UAM Vision Concept of Operations (ConOps) UAM Maturity Level (UML) 4

Version 1.0

Prepared by Deloitte Consulting LLP

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Acknowledgements

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Preface

This Vision ConOps is intended as a foundation to engage members of the UAM community and provide a consensus on the future vision of UAM operations. It provides a concept for more detailed discussion and a basis for the exploration of ideas using a common framework to inform the continued development and integration of UAM as part of the broader transportation system.

Advanced Air Mobility (AAM) encompasses a range of innovative aviation technologies (small drones, electric aircraft, automated air traffic management, etc.) that are transforming aviation's role in everyday life, including the movement of goods and people. Urban Air Mobility (UAM) represents one of the most exciting and complex AAM concepts with highly automated aircraft, providing commercial services to the public over densely populated cities. This concept has generated tremendous interest and industry investment. UAM envisages a future in which advanced technologies and new operational procedures enable practical, cost-effective air travel as an integral mode of transportation in metropolitan areas. It represents one of the most exciting and complex AAM concepts with highly automated aircraft providing commercial services to the public over densely populated cities. For this reason, the National Aeronautics and Space Administration (NASA) selected UAM as the initial goal of its AAM efforts[1] and the focus of this Vision Concept of Operations (ConOps) document.

UAM Community Vision ConOps: This Vision ConOps effort was led by experts from NASA's Aeronautics Research Mission Directorate (ARMD) in collaboration with the Federal Aviation Administration (FAA) and Deloitte's Ecosystem Advisory Group (a cohort of advisers with aviation, aerospace, and regulatory expertise). To develop this Vision ConOps, NASA, FAA, and Deloitte built upon the current body of aeronautical research and consulted with more than 100 stakeholder organizations. This UAM community includes entities ranging from legacy aviation leaders to innovators and new market entrants. Stakeholders consulted included the federal government, state and local governments, aerospace original equipment manufacturers (OEMs), local transportation organizations, prospective UAM operators, academia, industry standards-setting bodies, airports, service suppliers, and others (as described in Appendix G). This input was captured through the following methods:

- A series of more than two dozen interviews with industry experts, federal regulators, state and local governments, and industry trade groups provided insight into the challenges of UAM integration into the National Airspace System (NAS), as well as technology developments and a variety of perspectives as to how UAM systems will integrate.
- A series of two-day community workshops enabling active, detailed engagement of nearly 100 industry, academic, federal, and state stakeholder individuals. These workshops, hosted by NASA and Deloitte, explored UAM concepts in detail, and stakeholders were invited to collaboratively analyze and propose solutions to some of the greatest conceptual challenges behind UAM at an intermediate state.
- A review of more than 160 sources of UAM literature from across government, industry, and academia, which are listed in Appendix H.
- The public sharing of workshop input and document drafts for review and input across the UAM community. Feedback in the form of more than 1,000 comments and inputs on the document was received from industry groups, individual companies, academia, and government (federal, state, and local), among others.

Although effort was made to incorporate inputs from across the UAM stakeholder group, not all comments could ultimately be incorporated in this version. The team resolved conflicting comments or ideas while maintaining consistency with the known direction of regulators and ensuring the document was coherent and consistent. It is recognized that this is a rapidly evolving area and that concepts will likely change over time; as such, this Vision ConOps is a living document and is expected to evolve as concepts mature. The ConOps does, however, provide a vision of UAM concepts and solutions based on the broad insights from across the UAM stakeholder community at the time of its publication and is intended to serve as a UAM North Star for continued research and development of UAM. As a broad Vision ConOps, is not a detailed engineering document; rather, it focuses primarily on outlining a broad, high-level vision across all aspects of a UAM transportation system.

[1] NASA, "Advanced Air Mobility Overview," https://www.nasa.gov/aam

1.0 Introduction

Cities are growing, population density is increasing, and transportation infrastructure investment remains a challenge. These trends, combined with a series of technological advances and social trends from electric and semiautonomous aircraft to the sharing economy, are transforming the way people and goods move around urban and regional centers. Central to this transformation is recognition that aviation could play a much larger role in urban and regional mobility in the future.

UAM is the concept of expanding transportation networks to include short flights that transport people and goods around metropolitan areas. UAM is part of a larger paradigm shift toward AAM, in which new technologies and business models are enabling transformational applications of aviation, including allowing aviation to play an integral role in regional and local transportation. AAM is envisioned as a safe, sustainable, affordable, and accessible form of aviation for local and intraregional missions. UAM in this document describes the use of air travel as a practical and cost-effective mobility alternative for the general public, primarily serving urban areas extending into the metropolitan periphery. UAM has the potential to revolutionize urban transportation networks and play an integral role in future smart cities. In this future paradigm, urban air travel is widely used by the general public, enabling rapid movement between locations of high passenger demand as cities grow.

This Vision ConOps is the result of broad stakeholder engagement and is designed to provide a high-level, consensus-driven vision of the UAM stakeholder group at intermediate maturity. It describes broad operational concepts, high-level functional capabilities, and system requirements to place urban air travel within reach of the general public as a safe, cost-effective, and practical alternative to other modes of transportation. UAM is achieved through maturing technology capabilities and builds on the on-demand urban air travel seen in the late 2010s (e.g., on-demand helicopter services in New York City). When fully mature, it ultimately enables thousands of people to use autonomous/semiautonomous air mobility services every day in major cities. Many in the UAM community anticipate that future UAM services are delivered primarily by electric and hybrid-electric vertical takeoff and landing (eVTOL/hVTOL) aircraft that are quieter, incur lower operating costs, and employ technologies that significantly increase operational performance (e.g., autonomous systems).

UAM operations in this document are characterized as the transport of passengers in a metropolitan area. UAM presents unique challenges and new shared responsibilities between federal, state, and local regulators to create a sustainable UAM marketplace. UAM integrates existing and emerging technologies—including distributed electric (and hybrid-electric) propulsion systems, networked information technologies and federated third-party Air Traffic Management (ATM) service suppliers.[2] It applies new navigational and sensor technologies, as well as new technologies and automation, that increase manufacturing speed and efficiency while maintaining the same levels of safety. This Vision ConOps describes a system where hundreds of aircraft are operating simultaneously and are serving a limited number of UAM aerodromes within a metropolitan area.

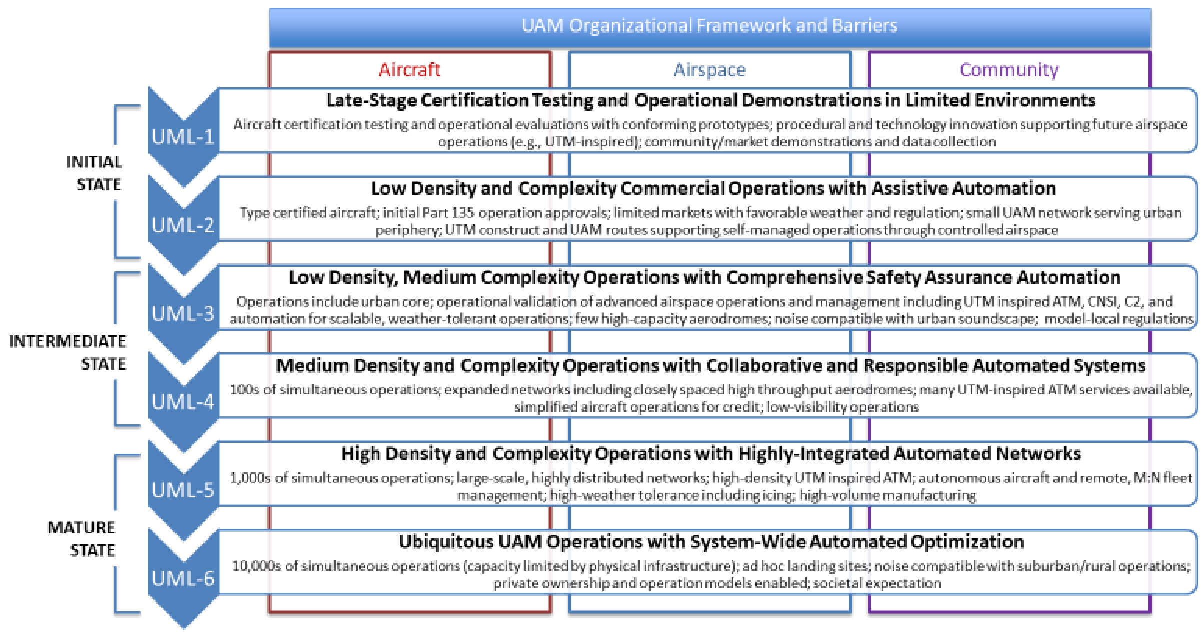
At this intermediate state, UAM is envisioned as an accessible form of transportation for the general public. This document focuses primarily on operations that occur close to the urban core, while acknowledging that UAM operations are not strictly limited to this environment. Higher volumes of UAM operations are enabled by third-party federated service suppliers that provide basic ATM services. This networked information-sharing capability is a revolutionary mechanism to manage air traffic for passenger-carrying operations. Also, as this document focuses on the UAM operations intended for the urban core, it primarily describes eVTOL and hVTOL aircraft with the capability for vertical takeoff and landing (VTOL). Additional AAM use cases (cargo delivery, operations outside the urban core, etc.) will be explored in subsequent concept development efforts.

[2] In the last few years, legislation (including the FAA Modernization and Reform Act of 2012) has shifted the direction of traditional government-supplied services to third-party service suppliers.

1.1 Background: UAM Maturity Levels

NASA has developed a framework for UAM Maturity Levels (UMLs), which categorizes anticipated evolutionary stages of a UAM transportation system into six levels. Each UML represents a level of maturity of the UAM ecosystem, with UML-6 representing the ubiquitous integration of UAM into daily life. Figure 1 shows the anticipated evolution through the UMLs.

Figure 1: In-Depth Description of the Various UAM UMLs



Each UML is characterized in terms of operational density, complexity, and reliance on automation.[3] Density refers to air traffic density and is defined as the number of UAM aircraft simultaneously operating at any given time within a single metropolitan area. Complexity considers a combination of factors including maximum potential capacity (i.e., throughput) at major UAM aerodromes, weather tolerance, the distribution of UAM aerodromes, integration of aircraft types, and operational integration. Automation reliance indicates the level of responsibility held by automated systems in the UAM system, although it is unknown if these are at an equivalent level across the entire UAM system.

1.1.1 Progression through the UMLs

A foundational assumption of the UML framework is that the overall UAM ecosystem will progress through these UMLs in order from UML-1 to UML-6.[4] Progression through the UMLs requires advancement in three primary areas: aircraft, airspace, and community integration. While the exact criteria for promotion to the next UML level are still being defined, Figure 1 provides generalized characteristics of UAM at each UML.

Another key assumption is that not every city with UAM services is expected to progress at the same rate or achieve the same level of maturity simultaneously. For example, UML-3 commercial operations may be occurring within the urban core of “City A” prior to any commercial service beginning in “City B.” Each UAM market can progress through the UMLs at its own pace influenced by factors specific to that location, including community

[3] George Price et al., Urban Air Mobility Operational Concept (OpsCon) Passenger-Carrying Operations, NASA/CR—2020-5001587, May 2020, https://ntrs.nasa.gov/citations/20205001587.

[4] Individual companies may not progress explicitly through each UML directly. For example, a company may move directly from UML-1 to UML-3, but it is assumed that other organizations are performing operations at UML-2 prior to any organization achieving UML-3

acceptance, local weather, existing infrastructure, the local regulatory environment, and geographic characteristics.

1.1.2 The Concept of Operations at UML-4

UML-4 consists of medium-density and medium-complexity operations with collaborative and automated systems. At UML-4, medium density is characterized as hundreds of simultaneous operations over a single metropolitan area. Medium complexity includes low-visibility operations, aircraft operating near one another in high-density routes, and operations to and from high-throughput UAM aerodromes. There are also automated systems that do not require human oversight or mitigation of potential failures for some functions. These collaborative and responsible automated systems enable humans to have roles that differ from those performed by humans in the 2010s.

1.2 Assumptions

UML-4 results from technology advancement and evolution over time (UMLs 1 through 3) and is a transitional stage before UML-5 and -6. This Vision ConOps is written from the perspective of the system at UML-4. To bring the ConOps into that perspective, this document makes the following assumptions:

- Although the system will not be fully evolved, many UAM operations and their associated regulations and authorities will have been established by UML-4. Characteristics of this intermediate state include UAM being safe, readily available, and affordable for the general public to use in a metropolitan area, but the system is not yet fully autonomous. (Figure 1 summarizes other differences in the UMLs.)
- Since this Vision ConOps is written from the perspective of UML-4, it assumes that UMLs 1 through 3 have been realized. Although different metropolitan areas may be at different UMLs at any given time, the assumption here is that at least one metropolitan area has achieved a UML-4 transportation system.
- Ultimately, the volume and complexity of UAM operations is expected to far exceed the capacity of traditional, human-operated air traffic control (ATC). Therefore, this Vision ConOps anticipates that UAM aircraft at UML-4 will utilize a network of Providers of Services to UAM (PSUs) that provide ATM services under rules and regulations established by the FAA. It is assumed that the FAA will not play an active operational role in managing the UAM aircraft under nominal conditions (i.e., ATM services will nominally not be actively provided by the FAA to UAM aircraft).
- This ConOps assumes that either modified or entirely new flight rules are implemented in at least portions of the airspace to enable safe operations at the anticipated traffic volumes in a wide range of weather conditions.
- This ConOps assumes that all nominal operations begin and end from designated takeoff and landing areas called UAM aerodromes. Some UAM aerodromes will have been built specifically for UAM.

1.3 Scope, Objective, and Viewpoint

The scope of this Vision ConOps is passenger-carrying operations at UML-4—an intermediate state of maturity in which UAM is widely accessible, but not yet ubiquitous. It describes system characteristics related to aircraft, airspace design, and community integration. It anticipates a diverse range of aircraft types, aircraft performance characteristics, and communications, navigation, surveillance, and information (CNSI) capabilities. It describes an operating environment that reshapes the FAA's role in ATM by utilizing PSUs and advanced aircraft technologies to provide the separation services typically provided by ATC, while maintaining the FAA's overall regulatory authority over the airspace. It also considers UAM's role in the larger air transportation ecosystem. This includes interaction with other air traffic (e.g., large commercial transport aircraft and sUAS) and the broader context of the larger transportation system, including the states, cities, and communities in which it operates.

The ConOps is presented using an organizational framework of pillars and barriers established by NASA (Figure 3), which provides a basis for:

- Further and more detailed discussion
- The exploration of ideas using a common framework
- The continued development and integration of UAM as part of our broader transportation system

The document is written from a future viewpoint of someone living in the UML-4 timeframe. This approach was chosen to allow the document to focus on the vision of UML-4. As a "Vision ConOps," this ConOps presents a generalized vision of the future with UAM and is designed to only imply high-level requirements on the UAM system; as such, it is not designed to suggest or prescribe any specific course of action to reach UML-4. In describing the anticipated system state at UML-4, it occasionally provides specific details or touches on possible methods to achieve UML-4 as illustrative examples or for clarity. The level of detail is, therefore, different from many ConOps documents, and the scope is broader than strictly those elements pertaining to the operations themselves.

1.4 Document Organization

This document is organized by the UAM framework detailed in Section 3.0 and contains several appendixes that provide supplementary concept information and the methods in which these concepts were derived. The specific sections are as follows:

- **Section 1.0: Introduction**—This section introduces UAM, its concepts, background, UMLs, Vision ConOps scope and objectives, and the organization of the document.
- **Section 2.0: The UAM Operating Environment**—This section provides an overview of the operational landscape of UAM in UML-4.
- **Section 3.0: The UAM Organizational Framework**—This section discusses the UAM framework and how it is used to organize and decompose the UAM concept into pillars and barriers.
- **Section 4.0: UAM Pillars**—This section contains the detailed UML-4 concepts organized by pillar and barrier.
- **Section 5.0: Path Forward**—This section describes near-term next steps for the maturation of UAM concepts and for subsequent revisions of this ConOps.
- **Appendix A: Cross-Cutting Barriers**—This appendix details the concepts that cross multiple pillars.
- **Appendix B: Roles and Responsibilities**—This appendix identifies the major stakeholders and their summary responsibilities.
- **Appendix C: Gate-to-Gate Operations**—This appendix identifies the major stakeholders, responsibilities, and handoffs through each phase of flight during nominal gate-to-gate (G2G) operations.
- **Appendix D: Use Cases**—This appendix describes a select set of contingency and off-nominal scenarios. These illustrative scenarios describe the high-level steps and responsibilities that would be taken in the event this scenario comes to fruition.
- **Appendix E: Acronyms List**—This appendix contains a comprehensive reference for the acronyms used in this document.
- **Appendix F: Glossary**—This appendix contains a reference of definitions for widely used terms in this document.
- **Appendix G: Contributing Stakeholders**—This appendix details the organizations that contributed to the concepts in this ConOps whether through direct input, one-on-one elicitation, community workshops, or comments against previous draft versions of this ConOps.
- **Appendix H: Bibliography**—This appendix details the sources used to develop the concepts in this ConOps.

For the rest of the document, the UAM "Vision ConOps" is referred to as "ConOps" for simplicity and ease of reading.

2.0 The UAM Operating Environment

At UML-4 UAM aircraft operate predominantly in the UAM Operating Environment (UOE) [5] The UOE (Figure 2) is a flexible airspace area encompassing the areas of high UAM flight activity. The maximum possible extent of the UOE is static and can be represented on traditional aeronautical charts. The extent of this static, maximal UOE can be redefined and recharted over time following accepted methods. The extent of the UOE is partially dependent upon where UAM service providers are authorized to provide services and the geographical extent of their infrastructure used to provide those services. Within this maximum area, there are flexible areas that are "available" and can change (i.e., the available area is "flexible"). For example, if the flow pattern at a nearby major airport changes, the available UOE may change to avoid potential traffic conflicts among UAM aircraft and traditional commercial airlines. Changes in the available UOE likely occur on the order of a few times per day; these changes, as well as the current extent of the available UOE, are reported in the PSU Network. Figure 2 shows an overview of the UOE and its various participants at UML-4. The UOE exists adjacent to actively controlled airspace rather than as a separate airspace class. It is expected that the rules and operating procedures for the UOE will mature as aircraft and PSUs[6] become more capable. The UOE is an Unmanned Aircraft System (UAS) Traffic Management (UTM)-inspired construct.[7] Like the UTM construct, the UOE is an area that coexists with the traditional airspace classes and is managed by third-party federated service suppliers.

The UOE is flexible and primarily located in urban and nearby metropolitan areas. Each metropolitan area's UOE is tailored to meet the needs of that area. Factors impacting the extent of the UOE include the topography of the urban an metropolitan area (e.g., building height), the layout of controlled airspace in the area (e.g., the location of and altitude floor of adjacent Class B airspace), the geography of the local area, areas of high demand, and unique airspace characteristics (e.g., restricted areas). Figure 2 simplifies the boundaries by showing the floor of the UOE reaching ground level, but it is anticipated that the UOE floor will reach ground level only where necessary, such as near ground-level UAM aerodromes. The UOE will not extend to the urban floor in all places because UAM aircraft are not likely to cruise near ground level [8] and so that UAM aircraft do not unnecessarily interfere with UTM operations. Where a major city and a minor outlying city are in proximity (e.g., the Dallas-Fort Worth or Washington, DC, Capital Beltway regions), the UOE may encompass both metropolitan areas.

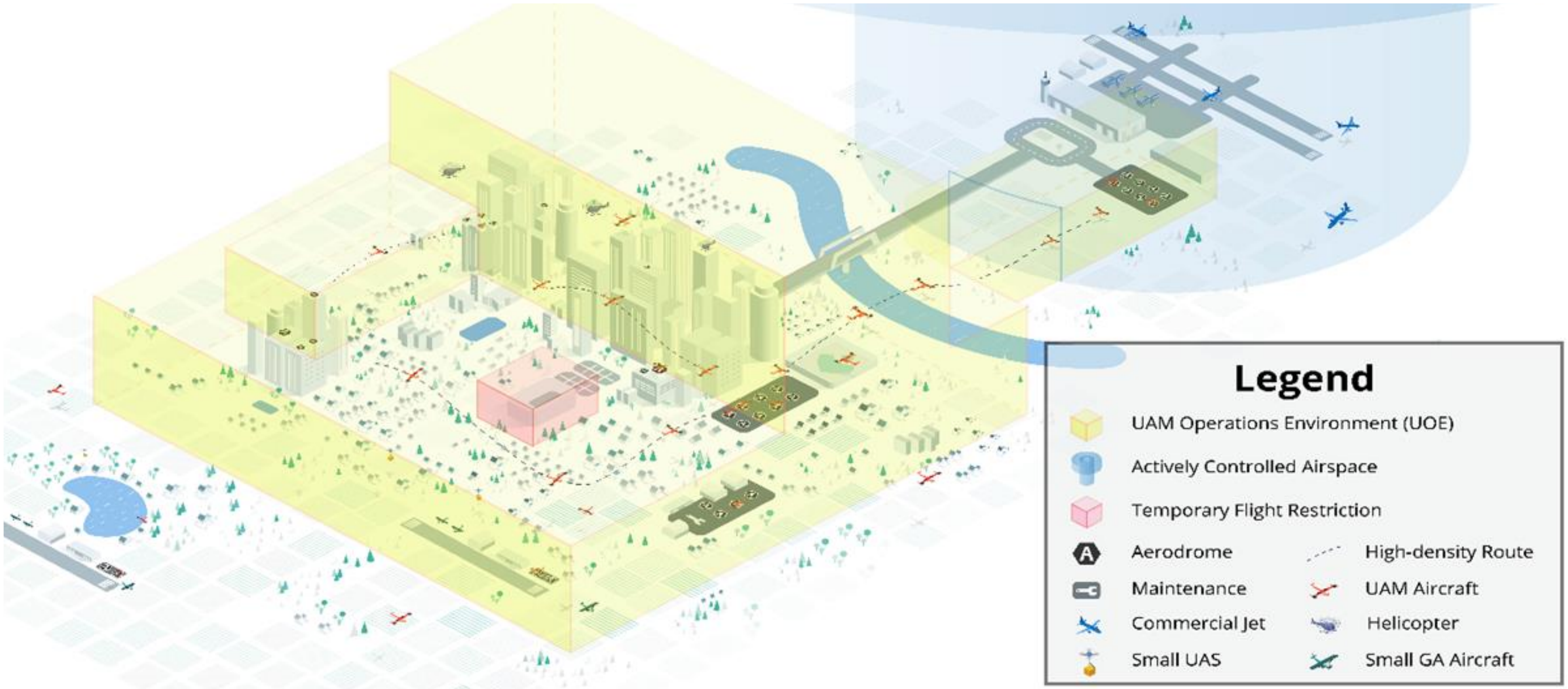
[5] Consistent with the concept descriptions in this document, the UOE is described at UML-4 (U4-UOE). Unless otherwise specified, each instance of UOE is assumed at UML-4.

[6] Services provided by PSUs include routing, traffic deconfliction, operational constraints, modifications, notifications, and information. A PSU is analogous to an Unmanned Aircraft System (UAS) Service Supplier (USS) in the UAS Traffic Management (UTM) paradigm and is contracted by the fleet operator (i.e., airspace user).

[7] FAA, Unmanned Aircraft System (UAS) Traffic Management (UTM) Concept of Operations v2.0, March 2, 2020, https://www.faa.gov/uas/research_development/traffic_management/media/UTM_ConOps_v2.pdf.

[8] It is anticipated that cruise altitude for most UAM operations will be at least 1,500 feet above ground level (AGL). Michael D. Patterson, Kevin R. Antcliff, and Lee W. Kohlman, "A Proposed Approach to Studying Urban Air Mobility Missions Including an Initial Exploration of Mission Requirements," presented at AHS International Conference, Phoenix, May 14–17, 2018.

Figure 2: Isometric Operational View of a Representative UOE



UAM aircraft can fly both inside and outside of the UOE (i.e., to reach the exurbs), but aircraft flying outside the UOE will follow the requirements of the airspace they operate within, including satisfying equipage requirements. Other aircraft can fly in the UOE if they are able to safely participate in the management and separation of traffic within the UOE, most likely through a connection with a PSU. One or more PSUs may operate in a UOE and may provide services throughout the entire volume or just a portion of it. The volume shown in Figure 2 is intended to be indicative of the volume of airspace where PSU service is available. In such cases, the UOE may extend into actively ATC-controlled airspace (such as the Class B, C, or D airspace surrounding an airport), as depicted in Figure 2, which includes a UAM aerodrome co-located with an airport. Departure and arrival routes to such UAM aerodromes for UAM aircraft through actively ATC-controlled airspace are established following a specified navigable path.[9] In such circumstances (operations transporting passengers to or from an airport), aircraft are equipped both for the UOE as well as the class of controlled airspace through which they intend to operate. UAM operations will continue to rely on PSUs when utilizing these paths and will not be in communication with ATC under normal operations.

At UML-4, it is anticipated that UAM is also one component in an intermodal transportation system and UAM aerodromes are located strategically near other forms of transportation, including traditional commercial aviation.

