 2030</th></tr>
<tr><td colspan="3">(no major capabilities added this timeframe)</td><td rowspan="3">6.2.1 Qualified third-party weather service providers

6.2.2 Qualified microclimate now-casting for urban weather</td></tr>
<tr><td>Research Completed</td><td>Technology & Standards</td><td>Policy Initiative</td></tr>
<tr><td>6.1.1 Weather needs for new entrants

6.1.2 Collection of weather data for urban areas and now-casting methodologies</td><td>6.1.3 Weather standards for UAS mission types

6.1.4 Standards for qualifying third party weather service providers</td><td></td></tr>
</table>

Table A6-1. Aviation Weather capabilities and activities for 2020–2025

to develop now-casting capabilities in urban areas and wherever microclimates might significantly impact UAS operations.

This research examines the potential for crowdsourcing weather data from commercially available personal weather stations, including understanding the necessary quality of data and calibration standards. Research also examines including real-time weather data collected by UAS vehicles.

6.1.3 Weather standards for UAS mission type

Weather standards for UAS mission types will be created to define the various weather elements that may impact a UAS mission such as surface wind, winds aloft, visibility, clouds and ceiling, turbulence, etc. Mission types will be defined based on characteristics such as vehicle weight and mission altitude, range and duration.

The standards will identify the weather data necessary to ensure safety of various UAS mission types, and the minimums safe levels for each. These weather standards will inform future weather research.

6.1.4 Standards for qualifying third party weather service providers

Some CAAs have developed methodologies for qualifying third party weather service providers. Standards will address calibration, data quality, data quantity, refresh rates and other aspects of urban weather provision using crowdsourced weather information.

<table>
<tr><th colspan="3">2025-2030</th><th>2030-2035</th></tr>
<tr><td colspan="3">6.2.1 Qualified third-party weather service providers
6.2.2 Qualified microclimate now-casting for urban weather</td><td rowspan="3">6.3.1 Qualified microclimate forecasting for urban weather
6.3.2 Upper atmosphere enhanced weather forecasts</td></tr>
<tr><td>Research Completed</td><td>Technology & Standards</td><td>Policy Initiative</td></tr>
<tr><td>6.2.3 Nowcasting and Forecasting conditions for very-high-altitude operations
6.2.4 Methodology for urban weather microclimate forecasting</td><td>6.2.5 Advanced weather decision support tools
6.2.6 Performance based weather standards for UAS mission type</td><td></td></tr>
</table>

Table A6-2. Aviation Weather capabilities and activities for 2025–2030

6.2 Aviation Weather: 2025–2030

The aviation weather capabilities envisioned to be available in this time frame and the next, along with the research completed, the technology and standards developed and the policy initiatives established during this time period are shown in Table A6-2, below.

6.2.1 Qualified third-party weather service providers

Qualification standards and certification processes for third-party weather service providers have been developed in the previous time period (see activity 6.1.3) and are implemented. Now-casting of urban weather is now being provided (see capability 6.2.2), increasing safety and reducing weather-related incidents for small UAS operations operating BVLOS. Additional research will be needed to provide sufficiently detailed weather data for other operations, such as those occurring at very high altitudes.

6.2.2 Qualified microclimate now-casting for urban weather

Some third-party service providers, in accordance with the performance-based standards developed in activity 6.1.3, are now accepted by regulators and ANSPs to provide now-cast weather information for urban UAS operations, enabling some advanced UAS operations to be approved.

6.2.3 Nowcasting and forecasting conditions for very-high-altitude operations

Research is conducted to determine what additional high-altitude weather and solar information is needed to enable increased density of very-high-altitude operations. For special vehicles, such as very lightweight high-altitude long endurance (HALE) vehicles, upper altitude weather changes and forecasts are better understood to minimize safety risks associated with those vehicles.

6.2.4 Methodology for urban weather microclimate forecasting

Research is conducted to determine what additional weather and microclimate information is needed to *forecast* microclimate weather in urban areas, and how to obtain that data. Wind behavior (e.g., wind shear, wind speed and direction) and temperature differentials around tall buildings are particularly important for many UAS urban operations.