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[9] An example of this could be a designated route for UAM aircraft that goes into the controlled airspace surrounding a commercial airport that is designed so that it does not interfere with other air traffic. Since there is great interest in integrating UAM in with other forms of transportation, co-locating (or closely locating) a UAM aerodrome with a commercial airport is a likely use case.

3.0 The UAM Organizational Framework: Pillars and Barriers

This ConOps is organized using NASA's UAM organizational framework. Under this framework, there are five pillars, which are described in Table 1, representing the major aspects of the UAM ecosystem:

- Airspace System Design and Implementation
- Individual Aircraft Management and Operations
- Airspace and Fleet Operations Management
- Aircraft Development and Production
- Community Integration

The two airspace pillars—Airspace System Design and Implementation and Airspace and Fleet Operations Management—pertain to design and implementation of airspace for the safe, efficient, and equitable operation and management of multiple aircraft within a UAM system. The two aircraft pillars—Individual Aircraft Management and Operations and Aircraft Development and Production—pertain to design, manufacturing, and system health of aircraft, as well as operations and maintenance of a single UAM aircraft independent of the sharing of airspace or other resources. The Community Integration pillar considers transportation integration and societal acceptance of UAM operations.

Table 1: NASA UAM Framework Pillars

Airspace System Design and Implementation: Design, regulate, and manage the airspace structure and supporting ground infrastructure to enable safe, efficient, equitable, and reliable UAM flights in and around metropolitan areas.
Individual Aircraft Management and Operations: Safely operate UAM aircraft in and around metropolitan areas while maintaining compliance with all required operational rules and procedures.
Airspace and Fleet Operations Management: Provide airspace operations management services as well as fleet operations management services that ensure safe, efficient, scalable, and resilient UAM operations in and around metropolitan areas.
Aircraft Development and Production: Design, certify, and produce airworthy, mission-capable, connected aircraft that operate safely in all weather conditions required by the mission, with adequate passenger comfort and sufficiently low levels of noise.
Community Integration: Achieve public acceptance and community integration of UAM aircraft operations in and around metropolitan areas by addressing UAM-related social concerns such as safety, security, affordability, noise, privacy, emissions, regulatory compliance, and legal liability.

Figure 3 and Table 2 show barriers critical to achieve each of the pillars. In addition, the concentric ellipses list cross-cutting barriers that apply to multiple pillars and represent challenges that require solutions that are integrated across pillars to achieve successful realization of UML-4 operations. Price et al. provide additional background information on the organizational framework and barriers.[10]

[10] George Price et al., Urban Air Mobility Operational Concept (OpsCon) Passenger-Carrying Operations, NASA/CR—2020-5001587, May 2020, https://ntrs.nasa.gov/citations/20205001587

Figure 3: UAM Organizational Framework and Barriers

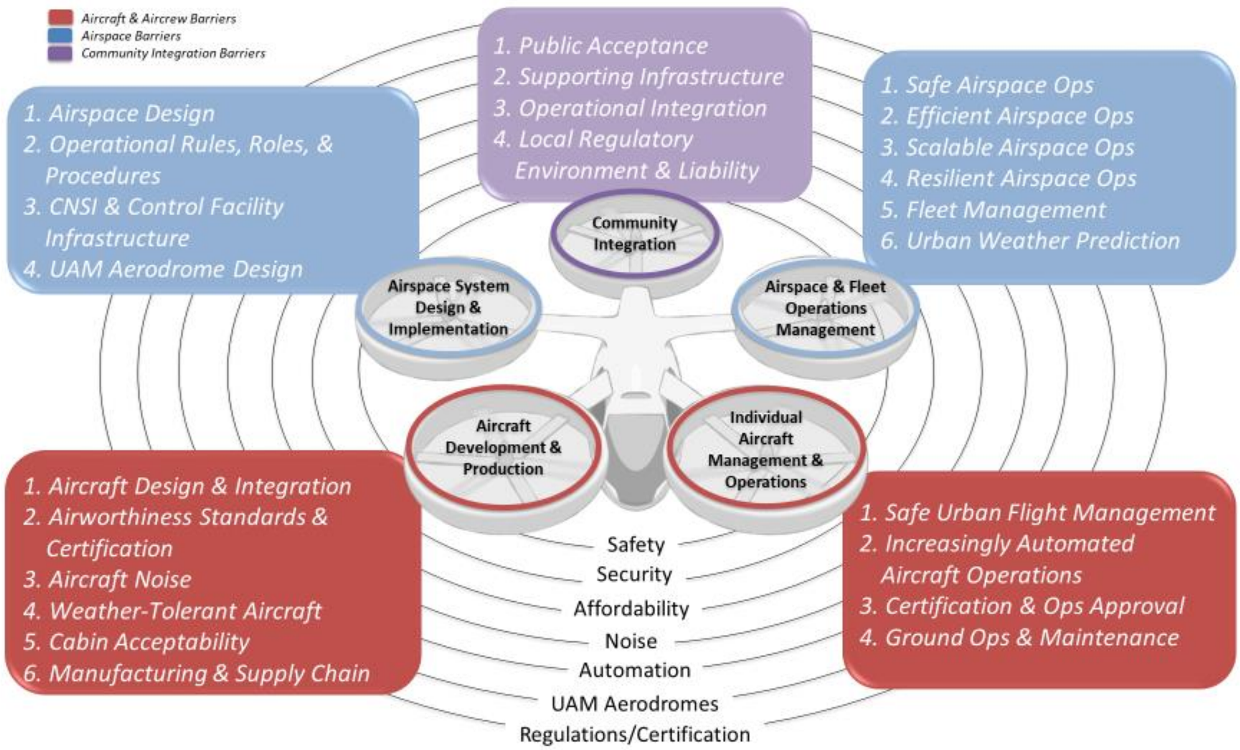


Table 2: NASA UAM Framework Barriers

Airspace System Design & Implementation	
Airspace Design	Challenges developing and implementing a practical, feasible, flexible, scalable, implementable, and equitable airspace design for UAM operations that includes considerations for interoperability of diverse missions and aircraft types (including piloted, semiautonomous/autonomous, VTOL, STOL, and sUAS), placement of UAM aerodromes to minimize community concerns such as noise and privacy, and cumulative fleet emissions (including noise and CO_2) over local communities.
Operational Rules, Roles, & Procedures	Challenges in developing operating rules, roles, procedures, and airspace management concepts of operation that enable safe and efficient operations and are compatible with urban environments, scalable operations, interoperability, and weather-tolerant operations.
CNSI & Control Facility Infrastructure	Challenges in developing and implementing in an economically viable manner sufficient, resilient, and secure CNSI infrastructure and control facility infrastructure, including spectrally efficient communication links, navigation services including but not limited to Global Positioning System (GPS), high-resolution weather surveillance near the ground, ability to account for non-cooperative aircrafts; and functionality in urban canyons.
UAM Aerodrome Design	Challenges with understanding of developing guidelines for optimal UAM aerodrome design and procedures to support the anticipated number of operations, including safe handling of contingency situations, minimizing noise impacts, and development of design guidelines and standards.
Individual Aircraft Management & Operations	
Safe Urban Flight Management	Challenges with capabilities for safe, efficient, and accommodating flight planning and execution in metropolitan areas, including navigation performance sufficient for urban environments in extremely low-visibility conditions, assuring controlled flight for safe contingency management (including cyber-attacks), and compliance with regulations and other constraints, such as noise limits.

Increasingly Automated Aircraft Operations	Challenges in developing highly automated capabilities and associated operational procedures to enable cost-effective scalability by increasing the ratio of aircraft operations to human operators and support staff.
Certification & Operations Approval	Challenges in developing a framework and corresponding methods of compliance for the holistic certification of advanced automation, humans, and operations of a UAM aircraft, as well as regulations and approval processes for commercial urban operations.
Ground Operations & Maintenance	Challenges with guidance and requirements to ensure safe and efficient maintenance and routine aircraft handling between flights, including considerations for UAM aerodrome design and operations.
Airspace & Fleet Operations Management	
Safe Airspace Operations	Challenges in developing and implementing an airspace operations management system and corresponding regulations that enable safe, secure, sustained, close-proximity, multi-aircraft operations in constrained urban environments and that allow for interoperability of diverse missions and aircraft types, including in off-nominal situations.
Efficient Airspace Operations	Challenges in developing and implementing an airspace operations management system that provides user-preferred routing while allowing equitable, predictable, and on-demand airspace access for diverse missions and aircraft types, including legacy as well as emerging operations.
Scalable Airspace Operations	Challenges in developing and implementing a scalable airspace operations management system to enable higher volumes of air traffic than exist today.
Resilient Airspace Operations	Challenges in developing and implementing an airspace operations management system that allows for graceful degradation of UAM operations in reaction to unintended disruptions to UAM services such as loss of GPS, flight services, CNSI, and/or weather information; UAM aerodrome issues; and cybersecurity attacks.
Fleet Management	Challenges with scalable, safe, secure, affordable, and efficient fleet operations management services that ensure safe navigation and efficiently handle aircraft operations throughout an operator's UAM network while managing contingencies, meeting mission demand, and minimizing the impact of aircraft fleet emissions (including noise and CO_2.) on the community.
Urban Weather Prediction	Challenges with weather forecasting with the spatial and temporal resolution needed to support safe UAM operations while maximizing aircraft and fleet productivity within their operating capabilities, areas of operation, and actual weather. These operations may require high-resolution weather prediction over short time frames for hyper-local conditions all the way to the ground.
Aircraft Development & Production	
Aircraft Design & Integration	Challenges in developing "mission-capable" integrated aircraft that are compatible with UAM aerodromes and meet all required attributes simultaneously to be safe; operationally and economically competitive with competing transportation modes; environmentally responsible; and secure from digital attack.
Airworthiness Standards & Certification	Challenges with the initial and continuing certification of novel and/or rapidly evolving aircraft in a cost- and time-effective manner, including developing certification requirements and means of compliance for aircrafts and propulsion systems, as well as ensuring harmonized international regulations and standards.
Aircraft Noise	Challenges in developing aircraft with acceptable noise characteristics, such as loudness and annoyance, during all phases of flight, including taxi, takeoff/departure, approach and landing, and cruise.
Weather-Tolerant Aircrafts	Challenges in developing aircraft that are capable of safely flying into and maintaining control in nearly all weather conditions, including icing, lightning, high winds, low visibility, high-density altitudes, and extreme temperatures.
Cabin Acceptability	Challenges in developing aircraft that provide an acceptable level of passenger comfort and payload protection, including consideration of ride quality, cabin noise, interior climate control, and vibrations.
Manufacturing and Supply Chain	Challenges in developing safe, certifiable, high-volume, affordable, secure, and rapid manufacturing capabilities, as well as a robust and scalable supply chain ecosystem.
Community Integration	

Public Acceptance	Challenges in achieving public acceptance of the UAM concept due to concerns over issues such as safety, non-user risk exposure, security, affordability, effects of increasing automation, noise, and privacy, as well as a lack of consensus on the public value proposition of UAM.
Supporting Infrastructure	Challenges in developing and implementing the supporting infrastructure required for integrating UAM operations into metropolitan areas, including UAM aerodromes, energy infrastructure, and test ranges.
Operational Integration	Challenges in implementing multimodal transportation integration that addresses operations-related community impacts, including security of passengers and cargo, protection from malicious use of aircrafts and denial of service attacks, and graceful degradation of the transportation ecosystem in reaction to disruption of UAM services.
Local Regulatory Environment & Liability	Challenges in enacting appropriate laws and regulations governing UAM operations (such as zoning, privacy, and noise regulations), striving for consistency across operating locations (such as states and municipalities); and developing a framework for the determination of liability associated with the development and operation of increasingly automated and semiautonomous and autonomous systems.

As this ConOps is written from the perspective of someone in the future at UML-4, Section 4.0 describes a system that has successfully overcome these barriers for each of the five pillars. The pillars are presented starting with the design of the airspace, how aircraft operate within that airspace, how many aircraft operate concurrently, and then discussion of aircraft design. Finally, this ConOps will look at how UAM ties to non-aviation-centric items in community integration. The order of presentation does not in any way indicate the relative importance of the various elements; all aspects must be successfully addressed to realize UML-4.

There are also seven cross-cutting barriers in addition to the barriers specific to each pillar (Figure 3 and Table 3). Appendix A describes the cross-cutting barriers that provide guidance, standards, and requirements for key elements that pertain to all five pillars.

Table 3: NASA UAM Framework Cross-Cutting Barriers

Safety	Challenges in enabling a UAM transportation system with safety levels that are acceptable to both users and the broader public.
Security	Challenges in defining the technologies, policies, and recommended practices for ensuring acceptable physical and cybersecurity for all elements of a UAM system.
Automation	Challenges in developing automation capabilities and associated regulations, policies, standards, and recommended practices that govern and help ensure their safe implementation into a highly scalable air transportation system.
Affordability	Challenges in creating a UAM transportation system that is cost-competitive with other common modes of transportation so that many individuals and businesses can use it.
Noise	Challenges in developing and operating UAM aircraft and fleets in manners that produce acceptable noise exposure to passengers and the communities in which they operate, including airspace design and operational considerations affecting frequency of operations or the impact of numerous aircrafts operating overhead at once.
Regulations/ Certification	Challenges involved in developing, implementing, and enforcing regulations and certification processes across all levels of government (federal, state, and local) that work together to ensure safety and community acceptance of UAM without unnecessarily restricting operations.
UAM Aerodromes	Challenges in designing, strategically siting, and constructing UAM aerodromes that (a) can handle high volumes of passengers and disparate types of aircrafts, (b) do not unacceptably affect the safety and efficiency of the NAS, and (c) do not cause public acceptance concerns related to noise, privacy, security, and affordability.

4.0 Urban Air Mobility Pillars

This section describes UAM concepts at UML-4 organized by the UAM organizational framework. Although an operational system will require integration across all the pillars, this framework provides an effective option for the decomposition of the system to enable detailed discussion and identification of enabling solutions.

4.1 Airspace System Design and Implementation

At UML-4, the UOE enables high volumes of complex UAM operations based on policy and regulations created and/or modified to accommodate UAM aircraft and operations. The UOE is an evolution in traffic management based on UTM concepts described in the FAA UTM ConOps 2.0.[11] In the UOE, ATM services are largely provided by private sector service providers, although public sector service suppliers may also exist. These ATM services are not provided by the FAA nor directly on behalf of the FAA, but by or on behalf of the users in a manner that meets requirements enacted by the FAA, which has full regulatory authority ove r the airspace. PSUs along with advanced aircraft technologies and appropriate flight rules (e.g., Digital Flight Rules[12]) enable high-density, complex UAM operations while minimizing workload impact to human-operated ATC.

The UOE is established through a collaborative design process with a larger role from state and local stakeholders (government, communities, businesses, etc.) where UAM operations will occur. The UOE coverage is tailored to a specific metropolitan area and in some cases UOE may extend into actively controlled airspace. This provides navigable UAM routes between metropolitan areas and actively controlled airspace[13] similar to special flight rules areas. The UOE extension into actively controlled airspace enables UAM operations in the terminal environment of existing controlled airports without active ATC management.

Significant technological advances in decision-making support tools, automation, and data management enable the UOE airspace to accommodate increasingly complex operations and higher volumes of air traffic at low altitudes. The increase in low-altitude air traffic includes passenger-carrying UAM flights, sUAS operations, growth of historical general aviation (GA) operations, and other UAM cargo operations. Additionally, these advances enable operational solutions to fleet noise, new CNSI capabilities, and the incorporation of UAM aerodromes into metropolitan transportation systems.

4.1.1 Airspace Design

The UOE substantially influences airspace design, management, procedures, and roles. UAM aircraft in the UOE largely operate in metropolitan areas extending into the urban periphery below the actively controlled Class B, C, D, or E to surface-level airspace around airports (Figure 2).[14] The UOE in this area is established through rulemaking, within existing airspace classes that has specific equipage requirements necessary to ensure safe operations of diverse aircraft configurations at higher densities than observed historically. UOE largely exist within

[11] FAA, Unmanned Aircraft System (UAS) Traffic Management (UTM) Concept of Operations v2.0, March 2, 2020, https://www.faa.gov/uas/research_development/traffic_management/media/UTM_ConOps_v2.pdf.

[12] David Wing and Ian Levitt, New Flight Rules to Enable the Era of Aerial Mobility in the National Airspace System, NASA/TM-2020-5008308, Nov 2020, https://ntrs.nasa.gov/citations/20205008308

[13] A generic term that covers the different classification of airspace and defined dimensions within which ATC service provided by the FAA to IFR flights and to VFR flights in accordance with the airspace classification.

[14] "Actively controlled airspace" in this document refers to Class A, B, C, and D airspace.

urban metropolitan areas at UML-4, but it is anticipated that the UOE and/or the rules governing operations within it will expand beyond urban and metropolitan areas at UML-5 and -6.

The UOE has a fixed maximal size that is tailored and charted based on the unique characteristics and needs of specific metropolitan areas and a collaborative airspace design process. The area of the UOE that is available at any given time is based on traffic demand and criteria established by the FAA. This means that although there is a fixed maximum size of the UOE, the area that is available is based on factors such as traffic demand, temporary flight restrictions (TFRs), needs of non-UAM airspace users, etc. Thus, the available and unavailable portion of the UOE is "flexible" (i.e., capable of being modified as needed). Changes in the available portion of the UOE are typically made on the order of a few times per day to accommodate evolving needs, such as changes in wind direction or periods of high demand — "rush hours."

UOE operations and PSUs seamlessly operate with airspace managed by traditional human-operated ATC in specific areas such as the terminal environment where preauthorized by FAA. ATC has access to all available real-time information about UAM operations, but does not generally monitor UAM operations; rather, ATC is alerted only in the case of an emergency or when UAM operations depart from their desired parameters. ATC has the capability to close the UOE as necessary. UAM aircraft that transition from UOE into ATC-controlled airspace must be equipped for and operate in accordance with the rules that govern those ATC-controlled airspace categories. Likewise, all aircraft operating in the UOE are required to follow all airspace equipage and aircraft performance requirements. These requirements include participating in the PSU Network, which is a digitally interconnected network of all PSUs in an area and provides a secure information exchange between users of the UOE. Subscription to a private or public PSU allows traffic management services to understand and track the location and intent of aircraft for safe traffic management services (separation, sequencing, etc.). This equipage is implemented in a manner that minimizes the impacts to GA aircraft.

Traffic management around UAM aerodromes in the UOE is a function of automated communication between PSUs and aircraft systems. UAM operations may also routinely extend into controlled airspace (e.g., to provide access to high-demand landing areas near airports) depending on the operations plan. Traffic management around UAM aerodromes located within these extensions into ATC-controlled airspace is the responsibility of PSUs with no active ATC management as long as the aircraft remains within the airspace that is designated for UAM operations. These extensions may be activated or deactivated (e.g., changes can be made based on airport runway configuration or ATC need) by the FAA as needed. Traffic management for UAM aircraft that experience an unplanned entry into ATC-controlled airspace is discussed in Appendix D: Use Cases. Similar to the way remote ATC towers operate, traffic management around UAM aerodromes may occur onsite or remotely.

High-Density Routes

Economic viability studies [15] show that UAM aircraft must be highly utilized to deliver a per-trip cost acceptable to the public and they must be conveniently located to enable broad public access to UAM. Therefore, although any aircraft that meets UOE requirements may operate in the UOE, the majority of passenger-carrying UAM operations at UML-4 occur along high-density routes between points where traveler demand is highest (Figure 4 and Figure 5).

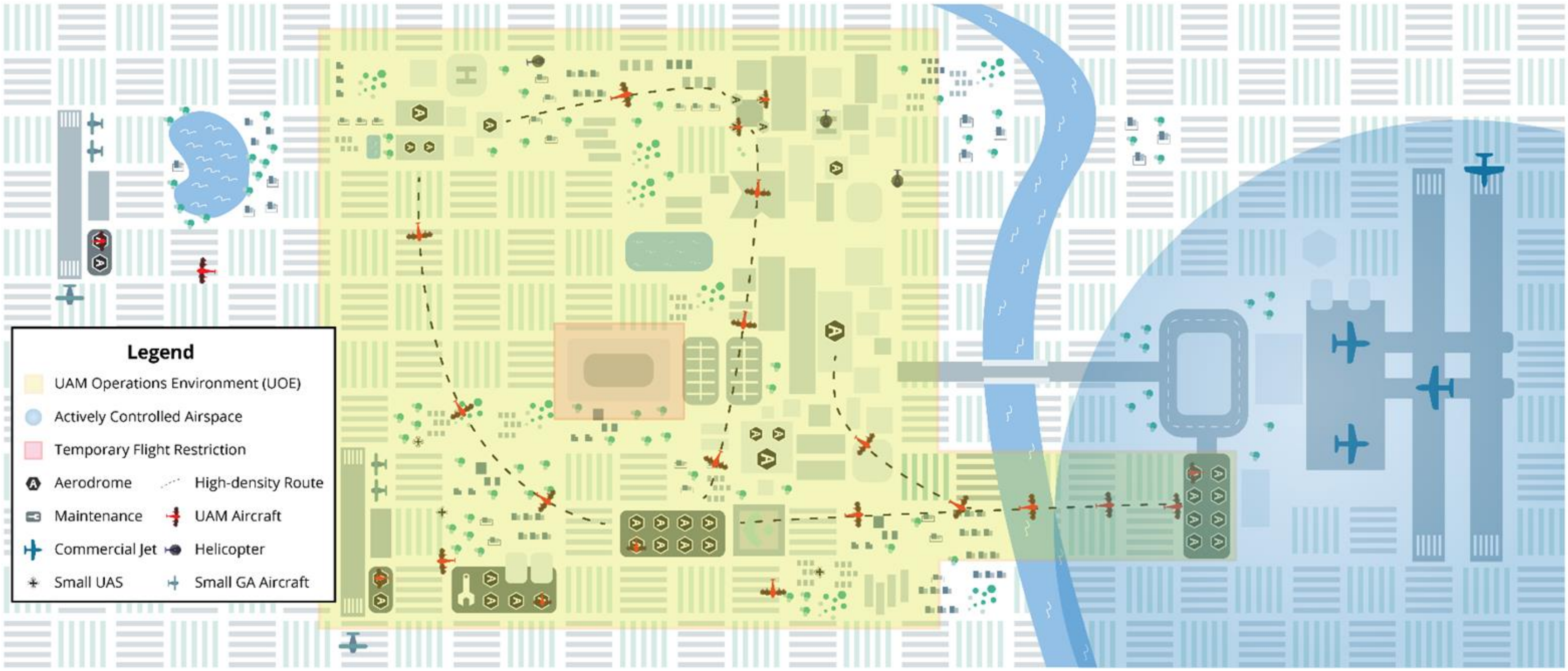
High-density routes exist solely within the UOE and require more advanced capabilities for managing aircraft than other areas of the UOE. Consequently, high-density routes are supported by air and ground infrastructure and are governed by operational procedures all designed to enable high volumes of air traffic. For example, high-density

[15] Rohit Goyal et al., "Urban Air Mobility (UAM) Market Study," November 2018, https://ntrs.nasa.gov/citations/20190001472.
Shahab Hasan et al., "Urban Air Mobility (UAM) Market Study," June 2019, https://ntrs.nasa.gov/citations/20190026762.

routes generally have redundant/emergency landing areas in greater numbers than other en route areas, enhanced micro weather sensing and prediction, and augmented CNSI infrastructure. High-density routes are also matched with UAM aerodromes with the appropriate infrastructure and capacity to feed these routes. Under the principle of airspace equity, any cooperative aircraft that meets UOE performance-based standards have access to these routes. However, flight characteristics dictate the aircraft trajectory and location of operation (i.e., the operations plan). These are implemented by PSUs to govern traffic flow and aircraft order sequencing for safe, efficient, and equitable access to the airspace. These criteria can be modified by the FAA as required.

High-density routes are dynamic based on demand and are negotiated with the FAA and community stakeholders. For example, some routes may only be open during morning and evening "rush hours" or before and after sporting events. High-density routes require more focused and deliberate community engagement to address public concerns over issues such as noise. These routes were developed over time and are modified as demand changes and community acceptance grows. The predictability of these routes facilitated community acceptance of UAM operations.

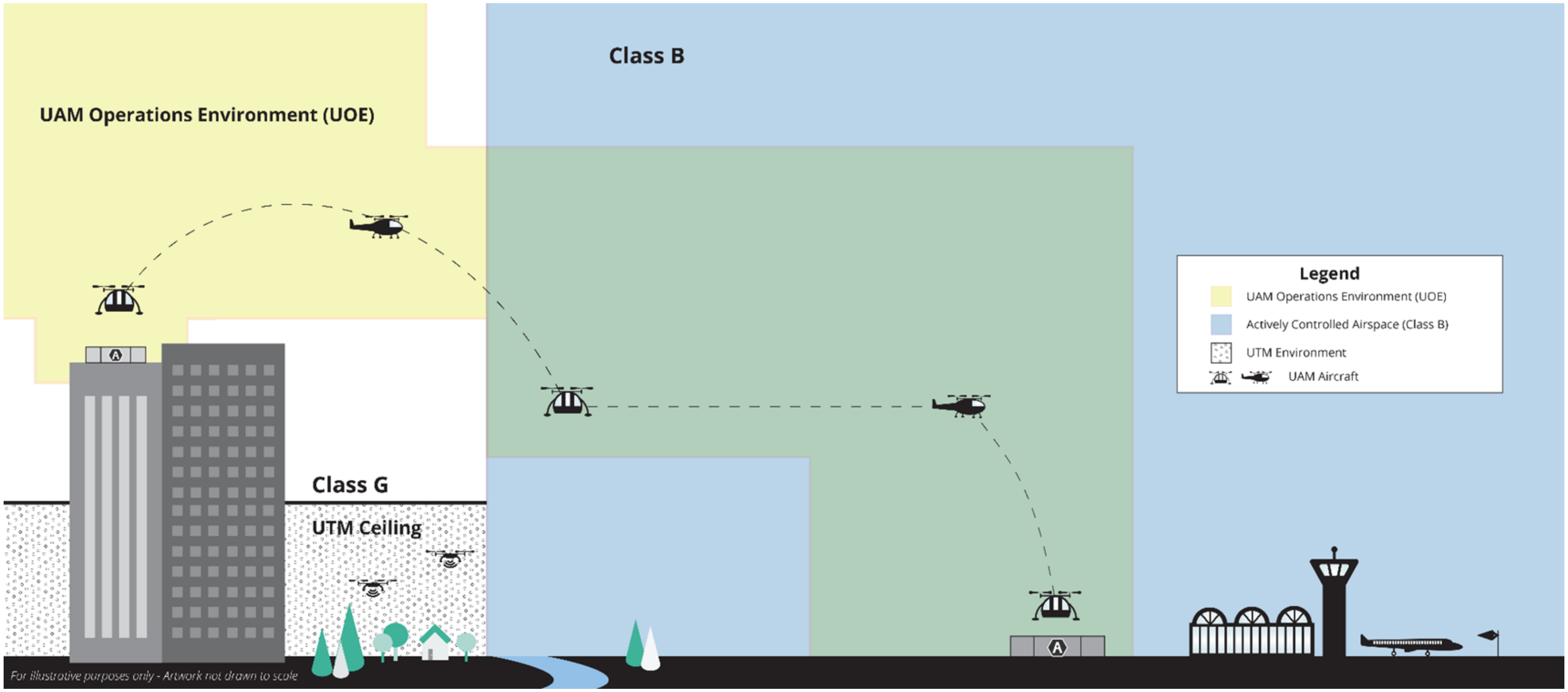
Figure 4: Overhead Operational View of a Representative UOE



For illustrative purposes only - Artwork not drawn to scale

This graphic shows a top-down image of the UAM operational view to illustrate the routing of aircrafts. High-density routes operate between areas of highest demand, which are shown in the figure to include parts of the urban core, the immediate suburbs, the major airport, and the minor outlying city. Near an airport, routes typically merge to enable orderly entry and exit of the actively controlled airspace without obstructing the arrival and departure corridors flown by commercial aircraft. Not all UAM flight occurs in high-density routes, and flight can occur outside the UOE so long as the aircraft is equipped for that airspace. The UOE is not exclusive to UAM aircrafts, as shown by the other aircraft flying in this area.

Figure 5: Side Operational View of a Representative UOE

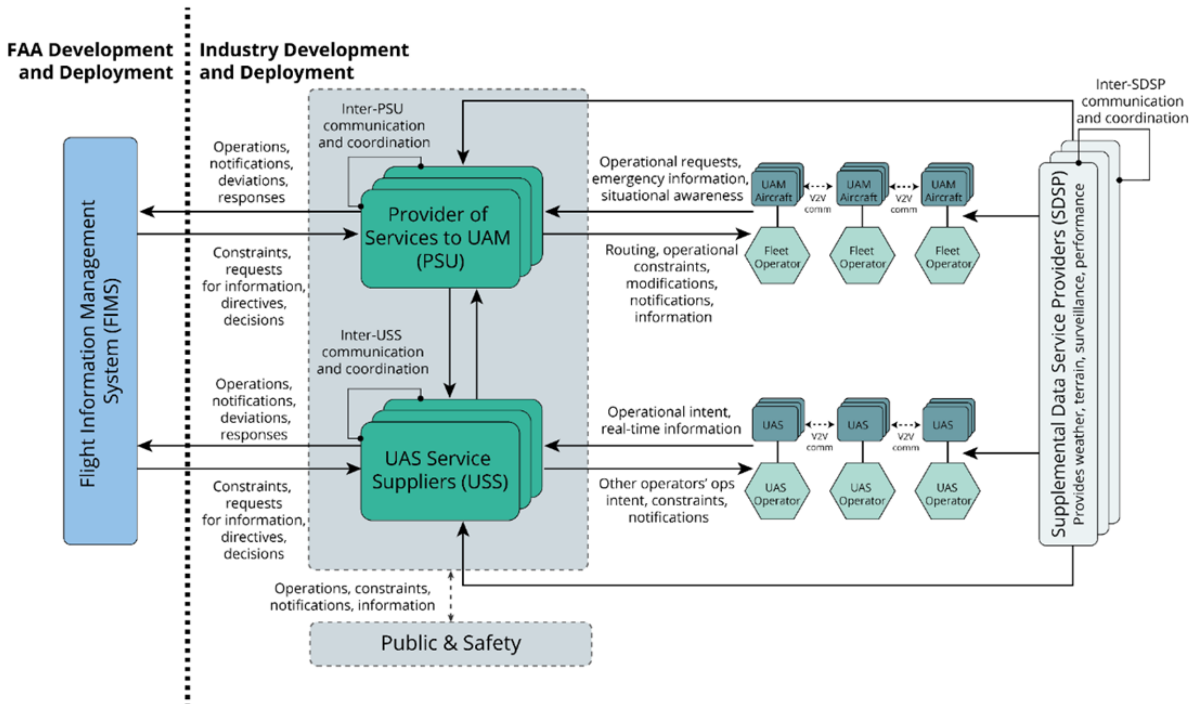


This graphic shows the entry into actively controlled (Class B, C, or D) airspace to reach a UAM aerodrome co-located with an airport. UAM approaches and departures have been designed so that they do not interfere with the approaches and departures of commercial jets. When flying in these areas, UAM aircrafts obtain their traffic management services from the PSUs, but also must be properly equipped to communicate with ATC (in off-nominal situations). In addition, the UOE and UTM do not actively exchange data at UML-4.

4.1.2 Operational Rules, Roles, and Procedures

UML-4 airspace operational roles, responsibilities, rules, and procedures are established and defined for the UOE. Many ATM functions are performed on behalf of fleet operators by PSUs. Many PSUs are third- party operated and supply flight safety services under rules and regulations established by the FAA. Qualified PSUs provide flight-planning support and ATM services (communications, separation, sequencing, information exchange, etc.) within the UOE. The PSUs also enable sharing of information among the fleet operators (the entity that employs the aircraft crew and, in some instances, performs dispatch duties[16]) and the FAA on operational intent, airspace constraints, and other necessary information to enable safe operations.

Figure 6: UAM Communications Networks



PSUs provide a dynamic common operating picture of the UOE (i.e., the ability to understand constraints, the location and intent of all air traffic, etc.) through information sharing and exchange between fleet operators, automated systems on the aircraft, and the FAA to achieve safe operations. The FAA has on-demand access to UOE operational information and can dynamically modify the airspace (e.g., close/expand areas and/or restrict operations) via a server-initiated data exchange ("push") to PSUs based on safety and operational demands (e.g., emergencies, sporting events, military operations). UOE rules and procedures apply to all aircraft operating within the UOE.

4.1.2.1 Airspace Rules and Procedures

All participants in the UOE are expected to abide by the appropriate operating rules, regulations, and policies for their intended operation. Operations are supported by an environment designed to promote shared situational awareness and cooperative operations through information exchanges. Within the UOE, fleet and UAM aerodrome operators, aircraft, and PSUs maintain a performance level necessary to ensure safety (separation from all hazards and obstructions, etc.). The requirements governing coordination between the PSUs in the PSU Network are based on standards developed and recommended by industry consensus standards development organizations (SDOs)

[16] A fleet operator may operate one aircraft or several.

and accepted by the FAA. The PSU Network governs and deconflicts PSU operations. In instances where multiple PSUs are operating in a single UOE, the PSU Network will serve to integrate and deconflict services and operations.

Right-of-way rules and other procedures to assist with safe mitigation in off-nominal scenarios are developed through industry consensus standards and approved by the FAA. These standards include procedures for communicating and responding to wide range of scenarios (e.g., aircraft in distress, UAM aerodromes unexpectedly closed, communications interference). Under emergency conditions, priority may be given to certain types of operations, such as an aircraft in distress, public safety, or law enforcement aircraft.

Key concepts to understand airspace rules and procedures for the UOE include participation, operations plan, and performance authorization. These concepts are described below.

- **Participation**: All aircraft must meet requirements established for the type of operation and associated airspace volume/route in which they are operating. Given the density and complexity of operations at UML-4, it is necessary for safe operations that there is a common understanding across all participants of the operational intent and capabilities of aircraft in the UOE; this common understanding is provided by PSUs, which provide ATM services. A fleet operator or aircraft that exits or enters the UOE as part of their operations plan may continue to share information with -UOE participants while they are outside of the UOE.
- **Operations Plan**: Prior to operating in the UOE, all aircraft must submit an operations plan. The operations plan is similar to a flight plan and contains flight path, planned departure/arrival times, alternate UAM aerodromes, and other data elements describing the operation that may be established by SDOs (e.g., Radio Technical Commission for Aeronautics (RTCA), American Society for Testing and Materials (ASTM), etc.) and approved by the FAA. The fleet operator is responsible for the transmission of the initial operations plan to the PSU. The PSU may suggest modifications to the operations plan, and negotiation between the PSU and fleet operator may occur before an initial operations plan is finalized. Changes to the operations plan can also be made during flight.
- **Performance Authorization**: The FAA authorizes all participants in the UOE through approval of the performance authorization. Authorization to operate within the UOE is automated and seamlessly integrated as part of the broader information exchange system among fleet operators, PSUs, and the FAA. The PSU transmits information from the fleet operator to the FAA, which automatically provides verification of authorizing to operate.

4.1.2.2 Communication Procedures

UAM aircraft connect via a data link to their fleet operator and PSU. In the case of fleet operations, the fleet operator may be a centralized or automated dispatch; alternatively, an individual aircraft crew of a UAM aircraft could serve as their own fleet operator. The fleet operator connects to a PSU for the operation. Aircraft also transmit information directly to other aircraft through vehicle-to-vehicle (V2V) communication, and to the PSU and their fleet operator. This information includes position information and data needed to aide in collision avoidance, separation, deconfliction, scheduling, and other ATM functions. The path of data transmission depends on the system's architecture, (e.g., aircraft, fleet operator, PSU) and the purpose of the information. Information to enable safe flight and requires constant updating such as proximity information, aircraft and obstacle mitigation, etc., is processed on the aircraft and communication that occurs V2V is pushed to the PSU Network for status monitoring. Information that changes less frequently (e.g., operations plan) can be processed at the PSU and pushed to the aircraft. The PSU also communicates with other PSUs within the PSU Network, as depicted in Figure 6, to execute strategic flight path planning based on standardized deconfliction and prioritization protocol approved by the FAA. The FAA, through Flight Information Management System (FIMS), can dynamically push constraints and directives to the PSU Network for inclusion in strategic and tactical (in-flight) planning decisions. Information that is transmitted over the PSU network adheres to agreed-upon interface standards.

Supplemental Data Service Providers (SDSPs) provide services that support operations directly to PSUs or fleet operators (e.g., specialized weather data, surveillance, constraint information). This information exchange occurs between the SDSP and PSU, aircraft, fleet operator, or combination of the three depending on the nature of the information. Time-critical information (e.g., weather) may go directly to the aircraft, where non-time-critical information (e.g., fleet management information) may go to the fleet operator, which then relays it to the aircraft. Other transmission variables (e.g., push vs pulled information or the frequency of updates) are dependent upon issues such as the nature of the information, the bandwidth required, and where the decision authority resides. All SDSP services meet required cybersecurity standards to operate in the PSU Network to ensure integrity of the network.

Public safety organizations such as first responders can access the PSU Network to monitor UOE operations. When responding to emergencies, these first responders can coordinate with the FAA to deactivate airspace above response scenes to prevent harm to overflying by UAM and/or UAS aircraft. The public is also able to monitor operations in the PSU Network for informational purposes as approved by the FAA and public safety agencies.

4.1.2.3 Roles

Several stakeholders have critical roles and responsibilities required for the successful structure of operations within the UOE, including the federal, state, and local governments; private-sector service suppliers; and fleet operators.

- **Provider of Services to UAM (PSU)**: At UML-4, PSUs provide ATM services that help enable safe and efficient UAM operations within the UOE with minimal FAA involvement. A PSU provides services within one or multiple UOEs. PSUs may be public (e.g., provided by a local government to manage its public aircraft), or private (e.g., a third-party service provider). The range of services provided varies from PSU to PSU, but each must meet minimum requirements for qualification by the FAA. The qualification requirements are based on standards developed and recommended by industry SDOs and accepted by the FAA. The PSUs communicate airspace restrictions, receive and coordinate operations plans, and approve dynamic route change requests from fleet operators. PSUs also exchange data and record data as required by regulators (e.g., the FAA) for regulatory and fleet operator accountability purposes. The FAA determines the process and criteria for qualifying a PSU-provided service. Not all services provided by PSUs are required to be qualified. For example, an air traffic separation service is required to be qualified, but an in-flight weather radar service does not require qualification. Depending on its infrastructure, a PSU may not provide services across the entire UOE. A fleet operator may act as its own PSU.
- **PSU Network**: The PSU Network describes a fully integrated system of multiple overlapping PSUs servicing the same geographic area/airspace volume. The PSU Network is a system of systems that provides discovery services (a directory of PSUs in a given area) and other intermediary services. The PSU Network provides secure information exchange between users of the UOE system including fleet operators, the FAA, UAM aerodrome operators, and others. Cooperative data exchange between the various PSUs and UOE users (fleet operators, FAA, aircraft, infrastructure, etc.) provides a fully integrated operating picture to support coordination, planning, aircraft deconfliction, conformance monitoring, and emergency information dissemination and response. The requirements governing coordination between the PSUs in the PSU Network are based on standards developed and recommended by industry SDOs and accepted by the FAA.
- **Supplemental Data Service Providers (SDSPs)**: SDSPs provide services that support operational decisions. This information can be provided directly to PSUs, aircraft, fleet operators, or UAM aerodrome operators (e.g., specialized weather data, surveillance, constraint information). Multiple service providers may provide similar information and be selected at the discretion of the user. The services supplied by an SDSP may be raw data, value added data, one or a suite of decision support tools. SDSPs providing safety-critical services are adheres to data performance and interface standards qualified by FAA (e.g., weather services). Those providing optional services (fleet management, passenger entertainment, etc.) may not require FAA qualification.
- **FAA**: The FAA is the federal authority over aircraft operations in all US airspace and provides the regulatory and operational framework for UML-4 operations. The FAA provides information on airspace constraints, such as

notices to airmen (NOTAMs), airspace restrictions, facility maps, Special Use Airspace (SUA), and Special Activity Airspace (SAA) activity transmitted via FIMS or other FAA provided resources directly to users or via PSUs. The FAA collaborates with the PSU Network by exchanging data with PSUs and operators to fulfill its obligations, to provide regulatory and operational oversight. The FAA certifies or qualifies, as appropriate, safety-critical elements in the UOE, including the aircraft crew, PSUs, and aircraft. Additionally, the FAA is the supplier of the FIMS.

- **Flight Information Management System (FIMS)**[17]: The FAA FIMS is an application program interface (API) gateway for data exchange between UOE (and UTM) users and FAA systems. FIMS delivers relevant NAS information and FAA directives to PSUs and provides access to any information it needs from PSUs.
- **Fleet Operator**: A UAM aircraft fleet operator is responsible for operational control of aircraft and fleet operations. Fleet operators include individuals operating their own single aircraft (e.g., owner/operator) or organizations operating a fleet of multiple aircraft for commercial use. The fleet operator is responsible for meeting regulatory requirements and certification, planning flights, and sharing operational intent and current position information of its aircraft with the PSU Network. Fleet operators manage UAM aircraft that may be piloted, remotely piloted, or highly automated. The fleet operator holds the operating certificate and is responsible for operational control.
- **Pilot in Command (PIC)**: For this ConOps, the PIC is a human individual who holds "final authority and responsibility for the operation and safety of the flight"[18] of a UAM aircraft. This individual may be onboard or off-board the aircraft. A PIC off-board the aircraft is a remote PIC (RPIC). Additionally, the PIC may be a pilot in the traditional sense of the term or could be part of the aircraft crew (defined below), having a modified role in which automation is responsible for some functions performed by a traditional pilot. In the remainder of this ConOps, it is assumed that the PIC is a member of an aircraft crew as opposed to a traditional pilot, though traditional pilots are not precluded from assuming the roles specified for aircraft crew. PIC may be responsible for operational control for one or more aircraft at any one time (e.g., via remote oversight have responsibility over multiple aircraft in flight).
- **Second in Command (SIC)**: A human onboard the aircraft with secondary and tertiary operational responsibility behind aircraft automated systems and the PIC. In instances where an onboard SIC exists, it is assumed that the PIC is operating in a remote capacity. The SIC has more responsibility than an aircraft steward and is fully trained and qualified for the assigned roles and responsibilities. A SIC does not require the same qualifications as a PIC. The SIC is a necessary role to build the safety case for a single PIC with operational control for more than one aircraft at a time.
- **Aircraft Crew**: The aircraft crew is responsible for the operation and safety of the flight and passenger well-being. The aircraft crew includes the PIC/SIC and may include other individuals and functions (e.g., aircraft steward to monitor passenger comfort and well- being). Aircraft crew roles, can be divided into four categories of overall flight management, which progress from strategic to tactical, are used: (1) mission management (i.e., planning and revising the overall mission, such as setting or changing a destination UAM aerodrome); (2) flightpath management (i.e., setting and revising the aircraft's flightpath to achieve the mission in an effective way); (3) tactical operations (i.e., making modifications to the aircraft's flightpath/state to ensure the safety of the aircraft in the short term, typically in response to an unanticipated hazard [e.g., flock of birds], which generally ignores the overall mission objective until a safe state is restored); and (4) aircraft control (i.e., maintaining the aircraft in a safe state).[19] Each aircraft crew member receives training and certification at a level deemed appropriate by the FAA for their role in the operation.
- **Ground Services**: Ground services to aircraft, including refueling/recharging, aircraft inspection, line maintenance, aircraft servicing (food/beverage/lavatory), deicing, aircraft reconfigurations, and other applicable services similar to today's commercial airports and FBOs ground services. These services are provided by licensed and certified personnel employed by UAM aerodrome operators, fleet operators, or third parties contracted by either the UAM aerodrome operators or fleet operators.

[17] FAA, Unmanned Aircraft System (UAS) Traffic Management (UTM) Concept of Operations v2.0, March 2, 2020, https://www.faa.gov/uas/research_development/traffic_management/media/UTM_ConOps_v2.pdf.
[18] 14 CFR §1.1 "General definitions."
[19] David J. Wing, Eric Thomas Chancey, Mike Politowicz, and Mark G. Ballin, "Achieving Resilient In-Flight Performance for Advanced Air Mobility through Simplified Vehicle Operations," presented at AIAA Aviation Forum, Reno, Nevada, June 15–19, 2020, https://ntrs.nasa.gov/citations/20205000771

- **UAM Aerodrome Operators**: UAM aerodrome operators are private or public entities responsible for ensuring the safety of individual takeoff and landing areas and ground services (embarkation, disembarkation, maintenance, etc.) provided at a UAM aerodrome, but do not control airborne traffic. A UAM operator that makes the decision to control airborne traffic must be qualified as a PSU. UAM aerodrome operators share takeoff and landing information with their PSU for dissemination across the PSU Network and can monitor the PSU Network for informational purposes. UAM aerodrome operators may provide passenger and/or cargo screening and security or may contract out this responsibility.
- **State and Local Government**: State and local governments have a greater role in UAM at UML-4 than in traditional aviation (i.e., that prior to 2020) because UAM operations occur largely in cities near local communities and businesses. State and local zoning requirements, noise ordinances, and land-use laws govern approval of the locations of UAM aerodromes and can impact the number and routes of UAM flights.
- **Other Stakeholders**: Other stakeholders include the general public, public safety entities (state, local, and federal law enforcement), multimodal partners, and national security entities, such as the Department of Homeland Security (DHS). SDOs such as those mentioned in Section 4.1.2.1, aviation authorities and safety bodies, SAE International, and the National Fire Protection Association (NFPA) all contribute to elements impacting the design of the UAM system. These stakeholders have access to information in the PSU Network as law and policy permit.

4.1.3 Communications, Navigation, Surveillance, Information (CNSI), and Control Facility Infrastructure

UAM at UML-4 is enabled by advanced CNSI technologies and services. Information exchange occurs through seamless, secure, and resilient information exchange between producers of data (e.g., aircraft, PSUs, SDSPs, FAA, and fleet operators) and users (e.g., aircraft, PSUs, FAA, SDSPs, and other stakeholders fleet operators). High numbers of UAM operations along with large quantities of information exchanged exceed the aviation-protected spectrum available in 2020. UML-4 operations are enabled by the transition to more capable systems and protocols.

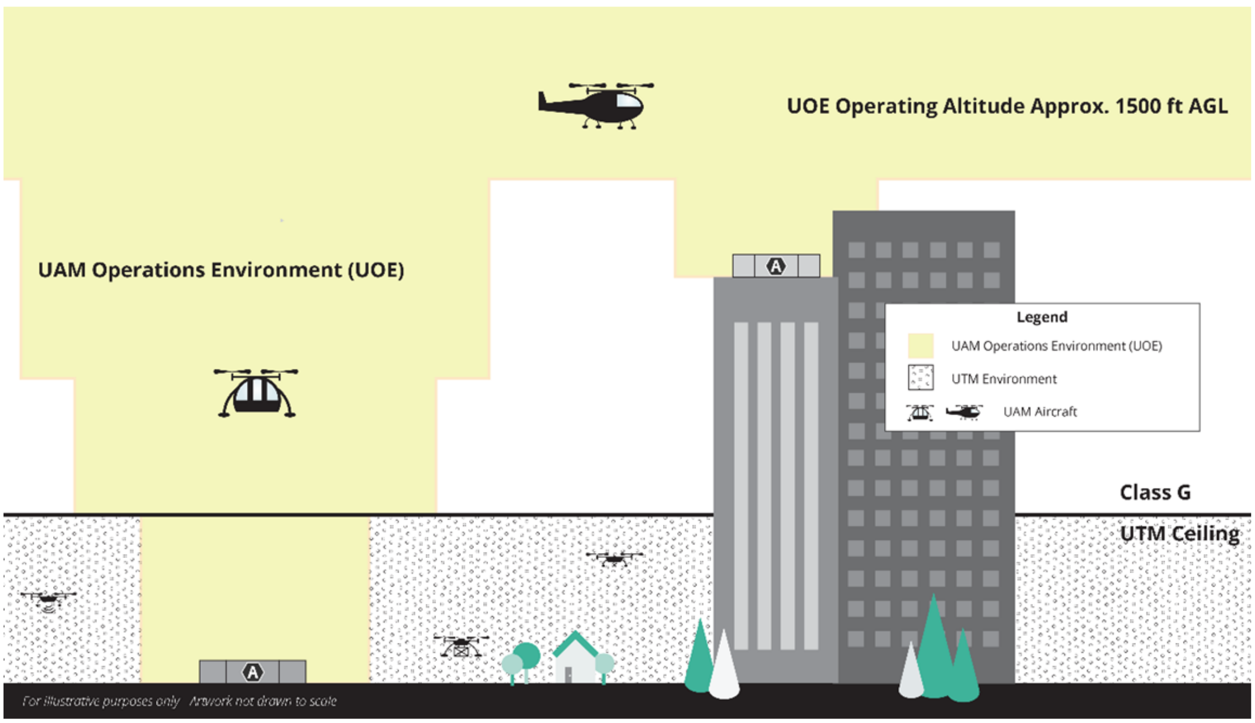
- **Communication**: At UML-4, fleet operators maintain communication with PSUs and UAM aircraft in compliance with regulatory requirements to support data exchange required for safe operations. This occurs through three different communications paths (aircraft to aircraft, aircraft to ground, and ground to ground) during three different stages of operation (surface, departure/arrival, and en route). To be able to safely operate in the vicinity of or on high-density routes into actively controlled airspace, the PIC is equipped with required ATC communication technologies needed to operate in actively controlled airspace. The PIC has the capability of communicating with ATC and controlling the aircraft to comply with ATC instructions so that the aircraft can operate in controlled airspace. Section 4.1.2.2 has additional information on communications.
- **Navigation**: Navigation components include systems on the aircraft and navigational aids. Performance-based navigation (PBN) capabilities enable dynamic precision trajectory-based operations (TBO), even in visibility-restricted conditions. UAM aircraft navigate using a combination of external data feeds and onboard capabilities (e.g., hardware, software, and transmission mechanisms) to operate with greater route conformance and separation minima. This greater degree of navigational accuracy allows aircraft to avoid obstacles, execute planned operations, or emergency landings under more restricted conditions than traditionally equipped and capable transport commercial aircraft today (2020).
- **Surveillance**: Surveillance operations for cooperative and non-cooperative operations, are supported by a range of ground, aircraft-borne, and satellite-based infrastructure that augment individual aircraft capabilities, enhance safety, and provide other information (e.g., non-cooperative aircraft or localized weather). Although surveillance information is utilized and shared by PSUs, in certain cases direct information exchange occurs among multiple aircraft and ground/satellite infrastructure to for tactical hazard identification and reporting.
- **Information**: Information includes data that is not captured as part of CNS and does not utilize aviation protected spectrum. It includes passenger internet access while in flight and non-critical information supporting UAM operations (e.g., SDSPs collecting raw data or passenger ticketing apps). This information may enter the PSU or other UAM networks if it adheres to security, performance and interface standards. The

information may also remain external to the UAM system but provides a key component to arrive at a successful business case.