The urban weather forecasting capability is predicated on the sufficient availability of qualified sensors and provides operators with information on overall uncertainty, as well as automatic updates and distribution of forecasts. This forecasting capability allows operators to have greater overall availability or, in some cases, allows an increased density of AAM operations.

6.2.5 Advanced weather decision support tools

Weather data is fully integrated into advanced weather decision support tools to incorporate UAS-specific constraints. ANSPs integrate new weather data and tools into automation, implementing TBO algorithms.

6.2.6 Performance-based weather standards for UAS mission type

Weather quality and information standards for different new entrant mission types (e.g., low-level BVLOS in urban environments, very-high-altitude vehicles, etc.) are developed and are published. These performance-based requirements are implemented by third party service providers, for example, who provide flight planning services for operators with uncrewed vehicles and missions.

6.3 Aviation Weather: 2030–2035

The aviation weather capabilities envisioned to be available in this time frame and the next, along with the research completed, the technology and standards developed and the policy initiatives established during this time period are shown in Table A6-3, below.

<table>
<tr><th colspan="3">2030-2035</th><th>2035-2040</th></tr>
<tr><td colspan="3">6.3.1 Qualified microclimate forecasting for urban weather

6.3.2 Upper atmosphere enhanced weather forecasts</td><td rowspan="3">(no major capabilities added this timeframe)</td></tr>
<tr><td>Research Completed</td><td>Technology & Standards</td><td>Policy Initiative</td></tr>
<tr><td></td><td>6.3.3 Very High-Altitude weather impact safety analysis methodology</td><td></td></tr>
</table>

Table A6-3. Aviation weather capabilities and activities for 2030–2035

6.3.1 Qualified microclimate forecasting for urban weather

Methodology to provide urban weather information for microclimate weather forecasting has been accepted by regulators and ANSPs and is implemented in some urban areas.

6.3.2 Upper atmosphere enhanced weather forecasts

Enhanced weather forecasts are routinely provided for very-high-altitude operations. These enhanced forecasts include weather information determined to be particularly relevant to those vehicles in activity 6.2.3.

6.3.3 Very-high-altitude weather impact safety analysis methodology

Guidance is published to assist operators to understand how weather may impact the unique designs of HALE and HASP vehicles. This methodology would help operators analyze the forecast and assess their weather risk for a given operation.

6.4 Aviation Weather: 2035–2040

(no major capabilities added in this timeframe)

6.5 Aviation Weather: 2040–2045

(no major capabilities added in this timeframe)

7 Cross-Cutting Research and Develoment

In addition to research, standards or policy related to specific aspects of air traffic management operations and safety, there is also a need for evaluation of cross-cutting issues that have broad application or implications for system capabilities, design and architecture. This section captures a number of key cross-cutting topics, shown in Figure A7-1, below. Many of these topics will have no clear outcome until the research and analysis are complete.

These cross-cutting topics are critical to maintaining the safety of controlled airspace and future operations and will require ongoing research across the time frame addressed by this roadmap to develop and mature the capabilities and functionalities. Several cross-cutting topics do not have any time-specific milestones:

- Cybersecurity;
- Acceptable levels of risk for new operations;
- Human autonomy teaming (HAT);
- Modeling of economic and social impacts to support investment decisions;
- Spectrum strategy for aviation communications;
- Increase public education of advanced aviation operations, benefits and risks; and,
- Assurance of autonomous aviation systems.