- **Electromagnetic Interference (EMI)**: Both cities and electric aircraft can be significant sources of electromagnetic radiation. CNSI systems, both on and off the aircraft, incorporate EMI protections against external and internal sources, including other onboard CNSI systems, electric propulsion systems, high-power radio and radar transmitters, power grid components, and lightning strikes.
- **Cybersecurity**: Adherence to cybersecurity standards support secure communication between all operational elements. These requirements include degraded communications and connectivity.
- **Control Facility Infrastructure**: Economically viable, sufficient, resilient, and secure control facility infrastructure has been developed for PSUs, fleet operators, and other stakeholders. This infrastructure supports spectrally efficient communication links; navigation services, weather surveillance, functionality in urban canyons, and the ability to account for non-cooperative aircraft. Monitoring of services and infrastructure is required to maintain efficiency and safety.

4.1.4 UAM Aerodrome Design

Figure 7: UAM Aerodrome Environment



This graphic shows the interaction between the UOE, a UAM aerodrome, and the UTM environment. UAM aerodromes below 400 feet AGL (such as those at ground level) will be located at altitudes in the UTM environment. To protect the UAM operations from the sUAS operations in the UTM environment, the UOE will extend down from the cruising altitudes in an "upside down wedding cake" manner to envelope these low-altitude UAM aerodromes. Where the UOE necks down, an sUAS is only permitted to enter when its UAS Service Supplier (USS) coordinates entry with the PSU Network. An "upside down wedding cake" may also exist at higher altitude UAM aerodromes (such as those on buildings), but those "upside down wedding cakes" are much less pronounced. The floor of the UOE is well above the UTM environment in most places. This is because most UAM flights cruise at altitudes approximately 1,500 feet AGL and higher (up to approximately 4,000 feet AGL).

UAM aerodromes are designed to meet the needs of individual cities and regions and have numerous location and design constraints. Their locations are driven by many factors, not least of which is the anticipated current and future demand. Consequently, UAM aerodromes are located throughout metropolitan areas (Figure 7). Local stakeholders (government, public, businesses, etc.) have significant input on UAM aerodrome locations as part of the public planning processes. Zoning ordinances, existing infrastructure, noise ordinances, and other environmental factors (e.g., trees, waterways, prevailing wind patterns) constrain UAM aerodrome locations and siting, and the types and quantities of aircraft that can operate from a UAM aerodrome. Additionally, UAM aerodromes have access to local utilities to accommodate demands for critical resources, including electrical grids, power, internet connectivity, and public accessibility. These demands further constrain feasible and viable UAM aerodrome locations and/or lead to changes in the local utility infrastructure to support UAM aerodromes. State and local regulatory authorities ensure that UAM aerodromes are designed and built in compliance with adopted required codes, such as following building and fire codes.

There are a variety of UAM aerodrome types including those with runways that allow for fixed-wing aircraft takeoff and landing, those that require VTOL, and hybrids of both UAM aerodromes types, particularly those in urban centers or other locations with dense building infrastructure, often have smaller footprints, and require VTOL and primarily serve transient aircraft. UAM aerodromes, including those in urban centers, have basic maintenance and repair capabilities. However, more extensive maintenance, repair, and overhaul (MRO) and long-term parking typically occur at UAM aerodromes and repair centers outside the urban core where real estate is less constrained. UAM aerodrome types also reflect their integration with other modes of transportation. For example, those commonly found at or near major airports are configured to allow passengers to easily access traditional commercial air services.

All UAM aerodromes meet the standards developed by the FAA and industry, including those for obstacle avoidance and off-nominal operations. UAM aerodromes are designed with operational limitations based on the unique location and operating characteristic of each particular that UAM aerodrome (e.g., taller buildings on one side of the aerodrome). Guidance for addressing these limitations is established in coordination with the FAA, UAM aerodrome operators, fleet operators, and local governments based on the unique operating characteristics of each UAM aerodrome. The UAM aerodrome operating and physical environment drive the design of the associated surveillance and navigation infrastructure supporting the UAM aerodrome. Communication capabilities also vary based on UAM aerodrome size, demand, and the desires of UAM aerodrome operators.

Many UAM aerodromes have capacity for emergency landings and redundancy to support landings at alternative locations in case the primary landing areas are unavailable and immediate landing is required for safety. Capabilities to support continued operations, such as maintenance, are typically co-located at UAM aerodromes in high-demand locations.

Being integrated with local transportation services, UAM aerodromes support the public by serving as major hubs for passenger and cargo traffic by UAM aircraft. To support this high demand, UAM aerodromes may be equipped with both fast-electrical charging systems (for fully electric aircraft) and fuel (for hybrid-electric aircraft). The physical security of the UAM aerodrome is the responsibility of the UAM aerodrome operator in accordance with applicable transportation security regulations. Cybersecurity of the UAM aerodrome is also the responsibility of the UAM aerodrome operator in accordance with applicable regulations.

4.2 Individual Aircraft Management and Operations

As mentioned in Section 3.0, the Individual Aircraft Management & Operations pillar pertains to the conduct of safe and efficient flight operation of individual UAM aircraft (i.e., "ownship"), independent of the sharing the airspace and other resources with other operations. Nominally, this includes preparations for a flight, the flight itself, and post-flight operations to ready the aircraft for another operation. Within this section, this process is presented in the context of a nominal G2G operation for an individual UAM aircraft, unlike other sections in this ConOps, because this format most logically presents Individual Aircraft Management and Operations scenarios. It should be noted that the G2G format does not work well for other pillars, such as Airspace System Design and Implementation and Airspace and Fleet Operations Management, due to their inherent focus on the broader system vice an individual aircraft experience.

The exclusion of considerations relating to shared resources from section is intended to focus this element on flight operations that are independent of the details of the ATM system. From a practical perspective, efforts to separate traffic-dependent and traffic-independent considerations results in a number of ambiguities since capabilities must ultimately be integrated. For example, in the tight confines of UAM terminal area operations, the ability to detect and maneuver to avoid other traffic must be integrated with a flight path management capability that considers other constraints such as nearby obstacles. The emphasis in this section is describing the operation of a single aircraft from the perspective of what's preferred or optimal from its own perspective, as well as what is feasible and safe given outside directives or preferences, such as those received from a fleet operator.

The description of this pillar is divided into four sub-sections: Safe Urban Flight Management; Increasingly Automated Aircraft Operations; Certification and Operations Approval; and Ground Operations and Maintenance. As introduced in Section 4.2.2, there are several aircraft crew archetypes in use relative to individual aircraft operations. When relevant to a sub-section, the common and unique characteristics of different crew archetypes are described. The majority of this discussion is located in Section 4.2.2, Increasingly Automated Aircraft Operations.

4.2.1 Safe Urban Flight Management

Safe urban flight management comprises the ability to operate safely and efficiently in the UOE. Key attributes of this environment include operations from obstacle-challenged urban UAM aerodromes in low-visibility conditions; operations in wind fields that may approach aircraft operational limits and in proximity to areas where winds may exceed these limits (e.g., certain urban canyons with adverse wind patterns); high-tempo operations when utilizing key system resources (e.g., takeoff and landing area of high-utilization aerodromes); precise 3D and 4D trajectory operations; operation at close to separation minima from obstacles; and limited opportunities for emergency landings away from aerodromes and designated emergency landing sites. Each individual UAM aircraft (regardless of its aircraft crew archetype as described in Section 4.2.2) can execute a forced landing safely at an unprepared site. The responsibility of the different agents (e.g., automated systems, PIC, etc.) could be different based on different archetypes in such scenarios.

For aircraft operating as part of a fleet, aircraft receive proposed operations plans prepared by the fleet operator, which includes information such as destination, routing, and contingency plans for a standardized set of foreseen contingencies ranging from routine (e.g., diversion to alternate aerodromes) to severe (e.g., options for emergency landings along route). The operations plan is augmented with additional information specific to the individual aircraft operations and the fleet operator's business model, such as a passenger/payload manifest. Prior to accepting the operations plan, the aircraft's automated systems and aircraft crew members assess the operations plan to ensure its compatibility with aircraft's expected status at the projected time of departure. Prior to departure, the aircraft's automated systems continually assess the aircraft's actual and projected status relative to the operations plan and notifies the fleet operator if a reportable mismatch is detected. Similarly, the fleet operator monitors and maintains the operations plan with its PSU and notifies the aircraft's automated systems if any reportable updates to the operations plan are needed.

With the aircraft prepared and loaded for flight (ground preparation is described in Section 4.3.4), the aircraft's automated systems/aircraft crew notifies the fleet operator and its PSU that the operations plan is ready to be executed. Any final updates are jointly reviewed and agreed to by the aircraft's automated systems, aircraft crew, fleet operator, and PSU interfacing with the PSU Network. The aircraft's automated systems receive a clearance to begin operations from the PSU. This clearance describes the operation using a combination of time-based and sequenced-based elements.[20] In keeping with the general philosophy of the UTM-construct that emphasizes "flexibility whenever possible, structure when necessary," the flight rules and supporting clearance elements of UAM operations accommodate the preferences of individual aircraft as much as possible and impose constraints only as needed to ensure efficient utilization and scheduling of system resources (e.g., demand- and capacity-balancing) and safe separation.

As the aircraft taxis from the staging or starting area, where it received its initial clearance, to the appropriate touchdown and lift-off area (TLOA) to perform its departure takeoff, its progress is monitored relative to its clearance as well as the sensed (i.e., actual) separation from other aircraft. Maintaining separation has priority over takeoff clearance. Upon reaching the TLOA and being next for takeoff, the aircraft awaits authorization to enter the TLOA from its PSU and uses its own sensors, including any aircraft crew members, to confirm that it is safe to enter (i.e., the TLOA is unoccupied by another aircraft and there is no aircraft on short final). If other aircraft are expected to use the TLOA in the immediate future, the aircraft must be ready for takeoff before entering the TLOA. This requires that any preflight checks of aircraft and passenger readiness are performed prior to entry. As quickly as practical after occupying the TLOA, the aircraft takes off and begins the in-flight portion of its mission.

Nominally, the aircraft's automated systems have real-time connectivity with multiple entities throughout the flight. These entities include any off-board aircraft crew (if applicable), the fleet operator (e.g., an operations control center), PSU, navigational systems, UAM aerodromes, and SDSPs. These entities help UAM aircraft to safely detect and avoid hazards in the air and on the ground in nominal, off-nominal, and contingency scenarios. To assure aircraft safety in the presence of lost or degraded communication, aircraft (including the presence of an aircraft crew, if applicable) have sufficient onboard capabilities for continued safe flight and landing when partially or fully separated from the PSU Network. Depending on the circumstances, this continued safe flight and landing capability may involve emergency procedures.

Throughout the flight, the aircraft's automated systems and aircraft crew monitor the current and predicted status of the flight relative to the expectations of the operations plan, communicating any significant changes to the fleet operator. Non-emergency changes to the operations plan (e.g., a change to the destination aerodrome) are nominally requested by the fleet operator, approved by the PSU, and accepted by the aircraft's automated systems. Time-critical changes, such as activation of a precautionary landing contingency plan, may be initiated by the aircraft's automated systems with communication to the fleet operator and PSU occurring as a consequence of the plan change.

[20] The interplay between time-based elements, sequenced-based elements, and the actual readiness to act on either have an important impact on the overall capacity of the airspace and the resilience of system operations in the presence of unexpected disruptions to the operations of individual aircraft.

Although the aircraft's automated systems are largely dependent on off-board resources and connectivity for long-range, strategic awareness (e.g., greater than approximately a few minutes or miles away), the onboard resources of the aircraft, including any onboard aircraft crew, provide real-time awareness of the proximal situation as needed to assure safety of flight. This includes traffic awareness sufficient for tactical separation and interval management, along with collision avoidance from both cooperative and non-cooperative traffic. The aircraft's automated systems have the capability to sense and avoid uncharted obstacles that may be encountered in the urban area and may be assisted by any onboard crew in these sense and avoid tasks. Aircraft's automated systems share awareness of uncharted obstacles and non-cooperative traffic with their PSUs who then share with PSU Network to assist with system safety. Given the relatively short range and duration of the flights, onboard weather sensors, such as radar, are limited and potentially optional depending on the preferences of the fleet operator.

Approaching the destination UAM aerodrome, aircraft nominally fly predefined arrival and approach procedures. Compared to the terminal area operations of the 2010s, in which many different types of approach procedures could be available to a given runway (e.g., Instrument Landing System (ILS), Localizer (LOC), Area Navigation (RNAV), etc.), UAM operations are based on a single, unified, and performance-based construct for the implementation and execution of procedures. This standardization simplifies the development of aircraft automated systems and the training of any crew that may be involved in the operations.

4.2.2 Increasingly Automated Aircraft Operations

Barriers to the scalability of aircraft operations that existed in the 2010s have been partially overcome by UML-4. One such barrier was the reliance on one or more pilots onboard each aircraft who have extensive, highly specialized training and associated experience requirements. In order to support 100s of simultaneous UAM operations in a metropolitan area the requirement for specialized training and experience has been reduced or, in some cases, eliminated through carefully developed and validated systems enabling increasingly automated aircraft operations. These automated systems relieve aircraft crew members from being required to learn and retain proficiency in a wide range of functions that automation performs.

There have been a variety of differing levels of responsible automated systems deployed at UML-4. Although the industry has nearly unanimously agreed for many years that "fully" automated aircraft will not be reached until the long-term, different organizations have pursued different pathways toward this long-term goal, and these differing approaches have led to multiple concepts being operationally deployed at UML-4. However, as discussed in Section 4.1, each aircraft has a human PIC; the PIC may be onboard or off-board and may have responsibility for more than a single aircraft simultaneously.

For illustrative purposes, this subsection briefly considers three aircraft crew arrangements or archetypes that are deployed. Characterization of the aircraft crew archetypes below consists of a high-level summary of responsibilities of the 1) onboard automation, 2) any aircraft crew other than the PIC, and 3) the PIC. The archetypes are named according to the aircraft crew composition and locations: 1) onboard PIC with no additional crew, 2) single-aircraft RPIC with no additional crew, and 3) multi-aircraft RPIC with onboard SIC. The three archetypes are each assumed to be supported by similar dispatch and mission planning functionality provided by the fleet operator. A delineation of responsibilities between the various actors for these three archetypes are given in Table 4.

Table 4: Responsibility Delineations for Three Archetypes

		Responsibilities for Archetype 1: Onboard PIC with No Additional Crew		Responsibilities for Archetype 2: Single-Aircraft, RPIC with No Additional Crew		Responsibilities for Archetype 3: Multi-Aircraft RPIC with Onboard SIC		
		Automation	PIC	Automation	PIC	Automation	PIC	Additional Crew: SIC
Mission Management	Verification of operations plan from fleet operator	Primary	Secondary	Primary	Secondary	Primary	Secondary	Tertiary
Mission Management	Maintenance of “standard” contingency plans	Primary	Secondary	Primary	Secondary	Primary	Secondary	None
Mission Management	Oversight of overall mission continuation	Secondary	Primary	Secondary	Primary	Secondary	Primary	Tertiary
Flightpath Management	Monitoring of active operations plan	Primary	Secondary	Primary	Secondary	Primary	Secondary	Tertiary
Flightpath Management	Optimization of active operations plan	Primary	Secondary	Primary	Secondary	Primary	Secondary	Tertiary
Tactical Operations	Detection of tactical hazards	Primary	Secondary	Full	None	Full	None	None
Tactical Operations	Maneuver management for mitigation of tactical hazards	Secondary	Primary	Primary	Secondary	Primary	Tertiary	Secondary
Aircraft Control	Aircraft stability and trajectory control	Full	None	Full	None	Full	None	None
Aircraft Control	Subsystem management	Full	None	Full	None	Full	None	None
Passenger/Cabin Management		Limited advisory functionality, such as monitoring of seatbelt status	Full	Primary	Secondary	Limited advisory functionality, such as monitoring of seatbelt status	None	Full

Table 4 lists responsibilities for aircraft crew members for various functions that are separated into categories based on the same framework for overall flight management described previously in Section 4.1.2.3 with the addition of the passenger/cabin management function. The different aircraft crew members are assigned either primary, secondary, or tertiary responsibility as shown in the table for these various roles.

4.2.3 Certification and Operations Approval

At UML-4, methods have been developed to test and certify semiautonomous operation, and historical regulations have been adapted to certify UAM aircraft operations such that automated systems are recognized as "responsible" for the performance of designated, safety-critical functions that have traditionally been the responsibility of human agents (i.e., pilots). Within the functionality specified in the aircraft type certificate, automation designated as responsible relieves the aircraft crew from having to perform or, in some cases, even being capable of performing the specified functions. Sufficient hours under pilot supervision across a range of operations (e.g., UAM progression from UML-1 through -4, continued development of advanced automated systems in traditional commercial aircraft, maturation of UAS technologies, etc.) enable some UAM aircraft to operate safely without a pilot onboard and allow for one remote PIC to simultaneously hold responsibility for more than one aircraft (e.g., a remote pilot may monitor several aircraft in operation with other members of the aircraft crew supporting other aspects of the operation).

Maintenance processes that have been developed and FAA-certified ensure aircraft are safely maintained by qualified maintenance professionals along with collaborative and responsible automated systems. Aircraft crew and maintenance professionals receive training and certification appropriate to their responsibilities for flight safety. Certification of fleet operators occurs under the framework regulations from the late 2010s (14 C.F.R. Parts 121, 135, et al.), depending on the nature of the operation. However, these regulations have been modified through the rulemaking processes as necessary to enable UAM operations.

4.2.4 Ground Operations and Maintenance

Ground operations at UAM aerodromes are the responsibility of the UAM aerodrome operator and are coordinated with the operator's PSU to ensure takeoff/landing areas are scheduled to meet the operations plan. Ground operations include the services necessary to enable safe operation such as aircraft charging, battery swapping, cargo handling, passenger movement control, and aircraft movement control. Personnel at the aerodrome direct passengers safely to their aircraft and perform necessary exterior predeparture checks such as ensuring the pad is clear of debris. Aircraft ground traffic control (i.e., navigation from the gate at which passengers board/disembark to the area where the aircraft lifts off and vice-versa) is managed by PSU-to-PSU connection. The PSU issues clearance for takeoff based on the aircraft's scheduled departure time, actual status, and other prioritization criteria that governs operations in the UOE. For many flights, navigation in this environment is nominally automated once the aircraft crew indicates the aircraft is ready for departure.

Maintenance is critical to safe UAM operations, with many UAM aerodromes having some basic level of maintenance capability. The UAM aerodrome operator may contract with fleet operators and ground services to provide routine aircraft maintenance at the UAM aerodrome. The services provided by UAM aerodromes vary based on the UAM aerodrome size and location. Major MRO services require significant physical space and occur at facilities outside of the urban core. MRO facilities are operated by licensed aviation technicians. UAM aircraft data is streamed for Flight Operations Quality Assurance and Maintenance Operations Quality Assurance (FOQA/MOQA) services to improve flight safety. Monitoring data is sent, as needed, during flight or taxi at the departure UAM aerodrome to allow the arrival UAM aerodrome to adequately prepare for aircraft-specific needs, such as charging and maintenance (if necessary). This aircraft health monitoring also communicates with the fleet operator when predefined sensor data is outside of tolerance limits to alert the fleet operator to potential maintenance issues before they threaten aircraft operation.

4.3 Airspace and Fleet Operations Management

Airspace and fleet operations management occurs through coordination between fleet operators, PSUs, and federal and local regulators. UAM fleets are owned and operated by private industry, individuals, or public entities and follow a variety of models based on economic and operational considerations. Airspace operations are managed by both public and private PSUs according to the rules and regulations enacted by the FAA. PSUs manage airspace operations consistent with the foundational principles contained in the service oriented UTM principles as described in the FAA UTM ConOps 2.0 [21] and the FAA UAM ConOps 1.0 [22]. These will promote safety along with access, equity, and operational efficiency across the UOE environment.

4.3.1 Safe Airspace Operations

Safety of UAM is addressed from both design and operational perspectives. Section 4.1.1 discusses how safety is incorporated into the design of the airspace system and this section describes how safety is incorporated into airspace operations. Safe airspace operations are enabled through a layered approach, in which different entities play larger or smaller roles depending on if they are associated with operations themselves or the processes to refine and improve those operations.

4.3.1.1 Operations and Procedures

Actions intended to mitigate operational risks and hazards are frequently codified into rules and regulations. These include transition into and out of ATC-controlled airspace or high-density routes, aircraft separation, common procedures (e.g., lost communications) and rules (e.g., IFR and VFR). Because of the density and short duration of UAM operations, preflight strategic deconfliction and in-flight tactical deconfliction are critical to helping maintain safe airspace operations.

PSUs provide preflight strategic deconfliction. Strategic deconfliction includes planning operations to consider anticipated traffic density, aerodrome takeoff and landing capacities, forecasted weather, available emergency landing areas, as well as areas where permanent and temporary flight restrictions may be in place. This strategic deconfliction is performed with input from and in coordination with multiple participants including the FAA (e.g., NOTAMs), other PSUs, fleet operators (via operations plans), UAM aerodrome operators (e.g., available landing areas), and SDSPs (e.g., weather and other information) who all share relevant data over the PSU Network. Entities providing data to or accessing data from the PSU Network adhere to appropriate data authentication and cybersecurity standards. The data shared over the PSU Network, which includes information such as departure time, desired flight path, intended arrival destination, and alternate UAM aerodromes, is defined by industry consensus and approved by the FAA. This data covers the entire UOE and data sharing enables other fleet operators and PSUs to develop accurate operations plan routings based on traffic density and other elements.

Information from the PSU Network, detect-and-avoid (DAA) capabilities, and V2V information exchange enable tactical deconfliction and separation assurance in nominal situations, such as maintaining safe separation when following another aircraft or sequencing for landing. They also support safety during off-nominal situations such aircraft experiencing an emergency. Due to the time constraints, DAA and onboard aircraft crew (when applicable), augmented by V2V information exchange, are the primary means of collision avoidance in situations where response times need to be in seconds, such as avoiding flocks of large birds or non-cooperative aircraft.

[21] Cooperative traffic management is conducted in compliance with a set of community developed and FAA-approved Community Based Rules (CBRs).

[22] FAA, Urban Air Mobility Concept of Operations v.1.0, June 2020, https://nari.arc.nasa.gov/sites/default/files/attachments/UAM_ConOps_v1.0.pdf.

4.3.1.2 Processes

Processes exist to refine and improve operations and procedures that continually enhance the safety of UAM operations. For example, high-density routes, separation standards, management of non-cooperative aircraft, and procedures for contingency situations (e.g., lost communications) are enhanced as the system matures during UML-4 to incorporate advances in technologies, improvements in aircraft design, data management, and CNSI capabilities. Additionally, fleet operators and PSUs have implemented their own safety management systems (SMSs), which are a systematic, top-down, organization-wide approach to mitigating risks and hazards and ensuring the effectiveness of risk management controls and safety assurance techniques. A SMS includes structured procedures, practices, and policies for the management of safety risk and is continuously evolving leading to improvements in effectiveness. Each SMS is supported by In-time System-wide Safety Assurance (ISSA) capabilities, which are systems that monitor data, make assessments, and perform or inform a mitigating action. ISSA capabilities contribute to safe airspace operations through services such as constraint management, conformance and system monitoring, and systems-level predictive and prognostic hazard identification. These capabilities utilize information from the PSU Network and other information sources in the NAS, such as aircraft automated systems, FIMS, and SDSPs, to help provide in-time risk management and safety assurance. Types of information shared across the SMS and leveraged by ISSA capabilities include geospatial constraints, weather, operations plans, and known locations of air traffic.