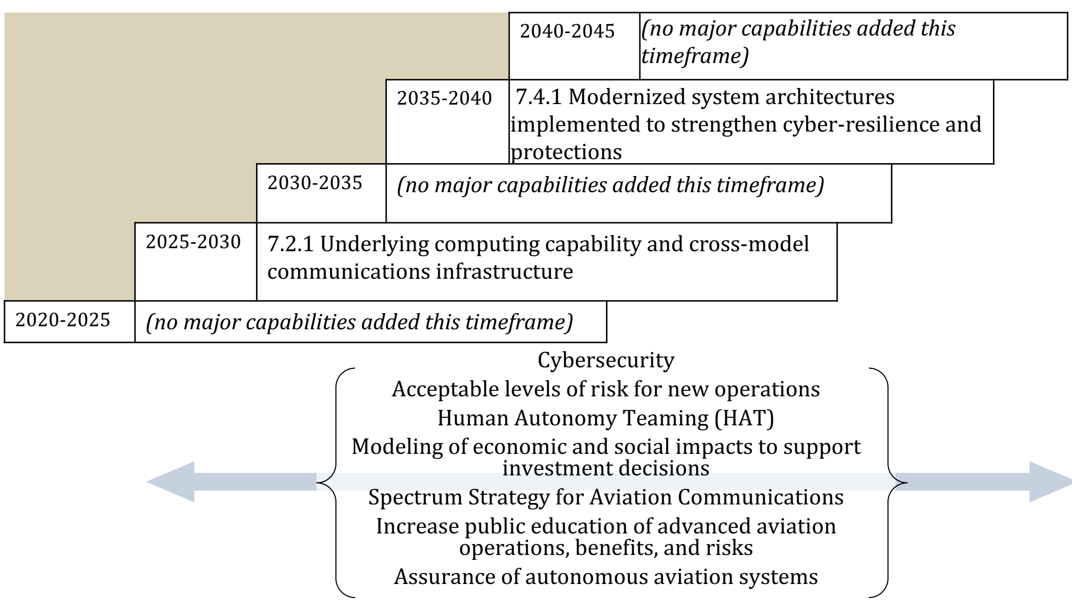

Figure A7-1 Evolution of Cross-cutting capabilities

Cybersecurity R&D and Best Practices

Cyber threats, either intentional or unintentional, can affect aviation digital assets and communications media. These threats can cause disruptions to operations as well as creating direct safety hazards.

Because the nature of these attacks is often criminal, there will be a constant need to:

- Assess ongoing threats to aviation assets and develop new monitoring capabilities;
- Evaluate system resilience and vulnerabilities of individual systems and enclaves;
- Develop cyber-resistant structures and recovery methodologies; and,
- Identify, isolate and prosecute sources of cyber attacks.

Further, cyber threats need to be assessed with respect to aviation service providers (ANSPs, CAAs, etc.), operators, airports and vertiports, as well as supply chain entities.

Education on cybersecurity best practices is also a critical, ongoing activity. This effort includes training individuals in an organization on proper procedures and verification techniques, education for managers on the organizational needs for cyber practices, to improved training for system designers in the incorporation of cybersecurity best practices and as new capabilities or systems are being envisioned.

Acceptable Levels of Risk for New Operations

As new aviation technologies and vehicles are introduced, the level of acceptable risk associated with a new mission or operation will need to be assessed or reassessed. This includes developing performance-based regulations addressing acceptable risk to any humans residing in the vehicle, risks to people in aircraft in the proximate airspace and risks to people and infrastructure on the ground.

For example, as commercial space operations and tourism increase in frequency, will the acceptable level of risk need to be adjusted from today's levels? How will airworthiness levels be evaluated and set? With respect to highly automated systems managing individual vehicles or airspace, what are the acceptable safety margins associated with system resilience and performance?

Human Autonomy Teaming

As aviation functions become increasingly sophisticated, new means may be needed for humans to effectively interact with them, including research on the allocation of roles and between humans and automation, means to effectively communicate system status and off-nominal conditions; and means to assess the need for intervening when humans are not behaving as expected. This can include innovations in visual presentation of information, better framing of aural and other alerts, monitoring of biological functions, etc.

Modeling of Economic and Social Impacts to Support Investment Policy

The ability for policymakers to make decisions on what aviation innovations to invest in (or to support via other policy mechanisms) will depend on availability of vetted, credible assessments that look at the costs and benefits from multiple perspectives. Cost and benefit categories include overall economic impacts (local and national), social equity considerations (where benefits are concentrated and where they are not present), health impacts (e.g., noise-related issues versus improved mobility and access to services), affordability, and opportunity cost (e.g., would investment in one capability delay development of a more important capability?).

These impact analyses will likely be needed for both local decision-making (e.g., whether to support UAM and RAM vertiports) as well as national decision-making (e.g., will a proposed rule change have a net positive benefit for the country?).