4.3.2 Efficient Airspace Operations

Efficient airspace operations can be considered from three perspectives: the aircraft, UAM operations, and that of the urban transportation system as a whole. The benefits achieved are realized across the entire transportation system. Less time in transit benefits the UAM aircraft in energy expended, carbon dioxide emitted [23], and the opportunity for additional revenue generation; it benefits the consumer with more rapid transits.

From the aircraft operational perspective, efficiency is measured by time and energy in route, energy and time to reach and descend from cruising altitude, and the aircraft's energy expended at the cruising level. Even at UML-4, aircraft efficiency is important. Enabling efficiency relies on multiple components focusing on enabling the aircraft to perform as efficiently as possible: collaboration between the fleet operator and the PSU, the ability to strategically deconflict operations, the ability to provide tactical deconfliction, the aircraft's weather tolerance, and the flexibility of UAM aerodrome departure and arrival procedures. The fleet operator has the greatest amount of information about the aircraft performance and which factors should be prioritized to achieve their business goals. The ability of the fleet operator to convey this information to the PSU and for the PSU to translate this information into appropriate trajectories is critical to allowing aircraft to operate efficiently. The PSU utilizes information from the fleet operators and its decision support tools to provide the fleet operator with a strategically deconflicted flight operations plan incorporating fleet operator preferences balancing against ensuring equitable access and safety standards that are accepted by the FAA. The aircraft's weather tolerance will impact the operators route choices. For example, having to avoid the potential wind shear near tall buildings could lengthen a route. UAM aerodrome arrival and departure procedures at UML-4 are not all optimized across multiple aircraft configurations. Not every aircraft is able to fly its most efficient flight path and power profile into and out of aerodromes. Enabling some flexibility within these procedures allows multiple aircraft configurations to achieve a greater degree of efficiency than procedures with restrictive approach and departure angles or paths.

From a UAM operations perspective, throughput of the entire system is a measure of efficiency. The number of aircraft able to safely operate during periods of peak demand reflects the efficiency of UAM operations. Greater

[23] Note that the carbon dioxide emissions may not occur at the aircraft during flight, such as in battery-electric aircraft that produce no "tailpipe emissions," but there may be emissions at some locations (e.g., a power plant) that may be reduced with more efficient operations.

throughput is enabled by preflight strategic deconfliction, efficient in-flight tactical deconfliction, and efficient UAM aerodrome operations. Similar to aircraft efficiency, strategic deconfliction based on effective intent sharing and information exchanges between fleet operators and the PSU is a key to enabling the maximum number of aircraft to operate in the airspace. Operations along high-density routes are governed by procedures that enable preflight planning, arrival/departure sequencing, and sequencing and spacing of aircraft along the route based on the operational characteristics associated with the aircraft (e.g., airspeed, actual navigation performance, maneuverability, V2V communications capabilities, etc.). FAA-approved community-based rules (CBRs), implemented by PSUs, govern traffic flow and aircraft order for safe, efficient, and equitable access to the airspace. These procedures can be modified by the FAA as required.

Technologies like sensors and real-time PSU Network data exchange enable performance-based separation with reduced minimums when compared to the ATM separation requirements of the 2010s. Fleet operator provided data is used to allow separation based on performance characteristics, operating environment, and predeparture and in-flight deconfliction.

At UML-4, with hundreds of operations, the maximum number of UAM operations is primarily driven by UAM aerodrome capacity including the connected multimodal integration and flows. PSUs provide traffic management services to UAM aerodrome operators to support arrival and departure procedures rely on V2V and aircraft-to-infrastructure information exchange to enable greater predictability and, therefore, into and out of the terminal throughput environment. Where multiple PSUs service routes to and from a UAM aerodrome, they seamlessly coordinate and negotiate efficient traffic flow. At UML-4, this occurs via a prioritization scheme developed by CBRs and approved by FAA. Prioritization and sequencing models will have been developed based on fleet operator business models and the FAA-approved CBRs. The specifics have been informed by research into the efficiency and impartiality of a variety of methods such as “first-come, first-served,” aircraft performance-based, or based on the service being provided (e.g., emergency services, number of passengers onboard, total tie saved for operation, etc.). Process and criteria are consensus-based and consider the needs of key stakeholders (federal, state and local agencies, airspace users, public, etc.) to ensure equitable service and safe operations. The PSU-supported inflight strategic deconfliction, flow negotiation, and prioritization enable the merging of traffic from multiple high-density routes or other trajectories without holding or gaps in the traffic as well as the ability of traffic to seamlessly enter the desired trajectory.

At UML-4, UAM operations enable an additional avenue to increase the overall urban transportation system capacity. Local transportation operators will have a variety of methods to inform passengers of system status and transportation modes options to accommodate their preferences, be it subway/rail, buses, taxis, or UAM. UAM operators may coordinate with the surface multimodal transportation providers to carry passengers to/from UAM aerodromes to maximize efficiencies. This coordination can take the form of industry alliances and partnerships to leverage surface transportation ecosystems or to be accomplished via a single company vertically integrating all services.

4.3.3 Scalable Airspace Operations

At UML-4, the volume and complexity of operations exceeds the capacity of traditional ATC, and UAM aircraft utilize the PSU Network to provide automated, tactical deconfliction and manage scheduling of routes, in addition to other services. System capacity is scaled to manage demand. At peak demand, all the capabilities and functionalities of the system are operating. This would include all or most high-density routes being available, alternative landing sites being available, all charging stations are operational, and all surveillance capabilities are operating. The volume of traffic associated with the term peak is not unlimited. The UAM system is unable to accommodate the full transportation demand normally met by other means of transportation in addition to the typical UAM demand. For example, passenger demand for UAM would be increased if a major highway was closed due to an accident just prior to rush hour, but the UAM system could not accommodate all the travelers that would typically travel along that major highway. During periods on non-peak demand, capabilities and functionalities would be appropriately scaled back to meet the lower demand. During early morning hours, for example, some high-density routes would be unavailable, alternative landing sites could be undergoing maintenance, charging stations would not be drawing power, and surveillance or navigational equipment could be off or in standby. Scalability provides benefits including reduced operational costs, less wear and tear or extended life on equipment, opportunities for maintenance and repair, and the ability to shape operations to reduce the impact on local communities.

4.3.4 Resilient Airspace Operations

Resiliency in airspace operations is the ability of the system to withstand a major disruption in operations and recover within an acceptable timeframe. Looked at another way, to be resilient, the system must be able to detect (including, potentially, the ability to predict) the major disruption, respond appropriately, and then rapidly recover. Another aspect of resiliency is graceful degradation, the ability to maintain limited functionality even when portions of the system have been degraded or rendered inoperative.

At UML-4, the system has incorporated an In-Time Aviation Safety Management System (IASMS), which features monitor, assess, and mitigate functions. The monitor feature is critical as a control to detect adverse events and operations. The strategic deconfliction of operations plans is a resiliency control to detect when operations could exceed the system's capacity. This monitoring function is found throughout the UAM operations, including aircraft health-monitoring information and models, aircraft location data to ensure the aircraft is on its approved flight path, the comparison of forecast to actual weather conditions, and systems to identify and track potential non-cooperative traffic. These and many other features are offered by the PSUs, fleet and UAM aerodrome operators, and SDSPs as safety enhancement features.

Redundant systems are a means for the UAM operations to respond appropriately to disruptions as it utilizes backup systems to continue critical functions while the primary system recovers. Having the ability to seamlessly switch between multiple PSUs within an urban area, preidentified emergency landing areas, and/or backup communications also improves system resilience. Many of these systems incorporate features that utilize redundancy in order to respond appropriately to emergencies. Acceptable means of compliance incorporating redundancy have been demonstrated for meeting system performance standards.

Another aspect of redundancy is UAM being an integrated part of an urban transportation system. Should adverse weather roll in, local commuters can take another means of transportation home, and, if there is an accident on the roads or a delay in the rail system, commuters can utilize UAM. This would include ensuring passenger-carrying aircraft are given prioritization over cargo aircraft during emergency landing situations, that databases are routinely backed up, and systems are not damaged when power is restored.

Responses to disruptions can be preplanned or developed when the disruption occurs. Utilizing preplanned alternate and emergency landing sites in the event of adverse weather is an example of an appropriate preplanned response. Fleet operators and PSUs coordinating the inflight rerouting of aircraft to mitigate the impact of an unexpected UAM aerodrome closure is an example of a response initiated when the disruption occurs.

Frequently, recovery from a disruption is relatively simple and outside of the control of UAM operations (e.g., electricity is restored, or the weather system passes out of the area). However, sometimes recovery may be an involved process, such as addressing an issue identified with automated systems or rebuilding infrastructure destroyed in a hurricane. Recovery from disruptions that are not outside the control of UAM operations benefits from multiple PSUs, SDSPs, and aircraft V2V operating in the system, and commonality across multiple metropolitan areas enables a greater supply capability and thus, in certain cases, a faster recovery.

4.3.5 Fleet Management

Management of fleets is largely left to the private sector; they have developed or adopted methods and technologies for efficiently managing fleets and maximizing workforce productivity (e.g., supply chain management and automation). Fleet operators have achieved high aircraft productivity by reducing downtime and optimizing fleet management for their particular mission(s). Demand for services is predicted to help locate the fleet to where it can ultimately be as productive as possible. Means to increase the average load factor on each flight are implemented (e.g., providing reduced fares to help fill fights). Fleet management also includes the operators' ability to mitigate or recover from contingencies and off-nominal events (e.g., an aerodrome closing due to a fire). To maintain competitiveness and meet the demand of fleet operators, PSUs have adopted concepts to increase the movement of fleets through the airspace (e.g., that fleet operators will shift aircraft around, divert flights to other places, shift people to other transportation modes, etc.).

4.3.6 Urban Weather

The weather in urban environments is more challenging to characterize than weather outside the urban environment. Urban environment-induced microclimates can cause sharp changes in wind speed and directions at the scales of meters. Both modeling and measuring current conditions in these microclimates requires higher-density weather and wind measurements than commonly deployed for traditional aviation operations. To achieve an adequate degree of weather resiliency that enables reliable and cost-effective UML-4 operations, a combination of airframe and airworthiness improvements, smart siting of UAM aerodromes, and a reduction in weather and wind uncertainty (compared to the state-of-the-art in the 2010s) is required. The weather information system in UML-4 is a combination of policy, reporting on current weather conditions, forecasting future weather conditions, and information distribution and decision-making. Weather data collection, analysis, prediction, and reporting has been tailored to meet the needs of the UAM operator to operate as safely and efficiently in high density airspace operations. Arriving at this structure was the result of work across many stakeholders from across the UAM and weather ecosystems (e.g., universities' offering degrees and research focused on aviation and urban meteorology).

4.3.6.1 Weather Policy and Regulations

The weather policy has evolved from requiring the fleet operator or pilot to be responsible for the quality of the weather information to one in which the requirement for quality is placed upon the data through the performance-based standards discussed in Section 4.3.6.3. The fleet operator is still responsible for becoming familiar with all available information concerning the flight, but at UML-4, standards have been updated or created for weather data performance, third-party service providers, and weather data interface standards. Fleet operators and aircraft crew are still required to be capable of recognizing hazardous weather situations and implementing appropriate actions or operating in hazardous weather in case of emergency.

Determining the parameters for defining hazardous weather is a process of continuous refinement between the aircraft manufacturers, fleet operators, UAM aerodrome operators, entities providing weather services, and the FAA. Aircraft manufacturers provide the aircraft operating envelope (e.g., control authority in crosswinds). The fleet operator provides envelopes for desired passenger comfort (e.g., acceptable rates of sudden descent). The UAM aerodrome operator specifies conditions that would require the closing of one or more of the landing/takeoff locations (e.g., dangerous building wake turbulence conditions). Weather service providers disseminate notifications of current and/or forecast hazardous weather informed by the FAA weather-related safety requirements along with decision-support tools (DSTs) utilizing this weather information to inform the fleet operators and UAM aerodrome operators when these parameters are met or exceeded. The process continues as aircraft capabilities improve, passengers become more seasoned, and weather forecasting and DSTs become more refined.

4.3.6.2 Weather Data Collection

Part of creating the UML-4 common weather operating picture is the collection of current weather information. As mentioned above, urban environments are challenging because manmade structures can create sudden changes in wind speed and direction both around buildings and as a result of thermal updrafts over dark surfaces, such as parking lots, and thermal downdrafts over cooler surfaces, such as parks. While urban environments are typically a few degrees warmer than rural locations, they still are subject to the weather of the local region that, along with manmade structures, can make aspects of ensuring adequate coverage a problem that is unique to each city. Solving this challenge in weather data collection required balancing the need for greater granularity of weather observations, at a microclimate scale, with the cost of taking those observations.

At UML-4, observations are taken using a layered approach with multiple types of sensors and sources. Three of the layers are described here. There are fixed, specialized weather-sensing infrastructure, weather data being generated by sensors aboard sUAS and UAM aircraft weather data identified by innovative thinkers utilizing sources such as traffic cameras and other cameras, car temperature sensors, and home weather systems. The fixed-sensing infrastructure is designed with several features not available in the other two. It is required to have greater redundancy, and it is scalable, so it is able to provide adequate data when aircraft are not flying as frequently (e.g., early morning hours or during unpredictable weather) while still being affordable. It is also installed to accommodate areas where a finer granularity of data is needed to such as near UAM aerodromes, in high-density routes and around high rises.

4.3.6.3 Weather Data

Weather data meeting performance standards, collected from sensors described above, is available for all users, including non-UAM users such as local departments of transportation and research entities. Utilizing performance standards for the data is a shift from the previous paradigm of certifying sensors to ensure that the data produced met specific specifications. This reduced the cost of sensors and enabled the innovative use of sensors and technologies to collect weather data. While local data sources across the country have a similar structure based on weather data interface standards, the funding model for the maintenance of this data varies across entities participating in UAM operations. While one city could have a publicly funded financial model, another could operate on a “credit system” with entities earning credits for contributing data (e.g., aircraft and aerodrome operators) and expending credits for selling products based on data downloaded from the system.

In addition to the data performance standards and data being correlated with its generating sensor, methods have been developed to continually monitor the data to identify potentially malfunctioning sensors or other issues that would impact the data’s accuracy.

4.3.6.4 Weather Modeling and Forecasting

At UML-4, new forecasting models have been developed. These models were possible because of the availability of data to validate the models, access to high-end computing (HEC) capabilities, and the contributions of the National Weather Service (NWS) and academic entities such as the National Center for Atmospheric Research (NCAR). Like the process to continually assess aircraft capabilities against potential hazards, forecasting models will continually improve as data sensors get better, HEC becomes better and more accessible, and because of research breakthroughs.

4.3.6.5 Weather Supplemental Data Service Providers (SDSPs)

Weather information is provided to UAM users as an additional service provided by a PSU, by a SDSP, or downloaded directly from where the local data is stored. Weather data utilized here is no longer "raw" data, it has been analyzed and likely formatted to best meet the users' needs. It is frequently associated with DSTs. Weather information at UML-4 is categorized to differentiate between required and enhancing. Required data would be needed to meet weather-related standards. The kinds of required data would include weather information necessary for the safety of flight (e.g., winds that could exceed aircraft operating capabilities) and hazardous weather information. Enhancing weather information could be incorporated with DSTs to recommend energy efficient aircraft routing or alerts to commuters of weather impacts that could impact either their trip to or from work. Another example of a DST would be to utilize the impact of weather conditions on sound to plan the route of an aircraft to remain within or below noise ordinances. Enhanced weather services are typically "fee-for-service" with a portion of the fees utilized to enhance data collection sensors and or DSTs and thus remain competitive with other weather service providers.

4.4 Aircraft Development and Production

UAM aircraft designs and technologies are developed and evaluated for safety, operational suitability, and environmental impact (e.g., noise and emissions). Manufacturers design, obtain certification for, and produce airworthy, mission-capable aircraft. Safety considerations are incorporated into the UAM aircraft design process. The regulatory framework has adapted from where it stood in the late 2010s to include UAM aircraft: previously existing regulations were modified to be performance-based and new means of compliance were developed and adopted that align with UAM aircraft and technologies.

There are many factors that are considered with respect to Aircraft Development & Production. For example: cabins are designed for passenger protection and provide acceptable levels of comfort and convenience for the anticipated duration of UAM flights; aircraft are developed that produce acceptable levels of noise adherent to noise standards and ordinances; aircraft are developed that can operate in all weather conditions required and supported by the mission; the design of the aircraft is closely linked with the manufacturing process, to enable the scaled aircraft production required for UML-4 operations.

4.4.1 Aircraft Design and Integration

The convergence of electrified propulsion systems, lightweight structures, and other advanced technologies enable aircraft to be designed that are tailored for UAM missions. These aircraft configurations and structures have been proven sufficiently reliable and survivable to enable safe operations in dense urban areas with passengers onboard. These advances have allowed for the design of aircraft with lower operational costs than possible in the 2010s that meet or exceed current safety standards. New standards exist for the testing and certification of these new technologies.

At UML-4, integrated, multidisciplinary design philosophies, including the integration of aerodynamics, propulsion, aircraft structures, and control systems, deliver improved performance and efficiency over previous aircraft. Fast, high-fidelity design and analysis tools support advanced aircraft designs that address UAM-related challenges. These approaches and techniques allow for more rapid update of aircraft and subsystems (e.g., engines/motors, batteries, interiors) based on technology advances, consumer preferences, and market pressures.

Advanced design, development approaches and techniques, and the adapted regulatory framework enable a wider variety of aircraft configurations to be designed for specific use cases or operating locations. For example, the performance requirements for aircraft in some regions or metropolitan areas may be different than others (e.g., vertical takeoff requirements in some localities with short runways feasible in others, cities at significantly different altitudes). Historical aircraft fuel reserve requirements have been modified to account for the short distance of UAM flights.

UAM aircraft design accounts for the unique considerations of flight at low altitude over densely populated urban areas. These design considerations include elimination of EMI and radio frequency interference (RFI) between onboard and off-board systems (e.g., cellular networks, and other radio frequency (RF)-emitting devices in urban areas including Wi-Fi routers). Additionally, buildings, terrain, trees, etc., all cause more variation in winds at low altitudes and thermals from places such as parking lots. UAM aircraft are designed to maintain sufficient control authority and acceptable ride quality through low-level turbulence.

New testing and verification approaches support cost-effective and rapid aircraft modification at high levels of safety. Validated tool sets supported by high-speed computing and advanced automation in design and testing have accelerated development cycles and brought the most promising concepts to market more quickly and more efficiently than was possible in the 2010s.

4.4.2 Airworthiness Standards and Certification

The regulatory framework has been enhanced to allow for the expeditious certification of multiple UAM aircraft configurations. Airworthiness standards for UAM aircraft are built on the Part 21 regulatory framework that was developed for manned aircraft. Depending on the combination of aircraft configuration and technologies utilized, existing certification standards are utilized, modified, or adapted for use. Where needed, additional standards for UAM aircraft have been developed to incorporate the unique elements of UAM operations (e.g., semiautonomous operation, advanced avionics software, distributed electric propulsion, and interoperability with the UOE). Certification tools, techniques, and processes have been adapted or developed for new technologies, materials, and aircraft. Approaches for aircraft and component certification, their components, and technologies have kept pace with accelerating technology development and UAM production while maintaining or improving safety levels as of the 2010s.

In some cases, standards that were developed for manned aircraft had been modified to account for the nature of UAM aircraft manufacturing. For example, rather than freeze the configuration, there may be ways for the process to be more adaptable so that manufacturers can certify as they build. New testing and certification standards and approaches leverage industry-developed standards and, to the extent possible, are harmonized internationally so that aircraft certification and flight operations are not cost-prohibitive to achieve globally and to support trusted and verifiable global production and supply.

4.4.3 Aircraft Noise

UAM aircraft are designed to produce noise levels that are acceptable to the communities in which they operate, at levels of only slightly above that of ambient urban noise. Aircraft noise is addressed primarily through advanced aircraft designs and the incorporation of noise-reduction technologies such as distributed electric propulsion and low-noise rotors. Community noise is measured and considered in the context of a fleet in addition to a single aircraft. Noise standards at UML-4 dictate lower acceptable noise as compared to those utilized at UML-1, -2, and -3 due to improved aircraft designs and operational procedures.

4.4.4 Weather-Tolerant Aircraft

UAM aircraft can operate in the weather and climate conditions they experience in the urban environment such as turbulence due to thermal heating/cooling or wind shear due to obstacles. UAM aircraft are designed for the geographies in which they operate (e.g., Denver’s altitude, Phoenix’s temperatures, Chicago’s wind speeds). Each aircraft type is designed with performance capabilities commensurate with the conditions expected in the locations in which the aircraft is desired to operate.

4.4.5 Cabin Acceptability

Aircraft cabins are designed to provide high levels of safety for passengers and cargo in both nominal operations and off-nominal and contingency events. This encompasses seat belts that are both effective and simple to use and, ergonomically designed spaces that reduce accidents and injuries. Aircraft are designed with integrated crashworthiness principles.[24] Airframe structural designs and other safety technologies (e.g., energy-absorbing seats) support occupant survivability in crash landings.

Passenger comfort considerations, such as cabin noise and vibrations, are also critical for cabin acceptability. Aircraft are designed so that necessary maneuvers do not provide significant adverse impact to passenger comfort. For example, they will minimize cabin vibration and noise, provide effective climate control, and assure passenger safety and to minimize discomfort during turbulence. Cabins are developed based on extensive consumer research and testing to develop strong understanding of metrics for passenger acceptance (e.g., ambient noise, natural and powered illumination, vibration, temperature, seating acceptability, and ride quality). Designs also account for safe and efficient access to the cabin by passengers, including children and persons with disabilities. Cabin designs support communication between passengers by reducing ambient noise (e.g., through active noise cancellation) and/or providing headsets, and cabins generally support other conveniences, such as personal communication devices and room for luggage.

4.4.6 Manufacturing

UAM aircraft are manufactured with advanced manufacturing techniques (e.g., additive manufacturing) that combine practices and processes developed across the automotive, aerospace, and other industries. Innovation in manufacturing is a key element of keeping aircraft costs low.

Approved manufacturing processes are supported by integrated design, modular configurations and kits[25], advanced materials, and other advanced manufacturing techniques. Manufacturing techniques are capable of scaling to supply to the quantity of aircraft required at UML-4, are flexible enough to deliver different aircraft configurations needed for different operational environments and can adapt to rapid innovation.

Techniques of non-destructive examination and testing are applied for efficient, cost-effective manufacturing to consistently deliver high levels of quality throughout the manufacturing process. Engineering simulation technology helps to identify potential failure points and test them extensively. These techniques are applied across the UAM aircraft and aircraft subsystem development process, as well as to aircraft system integration. Together, these aircraft design and integration techniques accelerate design, development, production, and safe introduction of UAM aircraft into the NAS. These technologies, accompanied by effective security risk management frameworks, tools, and standards protect the manufacturing of aircraft against a range of security threats (cyber and physical).

[24] T. Edwards, "NASA eVTOL Passenger Experience Final Report" (NASA Report Number HQ-E-DAA-TN70962), NASA, June 26, 2019, https://ntrs.nasa.gov/citations/20190028296.

[25] Given the size of UAM aircraft and advanced design and manufacturing capabilities, they could be configured on the flight line for inclement weather and to support longer trips with special range kits (e.g., trade out seats for power, additional propulsion, wing extensions, etc.).

4.4.7 Supply Chains

Mature supply chains, including secure digital processes to track parts and ensure authenticity and traceability, and enable rapid ordering and receipt of parts. Approaches for supply chain qualification are developed to keep pace with levels of production required for UAM aircraft manufacturing and maintenance.

Safety-critical and sensitive aerospace components subject to strict quality and authenticity standards are verified via secure electronic processes for tracking and authentication. Secure processes improve efficiency and traceability throughout the supply chain and deliver higher levels of assurance that parts are authentic and approved.

Supply chains have matured to support hundreds of UAM aircraft operating in metropolitan areas by leveraging approaches from the automotive and other industries while ensuring the levels of security and safety needed for air travel. For example, supply chains have less dependency on single suppliers, with greater diversity of manufacturers and distributors of parts and materials. Close integration among the OEMs, fleet operators, and component manufacturers allows for optimized supply chain management, manufacturing, and cost control.

4.5 Community Integration

At UML-4, UAM is part of a multimodal, metropolitan transportation system. Community considerations resulting from engagement with a broad spectrum of stakeholders have been integrated into the system for existing and future UML-6 operations. Within each metropolitan area, fleet operators, UAM aerodrome operators, and city planners have developed and begun implementing a comprehensive strategy for addressing community integration concerns. Supporting infrastructure and utilities required for UML-4 UAM operations into metropolitan areas have been developed (e.g., UAM aerodromes, CNSI, and energy infrastructure) and are an integrated part of the local power grid. There are multiple ownership and operation models for the supporting infrastructure, including public, private, and various forms of public-private partnerships, depending on the metropolitan area, local political leadership, operators' business models, and other relevant stakeholders' goals. Although UAM operations are tailored to the specific needs of each metropolitan area, commonalities such as UAM aerodrome design guidelines and high-power electric charging stations are the result of collaboration among federal regulators, the UAM community, and standards organizations. These commonalities enable the efficiencies associated with large-scale implementation.

This near-seamless integration of UAM into metropolitan life at UML-4 is the careful result of overcoming four key barriers with respect to community integration: obtaining public acceptance, including safety, public benefit, and environmental/community concerns; supporting infrastructure, including utilities, data networks, and UAM aerodromes; operational integration, including UAM aerodrome location, safety and security of passengers and cargo, and resilience of the transportation network; and local regulatory environment and liability.

4.5.1 Public Acceptance

A profitable UAM market relies on public acceptance of where the aircraft operate. Public acceptance is significantly influenced by demonstrated safety as well as the balance of many factors, including public benefit (e.g., increased travel options, increased local economic activity, more rapid emergency response, etc.), and environmental and community concerns (e.g., noise, air quality, and privacy). Addressing and achieving these facets of public acceptance requires effective engagement between the UAM industry, regulators, and the community. Efforts to promote public acceptance began well before UML-4 and will continue through UML-6. By UML-4, successful UAM operators have developed effective community engagement plans that provide mechanisms for feedback from the general public. These may include public meetings, feedback surveys, familiarization seminars, and other means to receive feedback from the community on needs and concerns and this feedback is then utilized to address concerns and continue the public's acceptance of UAM operation in their locality.

Safety
Demonstrations to the public that UAM is safe and capable of being a trusted mode of transportation took time and effort from many in the public and private spheres. Through effective and transparent oversight and regulation, regulators at all levels (from local to federal) established a strong foundation of positive public perception. Additionally, successful, thorough testing and pilot programs conducted by the government and industry along with the successful deployment of UAM aircraft and PSUs in low density operations that occurred in UML-1 through -3 have enabled the public to now generally view UAM as safe. The UAM industry has built confidence in the UAM system and gained market share in the overall transportation ecosystem by complying with regulations and being proactive in the identification of hazards and their safe resolution.

Although UAM operations have always had the goal of zero accidents, initial operations began with analysis that indicated operations could maintain a level of safety equivalent to or better than that required for passenger-carrying on-demand charter (Part 135) operations. The industry recognizes that the public perception of safety is not always the same as a statistical level of safety. Consequently, a collaborative process among the FAA, aircraft manufacturers, UAM operators, and the communities has been established. This continually evaluates the safety requirements especially when there are increases in operational complexity, the number of operations, and/or risks to people and property uninvolved in the operations. These earlier actions are what establish public confidence in UAM necessary to sustain a market where hundreds of simultaneous operations can occur in single metropolitan area.

Public Benefit
At UML-4, the public benefit of UAM has been firmly established through demonstration of multiple successful business cases. These include practical, positive impacts on local economies and in individuals' daily lives such as time-saving emergency responder, limited air shuttles, and cargo operations.

Employment by UAM manufacturers, operators, PSUs, SDSPs, and other elements of the UAM ecosystem create a mix of technical and non-technical jobs throughout the nation, including in urban, suburban, and rural communities (such as manufacturing and MRO facilities). Along with job-creation directly related to UAM, UAM has spurred economic growth and created additional jobs in the areas directly served by UAM such as a shops or restaurants that choose to open near a busy urban UAM aerodrome or through providing consumers access to town-center developments outside of the urban core bringing additional spending to outlying communities. Jobs related to the support of UAM such as maintenance facilities has brought additional jobs to areas outside of the urban core, including suburban and rural communities. Improved transportation options enabled by UAM increased economic activity include spurring business development in locations near UAM operational and maintenance hubs, and corresponding tax revenues. Reduced transit times enabled by UAM allow commuters to travel further and faster than ever before, yielding individual productivity and quality-of-life increases.

Environmental and Community Concerns
At UML-4, technologies and operational techniques have evolved to address environmental and community concerns. In conjunction with societal changes, such as increased telecommuting and electric surface vehicles, low-emission UAM technologies, such as high-efficiency aircraft with distributed electric propulsion, drive toward a net effect of lower carbon emissions in UAM markets with little noise pollution. Effective federal, local, and state efforts to engage communities (local communities, business communities, other stakeholders) consider and, where appropriate, mitigate concerns associated with the implementation and operation of UAM. Continued advancements in technology, operational procedures, and engagement techniques more effectively balance local

community concerns with broader societal benefits of UAM, including limited noise pollution from UAM operations.

At UML-4, federal regulators have established aircraft and fleet noise and emissions standards consistent with international norms and day-to-day operations are managed to address local noise and emissions concerns. Federal, state, and local environmental regulations establish a broad range of environmental and community requirements (e.g., the National Environmental Policy Act (NEPA), Clean Water Act, Clean Air Act, etc.). Public and private entities have developed processes to enable UAM operations in compliance with established regulations. These include effective community engagement and approaches developed over time through earlier UMLs. Levels of emissions for non-electric and hybrid-electric UAM aircraft have been iteratively developed to be compliant with state, local, and federal regulations. Continued collaboration between industry, federal, state, and local stakeholders inform operational techniques (flight routes, operational procedures, terminal procedures, and temporal modifications, etc.) to address localized concerns, such as limiting flight at night to reduce community noise or limiting emissions-producing aircraft operations.

Other adverse effects that need to be limited in the interest of community integration include privacy concerns and visual impacts. Mitigating privacy concerns related to UAM (e.g., low-flying aircraft that could discreetly surveil people and property) occurs through effective community engagement and mandated privacy policies for UAM aircraft, extending policies developed for UAS in the late 2010s. Communities have concerns about the visual impacts of UAM operations as well. Communities will have worked, and will continue to work, with local, state, and federal regulators within the established environmental framework to ensure compliance with evolving standards and reflect community desires.

4.5.2 Supporting Infrastructure

Supporting infrastructure in metropolitan areas includes utilities infrastructure (e.g., energy generation, distribution, and storage), data collection and dissemination networks (to support reliable CNSI), and UAM aerodromes. The physical supporting infrastructure ranges from public to privately owned bringing additional community concerns, including land use, ground traffic management, utility infrastructure, noise, data access, and integration with existing operations. UAM implementation has leveraged initiatives focused on city-wide & smart building operating systems and services, such as the Global Cities Technology Challenge (GCTC).[26] Although UAM aerodrome infrastructure operational needs were explained in Section 4.3.4, this passage focuses on the community integration concerns related to UAM aerodromes and other infrastructural requirements.

Utilities

With the proliferation of eVTOL and hVTOL aircraft use in UAM, operations at UML-4 place a significant demand on the utilities, including the energy infrastructure, of urban areas. Fleet operators and/or UAM aerodromes operators coordinate with municipalities and utility companies to ensure sufficient power is available for aircraft changing operations, and, although historically not provided by utility companies, coordinate with fuel suppliers (which could be utility companies) to ensure fuel is available at UAM aerodromes utilized by hVTOL aircraft. Innovative partnership models between UAM aerodrome operators, fleet operators, and utility companies have developed to offer benefits that extend beyond UAM, such as satisfying energy needs in other areas, (e.g., automobile charging stations) and incorporate alternative energy sources (e.g., solar/wind power collectors to both diversify the grid but to increase its resilience). Municipalities, operators, and utility companies cooperatively determine how much infrastructure investment is required to sustain a UAM market and will decide who bears the

[26] GCTC Smart Buildings Super Cluster, Smart Building Super Cluster Blueprint: Smart Buildings: A Foundation for Safe, Healthy & Resilient Cities, pp. 1–3, August 2020, https://pages.nist.gov/GCTC/uploads/blueprints/2020-SBSC-blueprint.pdf.

costs of improvements. In addition to electricity, at UML-4, it is assumed that other standard utilities (such as water, sewer, internet) are available at UAM aerodromes.

UAM Aerodromes

UAM Aerodromes at UML-4 are integrated with the existing infrastructure and, in many cases, required buildout of additional infrastructure. UAM aerodrome operators continue to build upon the effective relationships established at earlier UMLs to create appropriate infrastructure by both modifying existing structures and developing new, purpose-built structures. UAM aircraft utilize both preexisting UAM aerodromes (e.g., heliports, small airports) as well as UAM aerodromes that were specifically built for UAM purposes. UAM aerodromes may be publicly available to all, limited to one fleet operator or several specific fleet operators only, or limited to aircraft that meet certain performance standards. The nature of each depends on several factors, including ownership, business case, recharging/refueling infrastructure, consumer demand, type of operations at the UAM aerodrome, and airspace complexity. Passenger demand is a critical factor for determining suitable UAM aerodrome locations and influences infrastructure requirements. UAM aerodromes have been designed and built with scalability in mind for each location suited for the communities they serve. Collaboration with municipalities during development ensures community concerns are addressed, and communities are able to effectively control growth of the UAM market via local policies such as zoning regulations and noise ordinances.

4.5.3 Operational Integration

At UML-4, operational integration involves incorporating UAM into a multimodal transportation experience for passengers. This multimodal integration required addressing many operations-related community impacts, including UAM aerodrome locations and designs, passenger/cargo security and protection from malicious use of aircraft or denial of service attacks, and resilience of the transportation ecosystem in reaction to disruption of a mode within the ecosystem.

UAM Aerodrome Location

UAM aerodromes are key elements of enabling seamless operational integration of UAM into localities. Some aspects of UAM aerodrome design were covered previously in Sections 4.3.4 and 4.5.2, but there are many additional, integration-related issues that must be considered.

Locations of UAM aerodromes are strategic so that passengers can smoothly integrate with the broader metropolitan area transportation system. Wise UAM aerodrome placement creates opportunities to integrate UAM into other systems and technologies, such as public transportation (e.g., light rail), sharing economy modes (e.g., bike-sharing), or private modes (e.g., personal car). Strategic placement also prevents overloading the capacity of the other modes to which UAM connects. For example, placing a UAM aerodrome in an already overcrowded intersection with no additional space for passenger pickup/drop-off would create additional traffic congestion, which would hinder the potential time savings of the UAM mode, and should therefore be avoided. Strategic UAM aerodrome placement can also enable other infrastructure to provide mutual support for UAM and other transportation options, such as parking garages that can serve both a light rail station and a co-located with a UAM aerodrome.

Safety and Security of UAM Passengers, Cargo, and Aircraft

Safety and security are a key part of operational integration. UAM aircraft largely operate relying on automated and networked systems, and there are unique safety and security challenges, particularly with respect to cybersecurity. UAM aircraft rely on various automated systems which opens vulnerabilities. Systems are adaptable so that if a portion of a fleet cannot operate due to a cybersecurity event, such as a denial of service attack, there are ways for passengers to reach their intended destinations. Importantly, safety and security measures are designed so that the inability to use UAM as a transportation mode does not negatively impact other modes of transportation, such as creating excessive traffic.

Safety and security at UAM aerodromes are also key to operational integration. UAM aerodromes are designed and built with safety and security infrastructure in place so trusted travelers can move through the system with ease, passenger's safety is ensured, and bad actors are prevented from doing harm. Access is limited both for passenger waiting areas and for access to the physical aircraft. Passenger and cargo screening are expeditious, as long wait times would detract from the value of UAM being a time-saving mode of transportation. UAM is a popular mode of transporting people to larger airports, so some UAM aerodromes may be outfitted with Transportation Security Administration (TSA) security so that passengers can be cleared for boarding their flight prior to reaching the airport.

Resilience of the Transportation Ecosystem
The overall metropolitan area transportation ecosystem is adaptable, and mitigation strategies are in place to account for service disruptions on any particular mode, including UAM. As more individuals have shifted to shared transportation modalities (e.g., share automated [ground] vehicles), strategies like dynamic pricing help incentivize riders to pool with others for their trips, which effectively increases the capacity of transportation modes. Furthermore, continued information technology advancements have improved telepresence capabilities. These capabilities provide a virtual alternative to physical travel in some cases and enable individuals to change the time at which they travel more easily, which helps mitigate congestion across all transportation modes.

The addition of UAM as another accessible mode of transportation increases overall transportation network's resiliency. In a transportation ecosystem that includes UAM, when another mode of transportation is disabled, UAM is available to provide transportation for some of the impacted trips, alleviating congestion and delay. For example, if a major interstate through the heart of a major metropolitan area is forced to close (e.g., due to an accident or a bridge failure), the entire automotive transportation mode will experience widespread impacts in the area reaching far beyond that single, directly impacted roadway. However, with UAM, travelers have another option to select for travel, which can not only allow those individuals to reach their destinations more quickly, but also help reduce the delay in the automotive mode. As another example, consider when a thunderstorm system moves through town, shutting down UAM as a transportation mode. Because UAM is well-integrated into the transportation network, and because of the co-location of UAM aerodromes with other transportation methods, passengers who intended to travel by UAM will have other methods of transport available. Just as UAM can help alleviate the overburdening of other modes of transportation, city planners also take into consideration the impact of UAM activity and how the loss of the UAM mode impacts other modes of transportation. This planning and any associated resulting actions, such as incentivizing certain forms of transportation to effectively distribute travelers, enabling other modes to avoid oversaturation from the increase in passengers when there is a disruption in the UAM mode.

4.5.4 Regulatory Environment and Liability

The legal and regulatory framework for UAM incorporates the roles and authorities of federal agencies, state governments, local/city/municipal governments, and case law. The FAA is the primary federal regulator of UAM operations as it is responsible for regulating aviation safety. Other federal agencies work in conjunction with the FAA to regulate portions of the overall UAM system that fall within their purview, such as the Federal Communications Commission (FCC) regulating the aviation-protected spectrum band or the Environmental Protection Agency (EPA) for emissions.

Because UAM operations occur so close to where people live and work, there is much community interest in controlling a number of aspects of UAM, including UAM aerodrome location, community noise, operational limitations such as curfews, operations path planning, and other major concerns. Localities are permitted to develop their own ordinances, but ordinances that conflict with federal law or interfere with an exclusive area of regulation belonging to a federal agency (e.g., navigable airspace in the United States is exclusively regulated by the FAA) are preempted. Localities can have ordinances that address issues not preempted by federal law, so local ordinances impacting UAM typically cover topics that regulate the nature of use including zoning, noise, and privacy. Local regulators are also able to control development of a UAM market through mechanisms such as business licensing and safety inspections (such as those performed by a fire marshal).

As result of the new paradigm created by UAM operations, including the scale and frequency of operations, the FAA and industry have created forums and processes to engage state and local leaders to an even greater extent than they did in the 2010s. At that time, the existing regulatory framework to create or modify laws and ordinances (e.g., public hearings, planning boards, etc.) was utilized to codify the state and local requirements for UAM operations. Communities have maintained their authority to approve the location of ground infrastructure (e.g., UAM aerodromes, weather sensors, data towers) through mechanisms such as zoning ordinances and business permitting processes.

Like in the 2010s, the legal and regulatory framework for UAM operations includes legal liability statutes. These liability statues have been interpreted and refined through case law over the years of early UAM operations to UML-4 and through other applications that utilize related technologies, such as the self-driving car industry. Other aspects of the legal and regulatory framework, including the roles and authority of all levels of government (i.e., local, state, and federal), have also stabilized over time through a mix of efforts on the part of the UAM stakeholder group to coordinate standard laws and ordinances in states and localities across the US, as well as through litigation and case law. Specifically, unique aspects of UAM operations (e.g., the qualification of PSUs by the FAA) required a review of the statutes of the late 2010s to address aspects not covered.

Laws and other means to assign liability remain based on liability principles that apply to common carriers.[27] Consistent with these principles, UAM operations owe their passengers the highest degree of care.[28] Statutes impacting liability may be updated or refined to address the utilization of semiautonomous systems.

[27] FAA, Advisory Circular No. 120-12A, "Private Carriage Versus Common Carriage of Persons or Property," April 25, 1986, https://www.faa.gov/documentLibrary/media/Advisory_Circular/AC%20120-12A.pdf.
[28] Supreme Court of California, "Acosta v. Southern Cal. Rapid Transit Dist.," 2 Cal. 3d 19, 27, February 18, 1970.

5.0 Path Forward

The purpose of a ConOps document is to define how a system should operate from the user's perspective. For UAM operations, this document provides a vision for a coherent operations framework derived through community consensus and depicts the roles of the key stakeholders. Operational UAM services are expected to emerge as private industry and government interactively and collaboratively mature and implement the concepts described in this document. Thus, this ConOps is a first step to enable the goal of routine UAM service in and around urban areas.

Moving forward, it is envisioned that there are two parallel workstreams that will need to occur if these goals are to be realized. The first workstream would be to continue the maturation of an integrated ConOps for UAM, while the second would be to begin to use this coherent framework to derive requirements for areas such as implementation of hardware elements as well as policy and regulations to govern safe operations of a new transportation mode.

Because of the complexity of UAM operations with many industry and government stakeholders, it was imperative for the ConOps development team to work collaboratively with all stakeholders throughout the development of this document. Indeed, it would not have been possible to development this document without the active participation of the community. The ConOps development team is grateful for the support of the dozens of stakeholders who participated throughout this process. Without the continuous community input, a document of this breadth and complexity would not have been possible to produce.

Appendices

The flowing appendices transform the concepts in this document into their real-world tangible roles, responsibilities, operations, communications pathways, and situations. The appendices lay out the cross-cutting barriers, the major ecosystem stakeholders' roles and responsibilities, how nominal operations are envisioned to occur, and how stress may test the robustness of these concepts through a series of contingency and off-nominal scenarios. Although not exhaustive, these use cases paint the picture of how the operation is envisioned to occur and the series of events that will take place. With the complexity of operations, advancement in technology, and mix of operations, it is important to identify whom is doing what and when. Furthermore, these appendices contain useful reference information including an acronyms list, glossary, list of concept and document contributing stakeholders, and a bibliography of references used for the creation of the UAM concepts and ConOps.

Though several of these appendixes are standalone, Appendixes B through D build on the previous appendix by adding fidelity and complexity. They are organized as follows:

- **Appendix A**: Cross-Cutting Barriers
- **Appendix B**: Roles and Responsibilities
- **Appendix C**: Gate-to-Gate Operations
- **Appendix D**: Use Cases
  - Contingency Scenarios
  - Off-nominal Scenarios
- **Appendix E**: Acronyms List
- **Appendix F**: Glossary
- **Appendix G:** Contributing Stakeholders
- **Appendix H:** Bibliography

As stated previously, this document is a living document and these appendices will continue to be refined as the UAM concept matures. This living ConOps will be updated to reflect the latest research results, business models, and regulatory updates.

Appendix A: Cross-Cutting Barriers

Along with the barriers specific to each pillar, NASA has identified seven cross-cutting barriers. The barriers are safety, security, affordability, noise, automation, UAM aerodromes, and regulations/certification.

Each of these cross-cutting barriers transcends individual pillars and represents a major challenge to UAM integration that transcends individual pillars. The cross-cutting barriers highlight the need for integration of activities across the pillars to achieve the UAM vision. The cross-cutting barriers also provide a construct to group activity from each pillar to identify areas where pillars align and where there are interdependencies.

In the tables below, you will see statements that were made throughout this ConOps grouped by their best-aligned cross-cutting barrier. From these tables you can see how different integration activities from different pillars align to the same overarching goal.

A.1 Safety

The NAS is arguably the largest, most complex, and safest aviation system in the world. Because UAM operations are a component of NAS operations, it is expected that UAM operations are at least as safe as, if not safer than, those in other portions of the NAS. Safety metrics for UAM are as challenging to determine as those for the NAS and are still evolving in UML-4.

Safety of the NAS and UAM can be considered from a number of perspectives. For this UAM ConOps, the consideration of safety is from the design perspective, as reflected in pillars 1 and 4, and from the operations perspective as discussed in pillars 2 and 3. Design is considered to include activities that occur prior to flight (e.g., certification of aircrafts, validation and verification of automated systems, qualification of PSUs, and CBRs for equitable access). Operations include activities during flight (e.g., safe operation of an aircraft, an aircraft's adherence to an operations plan, the opening and closing of portions of the airspace or the selection of specific active approach or departure routes to an aerodrome).

If systems do not meet the minimum, publicly acceptable levels of safety, passengers will not utilize them, regulators will not approve them, and they will pose a hazard to those uninvolved in the operation. Safety management and assurance needs to occur through proven effective safety management techniques that are utilized today and can be adapted to incorporate the unique qualities of UAM along with innovative safety concepts such as IASMS and ISSA.

Below are the integration activities from each pillar that are aligned with safety:

Table A1: Safety Cross-Cutting Barriers

Pillar	Integration Activity
Aircraft Development and Production	• UAM aircraft designs and technologies have been developed and evaluated for safety, redundancy, risk, operational suitability, and environmental impact (e.g., noise and emissions). • Safety engineering is incorporated into the UAM aircraft design process. • UAM aircraft are designed for safety and availability for the characteristics of the local markets in which they operate (e.g., geographic locations [such as Denver], temperature extremes, rapid wind speed and directional changes, and significant microclimate turbulence zones). • At UML-4, the community, through the National Campaign and FAA leadership, has established an acceptable level of safety for UAM operations. The UAM system has not only met this level of safety but also will continue to improve over time, just as the commercial airline fleet has done historically. • Cabins are safe for passengers and cargo and designed to maximize passenger safety with integrated crashworthiness principals.

Pillar	Integration Activity
	— Designs also account for safe and efficient access to the cabin by passengers—including children and persons with disabilities. • Beyond passenger comfort, cabins are designed to provide the highest possible levels of safety for both nominal and off-nominal events. • Supply chain characteristics are similar to the automotive industry while assuring the levels of security and safety needed for air travel.
Individual Aircraft Management and Operations	• At UML-4, UAM onboard technology enables performance capabilities needed to safely conduct medium-density operations in populated urban environments. • These technologies enable aircraft to safely detect and avoid obstacles in the air and on the ground, to safely land in emergency situations, and reduce risk in emergency situations. • Safe urban flight management of individual aircraft is ensured by ATM provided by PSUs for operation and strategic deconfliction in the UOE. • Ground-based systems such as the ILS or its equivalent and systems to support en route UAM operations augment aircraft systems to provide additional safety, monitoring, and awareness. • It is expected the operational procedures avoid sensitive areas (e.g., due to safety or concerns) as well as permanent and temporary areas where restrictions may be in place by the FAA or negotiated with local authorities. • It is anticipated that the increasingly automated capabilities of aircraft reduce cost for aircraft crew training and aircraft operations while maintaining an equivalent level of safety. • To address the ground operations and maintenance barrier, UAM aircraft data is streamed for FOQA/MOQA services to improve flight safety. • It is assumed that at UML-4 maintenance processes have been developed that are FAA-certified to ensure aircraft are safely maintained by qualified maintenance professionals.
Airspace System Design and Implementation	• In the UOE environment, ATM services are provided primarily by private sector PSUs that meet requirements enacted by the FAA. PSUs can be public sector or private sector entities, but it is anticipated most are private sector entities. • The UOE is established through a collaborative design process that is used by the FAA today with enhanced input from state and local governments due to the increased impact on state and local stakeholders given a UAM's frequent low-altitude operations. • UOE coverage is tailored to a specific metropolitan area by the FAA with input from the community. • In some cases, the UOE may extend into ATC-controlled airspace to enable certain missions. • Significant technological advances in traffic management through the maturation of increasingly complex operations likely establish the capability to accommodate higher volumes of air traffic, including passenger and cargo UAM operations, along with other traffic requiring low-altitude traffic management in the UOE airspace (e.g., sUAS operations). Altitude management occurs via PSU system coordination within parameters established by industry consensus and preauthorized by FAA. • UAM aircraft in the UOE largely operate in metropolitan areas extending into the urban periphery below controlled airspace (except in the terminal environment) and above the urban canyon. • UOE operations and PSUs seamlessly operate concurrent with controlled airspace managed by traditional human-operated ATC in specific areas of the terminal environment where it has been preauthorized that safe operations can occur. • The UOE is tailored based on the unique characteristics and needs of the specific metropolitan environment and geography. • In the case where a fleet operator experiences an off-nominal event, redundant emergency landing locations exist to allow for safe landing in the form of en route UAM aerodromes and safe non-UAM aerodrome landing areas identified by automated systems. • At UML-4, en route operations generally occur above the urban canyon (area immediately above the urban environment) environment and below traditionally actively controlled airspace operations, reducing community noise, potential communications interference, etc. — To the extent possible, landing and terminal areas are placed outside of controlled airspace to avoid unacceptable additional ATC workload. • UML-4 airspace operational roles, rules, and procedures are established and defined within the UOE. • PSUs provide a dynamic, common operating picture of the UOE through information-sharing and exchange between fleet operators, aircraft, and the FAA to achieve safe operations. • The FAA has on-demand access to UOE operational information and can dynamically modify the airspace (e.g., close areas or restrict operations) via push (server-initiated data exchange) to PSUs based on safety and operational demands (e.g., emergencies, sporting events, military operations).