Spectrum Strategy for Aviation Communications

Aviation communications and services have traditionally occurred over a protected radio frequency spectrum that is not available for other uses. Both the allocated frequency band for aviation use and adjacent bands (that could potentially interfere) can be managed by a national spectrum policy. As wireless communications become increasingly prevalent outside of aviation, there is significant economic pressure to allocate current aviation spectrum for other uses, or to resist setting aside spectrum specifically for aviation use.

In addition to assessing specific spectrum challenges, overall architecture decisions can be informed by modeling tradeoffs assessing factors such as:

- The level of real-time performance data and metrics that is shared while in flight versus post-flight;
- The level of autonomy of a vehicle versus the use of an external system to monitor and provide inputs to the vehicle affecting its flight characteristics;
- Power, weight and on-board processing considerations;
- The extent of vehicle-to-vehicle coordination; and,
- The impact of the overall aviation safety risk associated with the spectrum strategy and the resulting mitigations needed.

The results of such analyses, in combination with national policy decisions, would be input to the international World Radio Conference (WRC) meetings in 2023, 2027 and 2031.

Increase Public Education of Advanced Aviation Operations, Benefits, and Risks

Industry and government coordination and investment to educate the public regarding advanced aviation operations and new vehicles will provide increased understanding of these operations, can help reduce resistance in communities, and can build a new generation of contributors that bring in new perspectives.

Public awareness of advanced aviation and autonomy considerations will be critical to introducing new capabilities into routine operational use. Public acceptance of these new modes can be affected, for example, by different perceptions of the risk that these operations introduce, relative to traditional means. Advanced aviation accidents, in particular, if not understood in a broader context, may result in significant public reactions that inhibit the ability to continue to develop AAMs to provide public benefits such as improved mobility or access to time-critical medications. Outreach to the public is also critical to ensure that communities feel that their concerns are heard.

Further, education for school-aged children, especially if emphasis is placed on access to underserved communities, can provide a new generation of innovators and participants in the next generation of advanced aviation.

Assurance of Vehicles and Systems

Maintaining an acceptable level of safety in airspace will include the increasing use of autonomy, both in vehicle systems and in the management of airspace. To ensure safety during the implementation of complex autonomous systems, advancements in software assurance techniques together with innovative regulatory methodologies will be necessary. High-fidelity modeling and simulations will be needed to verify and validate the complex software running autonomous systems, and these tools will themselves need to be verified and validated.

NASA is developing the Autonomy Verification and Validation Roadmap and Vision 2045, which identifies the major challenges and requirements for verification and validation (V&V) of autonomous vehicles intended for use in the NAS and presents a roadmap of necessary activities to achieve the needed capabilities. Future versions of this roadmap will reference specific activities of that roadmap.

While many of the technologies included in this section will require ongoing evolution, we have developed a progression of safety capabilities that we postulate will be developed between now and 2045. These capabilities are shown in the table below and are described in more detail with the supporting activities in the following sections.

7.1 Cross-Cutting Research and Development: 2020–2025

The cross-cutting capabilities envisioned to be available in this time frame and the next, along with the research completed, the technology and standards developed and the policy initiatives established during this time period are shown in Table A7-1, below.

<table>
<tr><th colspan="3">2020-2025</th><th>2025-2030</th></tr>
<tr><td colspan="3">(no major capabilities added this timeframe)</td><td rowspan="3">7.2.1 Underlying computing capability and cross-model communications infrastructure</td></tr>
<tr><td>Research Completed</td><td>Technology & Standards</td><td>Policy Initiative</td></tr>
<tr><td>7.1.1 Initial requirements for future high-fidelity airspace and vehicle modeling</td><td></td><td>7.1.2 Promotion of safety culture practices among new entrants</td></tr>
</table>

Table A7-1. Cross-cutting capabilities and activities for 2020–2025

7.1.1 Initial requirements for future high-fidelity airspace and vehicle modeling

Research on initial requirements needs to include definitions of the minimum required elements, level of fidelity, computational requirements, interfaces between models (e.g., an airspace model interacting with a vehicle model), models of human performance, etc., to allow potentially distributed system modeling and simulation. As increased understanding grows to safety considerations, these requirements will need to be updated.