Pillar	Integration Activity
	• Operations are supported by an environment designed to promote safety through information exchanges and shared situational awareness that cooperative operations require. • The UOE framework ensures the safe conduct of aircraft operations through the issuance of performance authorizations that ensure operational and performance requirements are met, the sharing of flight intent (flight path, departure time, departure/arrival and alternate UAM aerodromes among other elements) and airspace constraint information among operators, and the use of services, technologies, and equipage to deconflict flight paths. • At UML-4, all UAM aircraft operating in the UOE are required to follow all airspace equipage and aircraft performance requirements, including participating in the PSU Network. This includes sUAS as well as larger passenger and cargo aircraft that are piloted, remotely piloted, or highly automated. • Users operating outside of the PSU Network may voluntarily participate in the system by utilizing information from the network for situational awareness or participate actively in the system by making their position and intent known. • PSUs and participating aircraft are required to share data to support operational planning, aircraft deconfliction, conformance monitoring, and emergency information dissemination, and facilitate fleet operator response. • Defined standards and requirements for PSU data exchange are well established by UML-4 and are expected to be part of the requirements by FAA for PSU authorization. • At UML-4, a network of PSU providers delivers UAM traffic management services to enable safe and efficient UAM operations within the UOE with minimal FAA involvement. • The PSUs communicate airspace restrictions, receive and coordinate operations plans, and request dynamic route changes for its users. PSUs also exchange data and record data as required by regulators and the FAA for regulatory and fleet operator accountability purposes. • SDSPs provide enhanced services for safe operations to fleet operators (e.g., a, specialized weather data, surveillance, constraint information). SDSPs may also provide information directly to PSUs or fleet operators. SDSPs may provide safety-critical services. • The FAA's FIMS is an API gateway for data exchange between PSU Network participants and FAA systems. • At UML-4, fleet operators maintain communication with PSUs and UAM aircraft in compliance with performance criteria and regulatory requirements to support data exchange required for the operation. • PBN (or future PBN-like) requirements will enable precise flight operations, even in visibility-restricted conditions. The ability to manage cooperative and non-cooperative traffic are required for semiautonomous operations under visibility-restricted conditions with a combination of external data feeds and onboard capabilities, such as operating at reduced separation minima, long-range obstacle avoidance, and the exception of planned operations or emergency landings.
Airspace and Fleet Operations Management	• PSUs provide strategic and in tactical deconfliction by exchanging data within the PSU Network. This data set, with elements to be defined by industry consensus and approved by the FAA, includes information such as departure time, operations plan, intended arrival destination, and alternate UAM aerodromes. • Service suppliers (PSUs and SDSPs) serving UOEs are certificated by the FAA based on standards developed by standards development organizations (RTCA, ASTM, etc.) and implemented by the FAA. • Non-safety-critical SDSPs may operate in the PSU Network with FAA approval (rather than certification); however, safety-critical SDSP functions will also need to be certificated. • Operations are planned to avoid high-risk areas where possible (e.g., tall buildings, stadiums, etc.), as well as permanent and temporary areas where restrictions may be in place (either by the FAA or negotiated with local authorities). • System-wide tests for UML-4 include large-scale graceful degradation procedures and demonstrations to ensure that the system can handle large-scale disruptions. • Under the principle of airspace equity, any cooperative aircraft that meets UOE performance-based standards should have access to these routes; however, flight characteristics dictate the aircraft trajectory and location (operations plan) of operation. • The urban environment contains unique and challenging wind, turbulence, and temperature characteristics when compared to higher altitude flying and outside of urban canyon. • Urban microclimate weather, wind measurements and predictions, and appropriate data exchange allows fleet operators and UOE stakeholders to know if they are capable of safely completing a flight based on the aircraft's performance characteristics and the aircraft performance standards of other aircraft transiting in the high-density operations airspace.

Pillar	Integration Activity
	• Weather data collection, analysis, prediction, and reporting is tailored to meet the needs of the fleet operator to operate as safely, effectively and efficiently as possible within high-density airspace operations.
Community Integration	• Public acceptance is dependent on the balance of effects, such as safety, public benefit (e.g., equitable access, increased travel options), community impacts (e.g., noise, visual impact), and environmental impacts (e.g., wind, air quality). • At UML-4, the public view UAM as safe through successful demonstration of UAM aircraft at UML-1 through -3 and through successful pilot programs conducted by the government and industry. • In addition to complying with regulations, the UAM industry builds confidence in the UAM system by being proactive in the identification of hazards and their safe resolution. • In line with traditional aviation regulations for commercial air taxis, UAM operations will maintain a level of safety equivalent or better than that required for passenger-carrying, on-demand charter (Part 135) operations. More research and analysis are needed to discern the appropriate level of safety. • The vast increase in anticipated flights and the increased risk to uninvolved people indicates the need for safety requirements that need to be identified through collaboration between the FAA and stakeholders.

A.2 Security

Security consists of both physical security and cybersecurity. In the UOE, cybersecurity takes an even more outsized role than it does today given the reliance on automated systems to control aircraft. Physical security entails, for example, security of the aircraft, UAM aerodrome, and allowing only ticketed passengers beyond a security checkpoint.

Below are the integration activities from each pillar aligned with security.

Table A2: Security Cross-Cutting Barriers

Pillar	Integration Activity
Aircraft Development and Production	• Sensitive/critical aerospace components subject to strict quality and authenticity standards are verified via secure electronic process for tracking and providence and authentication (i.e., block chain, digital authentication). — Secure processes improve efficiency and traceability throughout the supply chain over paper-based methods at the same time delivering higher levels of assurance that parts are authentic and approved. These digital tools accompanied by effective security risk management frameworks, tools, and standards protect the manufacturing of aircraft against a range of security threats (cyber and physical). • Mature supply chains, including secure digital processes to track parts and ensure authenticity and traceability, enable rapid ordering and receipt of parts. • Supply chains to support the UAM industry are matured to support hundreds of aircraft operating in metropolitan areas. • Characteristics are similar to the automotive industry while assuring the levels of security and safety needed for air travel.
Individual Aircraft Management and Operations	• Ground operations and maintenance activities include cybersecurity precautions as updates and changes to the automated system present cybersecurity concerns.
Airspace System Design and Implementation	• Cyber-specific standards may be necessary given the reliance on automated systems. These requirements shall include degraded communications and connectivity considerations. • The implications of 5G-based connectivity include the effects of beamforming, frequency agility, and other features. These and other characteristics of the plausible telecom protocols for UAM connectivity deserve research attention.
Airspace and Fleet Operations Management	• PSU data can be accessed directly by public entities such as the FAA, law enforcement, DHS, or other relevant government agencies on an as-needed basis. To accomplish this, a PSU must be (1) discoverable to the requesting agency, (2) available and capable to comply with an issued request, and (3) a trusted source (i.e., FAA, Department of Defense (DoD), or law enforcement) as mitigation actions may be taken as a result of the information provided.

Pillar	Integration Activity
Community Integration	• UAM stakeholders incorporate measures to ensure the safety and security of passengers, cargo, and UAM aircraft and the communities in which UAM aircraft operate. • Mitigating the concerns related to adverse privacy effects of UAM occurs through effective community engagement and the mandate of privacy policies for UAM aircraft built upon those being developed for UAS today. • At UML-4, UAM integration into a multimodal transportation integration requires addressing operations-related community impacts, including passenger/cargo security, protection from malicious use of aircraft and denial of service attacks, and graceful degradation of the existing transportation ecosystem in reaction to disruption caused by UAM services. • Advanced-security technologies expedite passenger and cargo screening. The transportation ecosystem will adapt, and mitigation strategies are put into place to account for service disruptions on any particular mode.

A.3 Affordability

To sustain the density of operations planned at an intermediate state, UAM must be a cost-competitive alternative to other forms of transportation (e.g., trains, water taxis, etc.). Benefits, such as reduced travel time, convenient access, parking avoidance, and comfort, will encourage adoption of UAM. As technology advances, the likely higher initial costs of UAM transit when compared to alternative forms of transportation are reduced, enabling economies of scale and fueling the growth and maturation of UAM.

Below are the integration activities from each pillar aligned with affordability.

Table A3: Affordability Cross-Cutting Barriers

Pillar	Integration Activity
Aircraft Development and Production	• The convergence of electrified propulsion systems, lightweight structures, and other advanced technologies are widely used in VTOL aircraft configurations and aircraft structures and tested for reliability and crashworthiness. • These advanced technologies allow for the design of aircraft with lower manufacturing and operational cost as well as lower noise signatures that meet or exceed current safety standards. • New testing and verification methods, such as analysis tools, support cost-effective rapid production, update, and modification at higher levels of safety. • New techniques of non-destructive examination and testing are matured and applied for efficient, cost-effective airworthiness. • Closer integration between the OEMs, fleet operators, and manufacturers optimize supply chain management, manufacturing, and cost control.
Individual Aircraft Management and Operations	• It is anticipated that the increasingly automated capabilities of aircraft reduce cost for aircraft crew training and aircraft operations while maintaining an equivalent level of safety.
Airspace System Design and Implementation	• While any aircraft that meets UOE requirements may operate in the UOE, it is anticipated that the majority of passenger-carrying UAM operations at UML-4 will occur along flexible, high-density routes between points where traveler demand is high and it is cost-effective to develop the infrastructure and systems needed to support UAM operations for the public.
Airspace and Fleet Operations Management	• Fleet operators may coordinate with surface transportation providers to carry passengers to/from UAM aerodromes to maximize efficiencies. This can take the form of industry alliances and partnerships negotiated by stakeholders, including government bodies, to leverage surface transportation networks and ensure UAM operations can effectively work within the local transportation ecosystem.
Community Integration	• The public benefit of UAM is firmly established by UML-4 through demonstration of multiple successful business cases (e.g., emergency responder, air ambulance, and limited air shuttle). • Employment by UAM manufacturers, fleet operators, SDSPs, and other tangential elements of the UAM ecosystem creates jobs in both urban, suburban, and rural communities. • Improved transportation options enabled by UAM enables commuters to travel farther, faster than ever before, potentially reducing the congestion in urban cores and may spur business development in locations outside the urban core in response.

Pillar	Integration Activity
	• It is recommended that industry and UAM stakeholders (including local authorities and local governments) conduct studies to identify UAM aerodrome locations and routes that maximize early public benefit and feasibility. • The benefits of UAM may yield greater tax revenues and productivity increases, such as economic benefits derived from reduced transit time. • As the UAM market expands at UML-4, it is anticipated that business economics will exert downward pressure on cost, further increasing public consumption of UAM services.

A.4 Noise

Advances in aircraft noise reduction are critical to enabling operations at UML-4 and increasing acceptability of UAM operations in communities. Tolerance of noise may vary by time of day and noise frequency, among other factors. Regulators, community leaders, and industry need to work cooperatively to reduce noise and determine acceptable levels of noise in different areas within the metroplex (e.g., industrial, residential).

Below are the integration activities from each pillar aligned with noise.

Table A4: Noise Cross-Cutting Barriers

Pillar	Integration Activity
Aircraft Development and Production	• UAM aircraft designs and technologies have been developed and evaluated for safety, redundancy, risk, operational suitability, and environmental impact (e.g., noise and emissions). • Aircraft have been developed that produce acceptable levels of noise adherent to noise standards. • Advanced technologies (e.g., electrified propulsion systems, lightweight structures) allow for the design of aircraft with lower manufacturing and operational cost as well as lower noise signatures that meet or exceed current safety standards. • Aircraft noise is addressed primarily through advanced designs and the incorporation of noise-reduction technologies that enable quiet aircraft operations. • Aircraft are designed to meet noise levels that are acceptable to the communities in which they operate. • Noise is measured and considered in the context of a fleet in addition to a single aircraft. Noise standards for UAM continue to evolve. • Cabins are designed so that necessary maneuvers do not provide significant adverse impact to passenger comfort. — For example, cabin design minimizes cabin vibration and noise, provides effective climate control, and assures passenger safety and comfort during turbulence. — These have been developed based on extensive consumer research and testing to develop strong understanding of metrics for passenger acceptance (e.g., ambient noise, natural and powered illumination, vibration, temperature, and seating acceptability, and ride quality). Designs also account for safe and efficient access to the cabin by passengers—including children and persons with disabilities. • Cabin designs support communication between passengers by reducing ambient noise or providing headsets, and likely support other conveniences, such as personal communication devices and room for luggage.
Individual Aircraft Management and Operations	• Fleet operators factor local noise limitations during flight planning and during flight.
Airspace System Design and Implementation	• High-density routes are dynamic based on demand and negotiated with the FAA and community stakeholders. In some instances, it is likely use of certain routes is restricted to UAM aircraft meeting certain performance capabilities (e.g., speed and maneuvering). Communities be to influence high-density route establishment through community engagement considering environmental policy and through zoning ordinances.
Airspace and Fleet Operations Management	• Fleet operators manage the complexity and quantity of UAM operations to stay within noise regulations in place at an intermediate state.

Pillar	Integration Activity
Community Integration	• Adverse impacts for UAM are mitigated by prudent and collaborative evolution of the system by the government and industry. • At UML-4 technology evolved at sufficient levels to minimize the impact of noise. • Federal regulators have established aircraft and fleet noise standards and work with communities to limit the adverse impact of noise through operational modifications (locations where aircraft operate), temporal modifications (operations), and other modifications to address community concerns. • Aircraft technology continues to evolve throughout UML-4 leading to quieter aircraft at future UMLs. — Fleet and flight operations management techniques by industry, working in concert with regulators, also evolve through this level to minimize community impact of noise. • The supporting infrastructure for UAM will bring with it a number of additional community concerns, including land use, ground traffic management, utility infrastructure, emergency planning and evacuation infrastructure, noise, data access, and integration with existing operations.

A.5 Automation

Advances in automation are necessary to transform UAM from concept to a commonplace mode of transportation. Although the public is experiencing more and more automation in their daily lives, there is still much work to be done to make semiautonomous transportation common, necessary for operations to scale to UML-4.

Below are the integration activities from each pillar aligned with automation.

Table A5: Automation Cross-Cutting Barriers

Pillar	Integration Activity
Aircraft Development and Production	• Validated tool sets supported by high-speed computing and advanced automation in design, manufacturing, and testing accelerate development cycles and bring most promising concepts to market more quickly and more efficiently. • Automated systems, avionics software, real-time data transmission, and, in some cases, RPICs prevent flight into environmental operating conditions that the aircraft is not certified for based on data gathered from the PSU Network.
Individual Aircraft Management and Operations	• UML-4 likely has a combination of operations where failure cases are fully automated profiles and other cases that require some human intervention (e.g., to activate an automated contingency landing plan). • At UML-4, aircraft are highly automated and capable of performing most operations with minimal human interaction. • It is anticipated that the increasingly automated capabilities of aircraft reduce cost for aircraft crew training and aircraft operations while maintaining an equivalent level of safety. • During off-nominal and contingency situations, the aircraft crew has the ability to activate an automated contingency landing plan. • Automation at UML-4, more advanced than what is currently available, provides much higher speeds of computation and decision-making that enables the aircraft's automated systems to identify the lowest-risk emergency-landing alternative. • At UML-4, it is anticipated that advanced methods have been developed to test and certify semiautonomous operation, and existing regulations have been adapted to certify UAM aircraft operations.
Airspace System Design and Implementation	• High-density routes likely require advanced capabilities for managing aircraft. • Examples of these capabilities include separating and sequencing aircraft, allowing semiautonomous departure and arrival, and ensuring safety (e.g., redundant/emergency landing areas in greater numbers than other en route areas, advanced CNSI, micro weather capabilities, etc.). • It is likely that high-density routes dynamically develop as frequent point-to-point trips occur and may become static if desired by the community to add predictability to the operating environment. • Within the UOE, the fleet operator, aircraft, and PSU providers are always required to perform at a level high enough to maintain automated separation from all hazards in a fully accountable manner. • Dynamic scheduling (regularly updated and distributed across the PSU system as needed) mitigates the impact of delays and off-nominal events (e.g., on slotting and timing) by ensuring aircraft in a given area are situationally aware of other aircraft's operations plans and planned flight times.

Pillar	Integration Activity
	• Dynamic scheduling prevents congestion at UAM aerodromes and allow for efficient entry and exit. Dynamic scheduling must be able to respond to network outages and signal degradation. This may include additional schedule planning buffers to account for unplanned aircraft.
Airspace and Fleet Operations Management	• DAA and V2V information exchange (coupling) will allow aircraft to avoid each other, as well as allow semiautonomous UAM aircraft to avoid non-cooperative manned aircraft that are operating in an area where they lack the proper equipment to operate. Standardized procedures developed by FAA exist to manage non-cooperative aircraft in the UOE. • In addition to this strategic deconfliction, tactical deconfliction via onboard sensors and coordination with the PSU Network through PSUs will enable UAM aircraft to operate in close proximity compared to legacy ATM separation requirements. • Data is used to allow separation based on performance characteristics, environment, and predeparture deconfliction and will also be shared via PSU to the PSU Network to enable other PSUs to develop accurate operations plan routings based on traffic density and other elements.
Community Integration	• At UML-4, operational integration creates opportunities to integrate UAM into other semiautonomous systems and technologies, such as self-driving cars, to allow for a seamless transportation experience.

A.6 UAM Aerodromes

The FAA will assure that publicly funded UAM aerodromes meet federal requirements, and localities will ensure that private UAM aerodromes follow requirements and standards through their zoning ordinances and permitting process. Fleet and UAM aerodrome operators will work with local government and civic organizations to promote UAM acceptance and use through the number, location, zoning, and capabilities for UAM aerodromes in an urban area.

Below are the integration activities from each pillar aligned with UAM aerodromes.

Table A6: UAM Aerodrome Cross-Cutting Barriers

Pillar	Integration Activity
Aircraft Development and Production	• UAM aerodromes are sized and designed for the planned type and number of aircraft they support.
Individual Aircraft Management and Operations	• Ground operations at the UAM aerodrome are the responsibility of the UAM aerodrome operator who may contract with aircraft fleet operators and ground services to provide routine aircraft maintenance at the UAM aerodrome, as well as MRO providers to provide major services at facilities separate from their UAM aerodrome. • The services provided by UAM aerodromes vary based on the UAM aerodrome size and location. • MRO fleet operators establish facilities operated by licensed aviation technicians. • In-flight monitoring and information exchange between ground stations and UAM aircraft enable quick response to minor maintenance issues during routine scheduling at available UAM aerodromes.
Airspace System Design and Implementation	• To the extent possible, landing and terminal areas are placed outside of controlled airspace to avoid unacceptable additional ATC workload. • UOE extensions into controlled airspace provide access to UAM aerodromes near the airport. Extensions are strategically designed where there are lower levels of commercial aircraft activity in the airport vicinity. • All landing areas (i.e., UAM aerodromes) include capacity for emergency landings and redundancy to support landings at alternative locations in the case that the landing areas become unavailable. • Infrastructure to support operations like maintenance must be co-located at UAM aerodromes in high-demand locations. • Given the large number of UAM aerodromes condensed into a relatively small area compared to airports today, community approval is required in several key aspects of UML-4 UAM, including the locations of UAM aerodromes. • UAM aerodromes, like existing airports, are designed to meet the needs of individual cities and regions while also meeting standards and practices developed by the FAA and industry, including standards for obstruction evaluation and mitigation.

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UAM aerodrome design considers the physical location of the UAM aerodrome. Some UAM aerodromes are constrained by their environments, which will limit the types and quantities of aircraft that can operate from it.
State and local governments also dictate UAM aerodrome locations based on local zoning ordinances and requirements, as they do today with airports and heliports.
Ground services are provided by UAM aerodrome operators or third parties contracted by UAM aerodrome operators. Communication capabilities vary based on UAM aerodrome size, the demand of UAM aerodrome users, and the desires of UAM aerodrome operators.
It is anticipated that UAM aerodromes are not restricted to urban centers and will serve the urban periphery and rural areas.
UAM aerodromes outside urban centers may have expanded aircraft services, such as aircraft storage and major MRO facilities, and serve as intermodal hubs.
All UAM aerodromes need enhanced access to utilities to accommodate the intense demand on the local resources, including electrical grids, internet connectivity, and public accessibility.
UML-4 operations are likely to operate in an environment constrained by terminal-area capacity. UAM aerodromes have a limited number of departure and landing pads; this necessitates strategic spacing prior to aircraft departure.
</td></tr>
<tr><td>Airspace and Fleet Operations Management</td><td>
Procedures for departure and arrival sequencing (e.g., filing operations plan and departure approval) are executed between the fleet operator and the PSU using FAA-established policies and/or constraints.
Coordination of aircraft arriving into UAM aerodromes nominally occurs via the PSU.
Arrival and departure procedures use V2V and aircraft-to-infrastructure information exchange (such as microclimate winds) to enable greater predictability and throughput in the terminal environment.
Terminal and urban area forecasts and sensors are implemented or augmented by an expanded network that collects, analyzes, and shares near-real-time low-altitude (i.e., to the ground) weather data.
</td></tr>
<tr><td>Community Integration</td><td>
The supporting infrastructure and utilities required for integrating UAM operations into metropolitan areas must be developed (e.g., UAM aerodromes, energy infrastructure).
Supporting infrastructure takes various forms of a public, private, or public-private partnership ownership models depending on the metropolitan area.
The physical infrastructure necessary for UAM aerodromes, navigation, designated emergency landing areas, and data networks will range from publicly to privately owned.
UAM aerodromes at UML-4 are integrated with the existing infrastructure and, in many cases, required buildout of additional infrastructure.
UAM aerodrome fleet operators continue to build upon the effective relationships established at earlier UMLs creating appropriate infrastructure by modifying existing structures.
UML-4 also sees the emergence of UAM purpose-built structures that have UAM aerodromes integrated from the design phase.
UAM aerodromes may be public, limited to a single-fleet operator, or limited to aircraft that meet certain performance standards. The nature of each depends on various factors including ownership, business case, charging infrastructure, consumer demand, type of operations at the UAM aerodrome, and airspace complexity.
Passenger demand is a critical factor for determining suitable UAM aerodrome locations and will influence infrastructure requirements.
UAM aerodromes should be designed and built with scalability in mind for each location.
</td></tr>
</table>

A.7 Regulations/Certification

The FAA remains the regulatory body for the safety of operations in the airspace. Existing standards are modified, and new standards are developed as needed. Requirements across standards are aligned, and the certification process is expedited to keep pace with technology. Going along with current regulatory trends, the FAA uses performance-based certification in their process. In addition to the FAA as a regulator, the ecosystem is impacted by regulations from the EPA (e.g., emissions), FCC (e.g., spectrum), and local regulatory bodies.

Below are the integration activities from each pillar aligned with regulations and certification.

Table A7: Regulations/Certification Cross-Cutting Barriers

Pillar	Integration Activity
Aircraft Development and Production	• It is anticipated that the certification framework is performance-based. The path to certification is likely different from what exists in the 2010s once performance-based regulations are in place. • The current regulatory framework is adapted to include UAM aircraft; existing regulations are modified, and new regulations are adopted that align with UAM aircraft and technologies. • Much of the regulatory framework is already in place for the certification of UAM aircraft (in Part 21, as written). • Certification tools, techniques, and processes are adapted or developed for new technologies, materials, and aircraft, building on regulatory frameworks already in place. • Airworthiness standards for UAM aircraft build on the current Part 21 regulatory framework. • Depending on the combination of aircraft configuration and technologies utilized existing certification standards may be more or less applicable. • Surveillance standards and standards for DAA have been developed. Maintenance and inspection standards are needed in addition to aircraft standards. • Methods for aircraft and component certification for UAM aircraft, their components, and technologies keep pace with accelerating technology development and UAM production while maintaining or improving safety levels. • Manufacturers design, obtain certification for, and produce airworthy, mission-capable aircraft. • New standards have been developed for the testing and certification of advanced technologies (e.g., electrified propulsion systems, lightweight structures) and processes capable of supporting higher volumes of production. • In some cases, the current certification requirements have been updated. For example, rather than freeze the configuration, there may be ways for the process to be more adaptable so that manufacturers can certify as they build. • New testing and certification standards and approaches leverage industry-developed standards and, to the extent possible, are harmonized internationally so that aircraft certification and flight operations are not cost-prohibitive to achieve globally and to support trusted and verifiable global production and supply.
Individual Aircraft Management and Operations	• At UML-4, it is anticipated that advanced methods have been developed to test and certify semiautonomous operation, and existing regulations may have been adapted to certify UAM aircraft operations. • Certification of fleet operators likely occurs under the existing framework regulations (14 C.F.R. 121, 135, et al.), depending on the nature of the operation. By UML-4, these regulations have been modified through the rulemaking processes to enable UAM operations. • Evolution, testing, and certification, along with flight experience sufficient for the aircraft, enable simplified aircraft operation under certain conditions where humans observe and monitor systems, and only act in exception. • Sufficient hours under pilot supervision across the range of operations (e.g., UAM progression from UML-1 through -4, continued development of advanced automated systems in traditional commercial aircraft, maturation of UAS technologies, etc.) enable certification and approval of technologies that enable aircraft crew capabilities in UAM aircraft. • It is assumed that at UML-4 maintenance processes have been developed that are FAA-certified to ensure aircraft are safely maintained by qualified maintenance professionals.
Airspace System Design and Implementation	• Regulations may need to be modified and/or created to accommodate UAM operations, including volume limitations and aircraft spacing needs. • While not an airspace class itself, the UOE is an area, likely established through rulemaking, where UAM aircraft and traditional manned aircraft can safely operate in the metropolitan area and periphery within the UOE. UOE also has specific equipage requirements necessary to ensure semiautonomous aircraft and manned aircraft can identify each other. • UOE exists within existing classes of airspace (B, C, D, E, and G), although it is anticipated that the UOE environment is likely to expand geographically beyond metropolitan areas in UML-5 and -6. • PSUs dynamically adjust UOE according to criteria established by FAA in situations that require dynamic airspace adjustment such as temporary closures emergency response. • Due to density and to ensure safety, aircraft operating in UOE are required to meet the requirements established for the type of operation and associated airspace volume/route in which they are operating.