Airspace modeling

High fidelity simulations (i.e., digital twins) of airspace will play a key role in verifying, validating and potentially certifying highly complex and/or autonomous software and systems, and the digital twin itself will have to be verified and validated first. High-level requirements for any digital twin software intended to model and simulate airspace and airspace activities will have to be established during this period to support ongoing development activities.

Vehicle modeling

Digital twin design of vehicles will play a key role in verifying, validating and potentially certifying highly complex and/or autonomous software and systems, and the digital twin itself will have to be verified and validated first. High-level requirements for any digital twin software intended to model and simulate UAS (as well as traditionally crewed) aircraft and their activities will have to be established during this period to support ongoing development activities.

7.1.2 Promotion of safety culture practices among new entrants

The new entrant community has a significant portion of members who have not been exposed to traditional aviation safety practices, such as safety data sharing or use of SMS. This research is intended to answer the question: What are the practices that might encourage a more robust safety culture? These practices might include education, policy and legislative initiatives, economic incentives, etc.

7.2 Cross-Cutting Research and Development: 2025–2030

The cross-cutting capabilities envisioned to be available in this time frame and the next, along with the research completed, the technology and standards developed and the policy initiatives established during this period are shown in Table A7-2, below.

7.2.1 Underlying computing capability and cross-model communications infrastructure

<table>
<tr><th colspan="3">2025-2030</th><th>2030-2035</th></tr>
<tr><td colspan="3">7.2.1 Underlying computing capability and cross-model communications infrastructure</td><td rowspan="3">7.3.1 Capability to validate the safety of human-managed airspace and vehicles with autonomous vehicles</td></tr>
<tr><th>Research Completed</th><th>Technology & Standards</th><th>Policy Initiative</th></tr>
<tr><td>7.2.2 Autonomy recognition of data qualities

7.2.3 Government, Industry, and Community collaboration on airspace evolution strategy</td><td>7.2.4 Communications architecture and requirements for UAS and AAM operations

7.2.5 High-fidelity real-time models for human-managed airspace, airports and vehicles</td><td>7.2.6 Spectrum policy for AAM and UAS vehicle communications

7.2.7 Essential air service policy to reflect AAM services

7.2.8 Decision on creating new airspace classification and access requirements for low-altitude UAS</td></tr>
</table>

Table A7-2. Cross-cutting capabilities and activities for 2025–2030

The infrastructure necessary to provide processing power that enables simulations of regulated (human-managed) airspace and vehicles has been validated and is available for use. The underlying technology may involve, for example, massively parallel, high-processing computing infrastructure built for high-fidelity, fast simulation of regulated airspace and vehicles (e.g., implementing a digital twin infrastructure). This infrastructure also includes the necessary interfaces to allow high-speed collaboration across distributed models.

7.2.2 Autonomy recognition of data qualities

One of the challenges of increasingly automated systems is the ability to anticipate system response to data of varying quality. Automation systems may incorrectly interpret anomalous data, causing unanticipated states and safety risks. As highly automated systems and autonomous systems are introduced, there is an increasing need for automation to recognize and handle different data latencies, resolution or accuracies; as well being able to recognize, and being able to appropriately respond to invalid, inconsistent or missing data. A system may also need to operate safely (or enter a safe mode) when a key data feed is missing. Further assessment is also needed to understand the trustworthiness of data.

What are the algorithms that enable robust system behavior in the presence of imperfect data, especially in an environment too complex for a human to take over?

7.2.3 Government, industry and community collaboration on airspace evolution strategy

Many of the operational capabilities envisioned will include changes to airspace, possibly including airspace boundaries and performance requirements for operating within the airspace. Airspace structures such as fixed or flexible corridors have been postulated, along with potential requirements for operating in those corridors. Changes in airspace not only will affect what operations are enabled but also will have secondary effects on communities served by, or those existing nearby, operations enabled by airspace changes. Airspace changes often require significant rulemaking actions, taking years or even decades to successfully implement.

An airspace strategy that involves national and local governments as well as aviation stakeholders will be more effective with strong communications and collaborative effort, with transparency in capturing potential costs and benefits. These will address economic impacts on operators affected by potential changes in airspace access rules, as well as community impacts. Such a strategy is not a single effort but will be ongoing.

7.2.4 Communications architecture and requirements for UAS and AAM operations

Based on overall policy regarding the availability of radio frequency spectrum for operations associated with new entrants, basic requirements on communications architecture and performance need to be documented. This architecture, and the associated requirements for vehicles, operators and service providers, will accommodate needed communications, including transitioning safety-critical voice communications to digital communications (e.g., checklists), and the real-time transmission of SPIs with the expectation that other SPIs will not be transferred in real time.

7.2.5 High-fidelity real-time models for human-managed airspace, airports and vehicles

Regulatory authorities will need, by the end of this time frame, a validated capability to extensively evaluate, via fast-time simulations, proposed changes to operations, including changes to airspace, changes to procedures (including updates to human roles), new or adapted vehicles, etc. Similarly, highly accurate and detailed vehicle digital twin performance characteristics will enable testing of new airspace procedures or requirements, and for real-time evaluation of tactical or strategic conflict management actions. Vehicle digital twins will also be used for extensive testing of vehicle design factors, including physical characteristics, safety functionality and ability to conform to airspace requirements.

Such a capability may be distributed among multiple facilities and organizations, with established interfaces, proprietary data protections and configuration management procedures in place.

7.2.6 Spectrum policy for AAM and UAS vehicle communications

In this time frame, policy choices may include allocation of spectrum to support AAM and UAS vehicle communications, or they may designate other means for enabling required communications for contingency management, operational control, exchange of real-time data, etc. With the expected increase in the pace of operations, this policy decision will be required to support any significant growth.

7.2.7 Essential air service policy to reflect AAM services

Just as there can be a national policy supporting improved commercial air transportation opportunities for people living outside of metropolitan areas (including subsidies), there may also be consideration of policies that provide incentives for AAM transportation services (i.e., regional air mobility services) that may provide additional mobility for parts of the population. Such a policy needs to be supported through appropriate analyses of the costs, benefits and likely effectiveness of various policy options.

7.2.8 Decision on creating new airspace classification and access requirements for low-altitude UAS

Internationally, a decision is needed on whether to establish a new airspace classification for some airspace currently classified as “Class G.” This new classification would recognize the presence of UTM services and would have additional equipage requirements associated with operating in airspace with routine UAS BVLOS operations, including rural and urban mobility operations.

7.3 Cross-Cutting Research and Development: 2030–2035

The cross-cutting capabilities envisioned to be available in this time frame and the next, along with the research completed, the technology and standards developed and the policy initiatives established during this period are shown in Table A7-3, below.

<table>
<tr><th colspan="3">2030-2035</th><th>2040-2045</th></tr>
<tr><td colspan="3">7.3.1 Capability to validate the safety of integrated autonomous and human-managed operations</td><td rowspan="3">7.4.1 Modernized system architectures implemented to strengthen cyber-resilience and protections</td></tr>
<tr><td>Research Completed</td><td>Technology & Standards</td><td>Policy Initiative</td></tr>
<tr><td>7.3.2 Modern cyber-resilience architectures for safety service providers</td><td>7.3.3 High-fidelity real-time models for AI-managed airspace, airports and vehicles</td><td>7.3.4 Updated airspace equipage and performance requirements
7.3.5 Workforce roles for autonomous operations</td></tr>
</table>

Table A7-3. Cross-cutting capabilities and activities for 2030–2035

7.3.1 Capability to validate the safety of integrated autonomous and human-managed operations

High-fidelity airspace simulation capabilities (e.g., "digital twins") incorporating the behavior of autonomous air traffic management algorithms will be researched. The development of these simulations will include extensive testing and development of test suites so that a wide variety of off-nominal conditions can be evaluated.

7.3.2 Modern cyber-resilience architectures for safety service providers

By this time, ANSPs, service providers, operators and other aviation stakeholders will have upgraded their operational infrastructures to implement modernized architectures and processes that are resilient to cyber-attacks and other potential disruptions to services, communications and digital data.

7.3.3 High-fidelity real-time models for AI-managed airspace, airports and vehicles

In the years following this period, airspace, airports and vehicles are envisioned to be managed by artificial intelligence. Based on the standards guiding high-fidelity, real-time models for human-managed airspace, airports and vehicles in activity 7.2.5, standards for developing and validating models for AI-managed airspace, airports and vehicles will be available in this time frame. Technology will exist that can validate these non-deterministic models to an acceptable level of assurance, enabling them to be used to test new procedures, vehicles and airport configurations.

7.3.4 Updated airspace equipage and performance requirements

As governments, aviation stakeholders and communities develop a shared vision (see 8.2.2) and research matures, this understanding will potentially be translated into policy changing airspace access requirements for some airspace volumes.

7.3.5 Workforce roles for autononous operations

The move to highly automated or autonomous air traffic management will involve significant changes in human roles and levels of responsibility. There will also be issues regarding human accountability for different failure modes and appropriate compensation for these new roles or for people whose jobs change significantly. This policy issue will be a significant concern for key groups such as pilots, controllers, maintenance personnel, etc. Research in human machine interface focusing on roles and responsibilities will be performed in many domains, and much of the resulting knowledge will apply to aviation and air traffic management.

7.4 Cross-Cutting Research and Development: 2035–2040

The cross-cutting capabilities envisioned to be available in this time frame and the next, together with the research, technology and standards and policy initiative activities that need to be initiated during this period are shown in Table A7-4, below.

<table>
<tr><th colspan="3">2035-2040</th><th>2040-2045</th></tr>
<tr><td colspan="3">7.4.1 Modernized system architectures implemented to strengthen cyber-resilience and protections</td><td rowspan="3">(no major capabilities added this timeframe)</td></tr>
<tr><td>Research Completed</td><td>Technology & Standards</td><td>Policy Initiative</td></tr>
<tr><td></td><td></td><td></td></tr>
</table>

Table A7-4. Cross-cutting capabilities and activities for 2035–2040

7.4.1 Modernized system architectures implemented to strengthen cyber-resilience and protections

To maintain safety, modernized system architectures are implemented by ANSPs, users, operators, OEMs, PSUs and other aviation stakeholders.

7.5 Cross-cutting research and development: 2040–2045

(no major capabilities added in this time frame)

Appendix B: Methodology

The development of this paper has been informed by a lengthy literature search that includes multiple existing roadmaps and by engaging the community through interviews, tabletop exercises and workshops. The goal is to understand the challenges in enabling a data-rich and distributed architecture like the IASMS. NASA staff and subject matter experts both helped in identifying the safety needs associated with distributed data architectures and autonomy in aerospace in the areas of regulation, policy and standards, aviation law, operations, flight testing, accident investigation, cybersecurity, air traffic services, new entrance aviation, and legacy aviation.

To ensure that the roadmap included a robust set of anticipated new safety services and capabilities, the FSF team developed several short use cases or "vignettes," each focused on different time frames and different advanced operations as referenced in figure B1. In the spring of 2022, the team held tabletop exercises for each scenario with aviation industry SMEs to get additional community feedback on needed capabilities for IASMS in the 2035–2045 time frame.

Figure B 1. Tabletop vignettes

From the needed capabilities in the 2035–2045 timeframe, the Foundation postulated the question, "What key supporting activities will be needed in preceding years?" grouped into five-year "buckets." In general, a capability envisioned to be available for one five-year bucket (e.g., 2035–2040) would need research, supporting technologies, standards and associated policy decisions completed in the previous five and 10 years. To organize the roadmap, each activity was assigned to one high-level topic area, although in many cases, an activity could be associated with multiple topics.

A key consideration in this methodology is the balance of brevity with completeness. The steps captured are, in general, high-level, and do not capture individual steps in maturing research, validating capabilities or implementation.

An IASMS is intended to continuously monitor, assess and mitigate flight safety data. A thorough draft of the roadmap was presented and reviewed with subject matter experts. Refining the roadmap in this way helps to solidify several community voices into the first compete draft of the IASMS Roadmap.

Glossary and Definitions

4D	Four-dimensional
4DT	Four-dimensional trajectory
AAM	Advanced air mobility
ACAS	Airborne collision avoidance systems
ADS-B	Automatic dependent surveillance–Broadcast
AI	Artificial intelligence
ANSP	Air navigation service provider
ARC	Aviation rulemaking committee
ASIAS	Aviation Safety Information Analysis and Sharing program
ATC	Air traffic control
ATM	Air traffic management
Av-Fuel	Aviation fuel
BVLOS	Beyond visual line of sight
C2	Command and control
CAA	Civil aviation authority
CHI	Computer-human interface
Class B	Class B airspace
Class E	Class E airspace (including U.S. upper airspace above FL 600)
ConOps	Concept of operations
COO	Continuity of operations
COP	Common operating picture
COVID-19	Coronavirus SARS-CoV-2
cUAS	Counter-UAS
DAA	Detect and avoid
EFB	Electronic flight bag
eVTOL	Electronic vertical takeoff and landing
FAA	Federal Aviation Administration
FAR	Federal Aviation Regulation
FDR	Flight data recorder
FIR	Flight Information Region

FL	Flight Level
FSF	Flight Safety Foundation
GBSAA	Ground-based sense and avoid
HALE	High altitude long endurance
HAPS	High altitude pseudo-satellite
IASMS	In-time aviation safety management system
ICAO	International Civil Aviation Organization
IFR	Instrument flight rules
MBSE	Model based systems engineering
MSL	Mean sea level
NAS	U.S. National Airspace System
NASA	U.S. National Aeronautics and Space Administration
NPRM	Notice of proposed rulemaking
OEM	Original equipment manufacturer
OpEval	Operational evaluation
Ops	Operations
PSU	Provider of services to UAM
R&D	Research and development
RAM	Regional air mobility
SIXM	Safety information exchange model
SME	Subject matter expert
SMS	Safety management system
SPI	Safety performance index
SSP	State safety program
SWAP	Size, weight and power
TABS	Traffic awareness beacon system
TBO	Trajectory-based operations
TCAS	Traffic-alert and collision avoidance system
UAM	Urban air mobility
UAS	Uncrewed aircraft system
USS	UAS service supplier
UTM	UAS traffic management

VFR	Visual flight rules
WRC	World radio conference
xTM	Extensible traffic management

Autonomous self-separation: A vehicle's ability to either execute or communicate the appropriate adjustment to the flight path to maintain safety separation without a human oversight function.

Autonomous tactical separation management: A capability for an automated system to monitor and coordinate operations within an airspace environment, compliant with procedures and airspace regulations, to manage the flight in a safe manner.

Autonomy: The ability of a system or vehicle to operate a specific function without human intervention.

Extensible traffic management: Any such service that is provided outside IFR-managed airspace.

Human-in-the-loop: Systems in which the human must act for the system to perform a task; the human controls the system.

Human-on-the-loop: Systems that operate independently while a human monitors the operation and can intervene at any point to exert direct control.

Human-out-of-the-loop: Systems that, once programmed with the desired objectives, are fully independent and perform functions without any human intervention.

Human-over-the-loop: Systems in which automation perform functions and humans can manage the system and provide oversight, but cannot control it.

Integrated airspace: Airspace in which IFR, VFR and autonomous operations take place without intentional segregation or separation.

Resilience: The ability to mitigate hazardous conditions that may occur and to enable timely recovery from those that do occur while maintaining as much system functionality as possible.

Safety Data: All types of data and information that can help inform safety decision-making.

Safety Envelope: The actual boundaries of what is safely recoverable in operations by preventative or recovery measures. Outside this boundary, safety control becomes marginal to non-existent.

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An invitation for feedback

The Foundation is actively seeking the views and inputs of aviation stakeholders about this roadmap. This version was developed with input from a broad group of aviation stakeholders, including regulatory authorities, legacy operators, new entrants (operators and third-party service providers), air navigation service providers, airports and vertiports, and original equipment manufacturers. As we evolve this roadmap we will continue to need input from the aviation community.

If you'd like to provide feedback on this Roadmap or have other ideas to share with us regarding IASMS, please email us at Technical@flightsafety.org.

Thank you!