Pillar	Integration Activity
	• FAA remains the regulatory and operational authority for airspace and traffic operations, but the PSUs deliver flight-planning services (with the fleet operator ultimately responsible for the plan), communications, and separation, among other data elements, and enable the sharing of information between fleet operators and the FAA on flight intent and airspace constraints. • The FAA provides information to airspace users on airspace constraints such as NOTAMs, airspace restrictions, facility maps, SUA and SAA activity, and will collaborate with the PSU Network exchanging data with PSUs and fleet operators to fulfill its obligations to provide regulatory and operational oversight. • In addition, the FAA remains the federal authority over aircraft operations in all airspace, and the regulator and oversight authority for civil aircraft operations in the NAS. • State and local governments take on an enhanced role in UML-4 while maintaining similar responsibilities to what they have today.
Airspace and Fleet Operations Management	• The FAA develop processes, procedures, and protocols to push restrictions to PSUs. • The requirements for security, robustness, and resilience will have been established. Risk-based regulatory standards for 14 CFR Part 21.17, 23, and 27 aircraft may form the basis of such requirements.
Community Integration	• FAA maintains its role as federal regulator, and federal preemption will apply. However, given the new paradigm created by UAM operations (scale and frequency), the FAA and industry must engage local leaders to an extent even greater than they currently do. • Communities maintain their power to control the development of ground infrastructure (UAM aerodromes, weather sensors, etc.) through zoning ordinances, and noise through noise ordinances. • The legal and regulatory framework at UML-4 incorporates the tole and authorities of federal agencies, state governments, local/city/municipal governments, and case law. • Liability principles that apply to common carriers apply to for-hire, passenger-carrying UAM operations. • Other adverse effects that must be limited in the interest of community integration includes environmental concerns (such as emissions) and visual impacts. • Process for defining acceptable levels of emissions in conformance with existing emissions standards and as aircraft evolve any new standards is iterative by nature and compliant with state, local, and federal regulations. • Emission levels for non-electric and hybrid-electric UAM aircraft have been iteratively developed and are well established by UML-4 but may need to be reexamined as aircraft density increases. • As operational density increases, communities may have concerns about the visual impacts of UAM operations. Communities work with local, state, and federal regulators within the established environmental framework to ensure compliance with evolving standards and reflect community desires.

Appendix B: Roles and Responsibilities

This appendix details the major stakeholders at UML-4, specifically their high-level roles and responsibilities. These roles and associated responsibilities are modified and refined as the UAM concept matures and UML-1 through -3 are realized. Not all stakeholders will have an active role in UAM operations but will play a significant role in the establishment of regulations, certifications, infrastructure, and the like. For example, governments are critical during the establishment of the UAM system but will rarely be involved in the day-to-day operation. Additional appendices will further detail specific roles and responsibilities through the various phases of flight in UAM operations.

Table B1: Roles and Responsibilities

Entity	Responsibility
Federal Aviation Administration (FAA)	• Regulates and oversees civil aircraft operations in the NAS. • Provides the regulatory and operational framework for UAM operations. • Defines and provides information on airspace constraints, such as NOTAMs, SUA, SAA, and temporary flight restrictions. • Provides information to the PSU Network. • Maintains FIMS.
Fleet Operator	• Responsible for the management of aircraft operations under their control and the safe execution of each flight. • Responsible for meeting regulatory requirements, flight planning/execution, sharing operational intent information, and safely conducting operations.
City, State, and Local Governments	• Develop and enforce zoning regulations for UAM aerodromes. • Develop and enforce noise ordinances. • Influence development of flight procedures (e.g., approaches/departures to/from UAM aerodromes, location of high-density routes). • Given the large number of UAM aerodromes anticipated in a single urban environment, state, city, and local governments will take on an increased role with managing aviation-related and aviation-adjacent issues requiring their approval such as location of UAM aerodromes, zoning, infrastructure upgrades, and noise abatement.
Supplemental Data Service Provider (SDSP)	• Provide information supplemental to flight operations (i.e., non-safety-critical data), such as weather and additional traffic awareness.
Provider of Services to UAM (PSU)	• Cooperative data exchanging platforms to provide common operating picture and shared situational awareness to users. • Supports operational planning, aircraft deconfliction, conformance monitoring, and emergency information dissemination.
Pilot in Command (PIC)	• The PIC is a human individual who holds "final authority and responsibility for the operation and safety of the flight" of a UAM aircraft. • This individual may be onboard or off-board the aircraft. • A pilot off-board the aircraft is a RPIC. • The PIC may be a pilot in the traditional sense of the term or could be part of the aircraft crew (defined below), having a modified role in which automation is responsible for some functions performed by a traditional pilot. • The PIC is a member of an aircraft crew.
Second in Command (SIC)	• A human onboard the aircraft with secondary and tertiary operational responsibility behind aircraft automated systems and the PIC.

Entity	Responsibility
	• The SIC has more responsibility than an aircraft steward and is fully trained and qualified for the assigned roles and responsibilities. A SIC does not require the same qualifications as a PIC. The SIC is a necessary role to build the safety case for a single PIC with operational control for more than one aircraft at a time. • The SIC is a member of an aircraft crew.
PSU Network	• The PSU Network describes a fully integrated system of multiple overlapping PSUs servicing the same geographic area/airspace volume. • Delivers traffic management services, provides framework for secure information exchange, and supports route planning.
Aircraft Crew	• Individual(s) onboard or off-board the aircraft to communicate, ensure passenger comfort during flight, and provide limited loop monitoring are trained and certificated at a level deemed appropriate by the FAA, with presumably less requirements than of a Part 61 pilot.
UAM Aerodrome Operator	• Management of operations at one or many UAM aerodromes under their control and the safe takeoff, landing, and ground operations of each flight. • Meeting regulatory requirements. • Sharing operational information, such as UAM aerodrome/landing pad(s) availability, with the PSU Network. • Safety of embarking and disembarking passengers. • Providing physical security through the screening of passengers, baggage, and general cargo. • Providing cybersecurity of their own systems and infrastructure.
Ground Services	• Provide ground-based services to aircraft, including refueling/recharging, aircraft inspection, line maintenance, aircraft servicing (food/beverage/lavatory), deicing, aircraft reconfigurations, and other applicable services similar to today's commercial airports and FBOs ground services. These services are provided by licensed and certified personnel employed by UAM aerodrome operators or third parties contracted by UAM aerodrome operators.
Other Government Agencies (OGA)	• OGAs in the UAM stakeholder community include, but are not limited to, TSA, FCC, National Telecommunications and Information Administration (NTIA), National Oceanic and Atmospheric Administration (NOAA), EPA, DHS, Department of Commerce (DoC), etc.
Other Stakeholders	• Public safety officials and the public can also exchange data with the PSU Network through a SDSP or a PSU in order to respond to events in the UOE.

Appendix C: Gate-to-Gate Operations

To illustrate the UAM operation, it is critical to detail the nominal G2G operation. This appendix is intended to illustrate the major stakeholder roles in each major phase of the nominal UAM operation from preflight, through flight, to landing and disembarking. Though this is not an exhaustive list; it is meant to illustrate the various responsibilities during each phase of flight, including hand-offs and information exchange across stakeholders. It is also possible for a single entity to hold many of the roles described; for example, the fleet operator and UAM aerodrome operator may be the same company. Establishing this operational baseline is paramount to then detail operational permutations.

Table C1 summarizes the major steps that would occur G2G in the nominal scenario. These steps are not exhaustive and are not ordered in a chronological manner, but rather meant to illustrate a stakeholder's general responsibility. This table walks through six phases of flight: preflight, takeoff, climb, cruise, descend, and land/disembark. Roles include fleet operator[29], PSU, FAA, UAM aerodrome operator, and aircraft and aircraft crew. The aircraft's automated systems and aircraft crew are linked together because there are various operating models at UML-4 that each allocate responsibility differently between these entities (as described in Section 4.2). The aircraft crew, either onboard the aircraft or at a remote location, hold safety-critical roles.

[29] The fleet operator could operate a fleet of one aircraft, such as would be the case with an individual owner-fleet operator.

Table C1: Summary of G2G Operations for each Major Stakeholder

	Preflight	Taxi and Takeoff	Climb and Cruise	Descend	Land, Taxi, and Disembark
Fleet Operator	• Files operations plan • Verifies passenger manifest and destination • Performs dispatch duties	• Approves taxi/takeoff authorization	• Monitors conformance to operations plan • Monitors aircraft health and status • Maintains open data exchange with PSU and aircraft • Makes updates to destination, etc., as needed	• Monitors conformance • Monitors aircraft • Maintains open data exchange with PSU and aircraft	• Monitors conformance • Monitors aircraft • Assigns gate (shared with UAM aerodrome operator) • Confirms aircraft ready for turnaround
PSU	• Conducts strategic deconfliction and negotiates resolution(s)	• Transmits taxi/takeoff authorization and departure sequencing command	• Conformance monitoring • Communicates updated operations plan • Assists with tactical deconfliction • Maintains open data exchange	• Conformance monitoring • Communicates sequencing and route changes • Issues landing clearance • Sequences aircraft into UAM aerodrome	• Confirms all clear for aircraft landing • Gives taxi instructions • Closes operations plan
FAA	• Approves operations plan through automated data exchange	• No active participation but maintains authority over airspace			
UAM Aerodrome Operator	• Screens passengers and cargo • Performs passenger boarding • Confirms all clear for departure	• Confirm all clear for aircraft departure	• N/A	• Confirms UAM aerodrome clear for aircraft landing • Allocates landing pad and debark area	• Confirms landing area is clear • Assigns gate (shares with fleet operator) • Approves/moves aircraft to gate area
Aircraft and Aircraft Crew	• Performs systems check • Confirms aircraft ready for departure	• Executes takeoff procedure and sequencing	• Executes climb and cruise procedures • Maintains V2V data exchange and executes tactical deconfliction and collision avoidance • Monitors systems and pushes aircraft health and status to fleet and UAM aerodrome operator	• Executes descent procedure and sequencing • Maintains V2V data exchange and executes tactical deconfliction and collision avoidance	• Scans and confirms all clear for landing • Executes landing procedure and taxi • Identifies needed maintenance/turnaround requirements

For each phase of flight, the detailed steps are described below. They are written in a chronological manner; however, the order, detail, and fidelity of these steps are refined through research, test, and realization of UML-1 through -3.

All fleet operators must receive a performance authorization from the FAA to operate in the UOE. This performance authorization covers specific aircraft, aircraft crew, and operations. Once authorized, the fleet operator stays within the bounds of what has been authorized under an honor system arrangement; operating outside of the bounds of a performance authorization can bring legal recourse.

Preflight
At the beginning of each day, the UAM aerodrome operator confirms UAM aerodrome safety and operational status (including capacity) and shares that information via the PSU Network, and the fleet operators acknowledge receipt of the message from the UAM aerodrome operator[30] to confirm that they are in possession of the safety and operational status of the UAM aerodrome prior to beginning operations. Ground crew performs a run-up check to ensure that the aircraft is operational and that it did not sustain damaged overnight that is undetectable via visual inspection alone. Fleet managers run updated demand models (based on weather, events, time of year, etc.) to stage and prep aircraft, gates, and operations across the network of UAM aerodromes. The demand models are continuously updated and readjusted in collaboration with partner multimodal systems as passenger apps and other services provide validated true demand. As personnel and passengers arrive at the UAM aerodrome, they are appropriately screened, and passengers are directed to appropriate locations prior to boarding. Passengers receive a full safety briefing. The fleet operator files the operations plan, and the PSU approves via data exchange ("handshake") and makes the operations plan available to the FAA. Additionally, the aircraft crew reviews the operations route.

After the aircraft's automated systems performs a walkaround, either physically or virtually, and confirms to the UAM aerodrome operator and fleet operator that the aircraft is ready for boarding, the passengers are safely escorted to their aircraft. With the passengers onboard, the aircraft crew addresses any passenger questions or additional needs either in person or electronically. The aircraft's automated systems and/or aircraft crew performs a systems check and send a confirmation to the UAM aerodrome operator and fleet operator that the aircraft is all clear for departure. The fleet operator authorizes flight and shares that flight is authorized with the aircraft's automated systems, aircraft crew, UAM aerodrome operator, and PSU.

Taxi and Takeoff
The PSU assigns a takeoff slot and, in coordination with the UAM aerodrome operator, initiates departure sequencing. Once departure sequencing is determined and communicated across all relevant aircraft (incoming, at the gate, taxiing), aircraft crew, and fleet operators, the UAM aerodrome operator gives the final all clear for aircraft departure and issues the taxi/takeoff authorization to the PSU and fleet operator. The PSU transmits the taxi/takeoff and departure sequencing command and any updates to the operations plan (e.g., delays, estimated time of arrival (ETA) to the fleet operator, who will confirm that the aircraft is clear to takeoff and approve the taxi/takeoff. The aircraft's automated systems and/or aircraft crew then executes the taxi/takeoff procedure, maintains V2V data exchange, and executes tactical deconfliction and any necessary collision avoidance maneuvers. The aircraft crew keep passengers informed of updates before the aircraft leaves the gate and when the aircraft is cleared for takeoff. The fleet operator tracks the aircraft's progress.

Note: Unless the FAA is the UAM aerodrome operator, it does not actively participate in this phase other than to maintain overall authority for airspace operations.

Climb and Cruise
After takeoff, the aircraft's automated systems execute the climb/cruise procedure, maintains V2V data exchange, and executes tactical deconfliction and collision avoidance as necessary using onboard DAA capabilities. Throughout the flight, the aircraft's automated systems monitor systems and pushes relevant health and status to the fleet operator so that any addressable aircraft maintenance issues can be addressed once the aircraft lands. The fleet operator monitors conformance with the current operations plan, aircraft energy management and reserves, and real-time flight status, and shares the flight status information with the destination UAM aerodrome

[30] For the purposes of this discussion, assume all send messages are acknowledged by the receiver of the message.

operator. Weather data is exchanged between PSUs and fleet operators, PSUs and aircraft, and V2V. The aircraft crew is kept informed by fleet operators of any forecasted weather conditions that could impact the flight and provide that information to passengers. The PSU 1) tracks aircraft performance and alerts the fleet operator of operations plan deviations and 2) tracks updates (UOE status, weather events, aerodrome closure, operations plan revision, no-fly zones, etc.). The PSU exchanges updates to the operations plan when necessary (including sequencing of reroutes) with other PSUs, the fleet operator, aircraft, aircraft crew, and UAM aerodrome operator, if applicable, and the aircraft crew updates the passengers. As the aircraft proceeds according to its operations plan, it executes tactical rerouting when necessary, and the destination UAM aerodrome operator monitors and communicates availability to the PSU, fleet operator, aircraft, and aircraft crew.

Note: The operations and roles and responsibilities are not materially different during climb and cruise operations. For simplicity, they are presented together, and differences are noted. Unless the FAA acts as one of the other agents (e.g., the UAM aerodrome operator), it does not actively participate in these phases other than to maintain overall authority for airspace operations.

Approach

As the aircraft enters the approach phase of flight, the UAM aerodrome operator reconfirms that the UAM aerodrome is clear for aircraft landing, allocates a landing pad, and shares that information with the PSU, aircraft, fleet operator (and ground services), and aircraft crew. The PSU determines the arrival and landing sequence and communicates this information to the UAM aerodrome operator, fleet operator, aircraft, and aircraft crew. The fleet operator monitors conformance with the current operations plan, aircraft energy management and reserves, and real-time flight status, and shares the flight status information with the destination UAM aerodrome operator via the PSU Network. The PSU tracks aircraft performance, alerts the fleet operator (if necessary) of any nonconformances to the operations plan, and issues the landing clearance to the fleet operator. The UAM aerodrome operator confirms that the aircraft is cleared to land, and the PSU shares that information with the aircraft's automated systems, aircraft crew, and UAM aerodrome operator. The aircraft crew informs the passengers. The aircraft's automated systems/aircraft crew executes the approach procedure and sequencing and maintains V2V data exchange to execute tactical deconfliction as necessary using onboard DAA capabilities as it approaches the UAM aerodrome.

Note: Unless the FAA acts as one of the other agents (e.g., the UAM aerodrome operator) is the UAM aerodrome operator, it does not actively participate in this phase other than to maintain overall authority for airspace operations.

Land, Taxi, and Disembark

During the final phase of flight, the fleet operator tracks aircraft progress, and the UAM aerodrome operator confirms that a landing pad on the UAM aerodrome is clear and provides this information to the PSU, fleet operator, aircraft, and aircraft crew. The PSU confirms to the aircraft's automated systems that it is cleared for landing. Once cleared for landing, the aircraft crew confirms that the aircraft is ready for landing, and the aircraft's automated systems and aircraft crew scan the landing area to confirm that there are no hazards, and the aircraft's automated systems conduct a final systems check and executes landing. The aircraft's automated systems inform the UAM aerodrome operator, ground services, and fleet operator when the landing is complete. The PSU provides taxi instructions to the gate assigned by the fleet operator, which the aircraft's automated systems/aircraft crew follow. After reaching the to the gate, the aircraft's automated systems and/or aircraft crew communicate when it is safe for ground services to approach the aircraft and passengers to disembark. Ground services assists passengers to disembark and ensures that they are safely distanced from the active areas on the UAM aerodrome. The aircraft crew informs the UAM aerodrome operator that the aircraft is evacuated, and the UAM aerodrome operator coordinates the servicing of the aircraft with the ground services.

Note: Unless the FAA acts as one of the other agents (e.g., the UAM aerodrome operator), it does not actively participate in this phase other than to maintain overall authority for airspace operations.

Appendix D: Use Cases

While nominal operations are described in Appendix B, the following use cases were designed to be illustrative and demonstrate, at a high level, the actions that occur and the stakeholders who are involved in the event of a diversion from a UAM operation's intended plan. The use cases in this appendix can be broken into two categories: contingency and off-nominal events. Contingency scenarios divert from the operations intended plan but are circumstances that are expected to occur with some degree of frequency. Off-nominal scenarios reflect extraordinary events that may occur during UAM operations. In either case, contingency and off-nominal scenarios represent situations that the UAM ecosystem must be thoroughly prepared for in the interest of aviation safety.

These use cases and their associated stakeholders, communications, and operations were developed through UAM stakeholder group engagement, including government officials from various federal agencies, state and local government leaders, aerospace OEMs, local transportation leaders, prospective UAM operators, academics, industry standards-setting bodies, airports, service suppliers, and others as described in Appendix F. These use cases were refined over the course of several integrated working sessions and developed through group consensus. These use cases were used to test the robustness of the envisioned concepts and whether they can respond to contingency and off-nominal situations.

The use cases are distinct from business cases, in that they are not meant to demonstrate a business value for UAM. They are also not designed to provide the level of detail necessary for standard operating procedures (SOPs) but may serve as early guidance for the detailed development of UAM capabilities, roles, responsibilities, high-level functional capabilities, and system requirements.

As the UAM concept matures, it is important to determine, for each use case, which stakeholder 1) makes the decision that a certain condition exists requiring a departure from nominal operations (e.g., who determines that the passenger is "in distress") and 2) selects and initiates the course of corrective action.

This appendix is organized in the following manner:

- Contingency Scenarios
  - Passenger in Distress
  - Weather Restricts Landing
  - Non-cooperative Aircraft
  - UAM Aerodrome Closure
- Off-nominal Scenarios
  - Loss of Navigation
  - PSU Network Outage
  - Unplanned Entry into Actively ATC-controlled Airspace
  - Individual Aircraft Failure
  - All Aircraft Land

Additional use cases may be added, and existing use cases modified as the UAM concept matures, additional research is performed, and UML-1 through -3 are realized.

Contingency Scenarios

As mentioned above, contingency scenarios are those scenarios that divert from normal operations but are routinely planned for because they are expected to occur with some degree of frequency. Stakeholders have developed plans and procedures to execute if any number of contingency scenarios occur to ensure the safety of the passengers and operation. Stakeholders have developed SOPs to execute in the event of contingency scenarios. The below scenarios are meant to illustrate several examples of potential contingencies. Each scenario describes the aspects of the operation that deviate from the nominal operation.

Passenger in Distress

If a passenger is in distress (physical, emotional, or otherwise that requires a diversion or immediate landing) as reported by the passenger(s) or detected by the aircraft crew, the onus is on the aircraft crew to manage the contingency, orchestrate the response, coordinate with PSU, and keep the onboard passengers informed. If the PIC is not on board the aircraft, this coordination occurs remotely. Once the PIC communicates to the PSU that there is a passenger in distress, the PSU provides the PIC with priority routing options to an appropriate alternate landing location, and notifies other PSUs, airborne aircraft, and the UAM aerodromes of the change. This could include direct routing to the planned UAM aerodrome or routing to an alternative UAM aerodrome. The aircraft's automated systems execute the new operations plan upon the PIC's command. The destination UAM aerodrome assigns a priority landing arrival and parking slot, and the ground crew provides assistance once the aircraft lands. The FAA is unlikely to play an active role during this type of emergency, but incident reports are likely filed afterwards.

Weather Restricts Landing

If inclement weather restricts an aircraft's ability to safely land, the PIC communicates with the PSU to make the decision to execute an alternate operations plan. This can be a predetermined secondary operations plan or a new operations plan. New plans, which can include holding or a diversion to another UAM aerodrome, are negotiated between the PIC and PSU and are ultimately accepted by the PIC. The PSU or the fleet operator may suggest the new plan, but the PIC is responsible for acceptance and execution of the alternate plan. Upon selection of the plan, the PSU alerts other PSUs, airborne aircraft, and the alternate UAM aerodrome (if applicable) and interfaces with any weather SDSPs informing them of the current weather conditions. The aircraft's automated systems execute the new operations plan upon the PIC's command. This scenario highlights the importance of having a secondary operations plan ready at all times.

Non-cooperative Aircraft

There is an underlying assumption that PSUs have the capability to detect non-cooperative aircraft and determine if there is a conflict with other airborne aircraft. If a PSU detects an aircraft within the UOE and determines that it is non-cooperative (e.g., it is not identifying itself, not following its filed operations plan or does not have a filed operations plan), the PSU notifies the FAA (for their awareness) and a set of pre-identified UAM stakeholders such as aircraft, fleet operators, other PSUs, UAM aerodromes and possibly airports, and city authorities of the non-cooperative aircraft's position, direction of flight, and other available information by whatever means are available including sharing surveillance information if need be. The PSU incorporates tactical deconfliction and likely increases distance between aircraft (i.e., gives closely located aircraft additional buffer from minimum required aircraft separation) to enable increased margin for tactical maneuvers around non-cooperative traffic. The PSU may recommend to PICs and fleet operators new operations plans as part of the tactical deconfliction, and the aircraft's automated systems carry out those operations plans upon the PIC's command. If the PIC rejects the new operations plan, the fleet operator relays that information to the PSU and the PSU reevaluates and negotiates until a plan is accepted. Aircraft not impacted by the non-cooperative aircraft carry out their original intended operation. UAM aerodrome operators have no applicable role unless a new operations plan impacts their arrival schedule. In this scenario, UAM aerodrome operators negotiate with PSUs to deconflict arrivals as part of the plan development and are included in the PSU recommended operations plan to the PIC.

UAM Aerodrome Closure

If a UAM aerodrome is closed for any reason (safety criteria, weather, gate contention, etc.), it is the onus of the UAM aerodrome operator to inform the PSU. UAM aerodrome operators have established procedures for notifying PSUs that they are closed when communications links are broken. The PSU pushes this information to other PSUs, the fleet operators, other UAM aerodrome operators, and SDSPs, and identifies proposed route plans for airborne aircraft scheduled into the closed UAM aerodrome, and issues new routes to aircraft that are impacted by the closed UAM aerodrome. The airborne aircraft negotiate a new operations plan with the PSU and execute upon the PIC's command. The UAM aerodrome remains closed until the UAM aerodrome operator deems it safe for operations at which point it notifies the PSU who then informs the rest of the applicable stakeholders (PSUs, fleet operators, SDSPs, and other UAM aerodromes). Depending on the rationale for UAM aerodrome closure, the UAM aerodrome operator files an incident report.

Off-nominal Scenarios

As mentioned above, off-nominal scenarios reflect extraordinary events that may occur during UAM operations. These events are anticipated to occur extremely in-frequently (if at all) but are and planned for, nonetheless. As with contingency scenarios, stakeholders have developed plans and procedures to execute when off-nominal scenarios occur to ensure the safety of the passengers and operation. The below scenarios are meant to illustrate several examples of potential off-nominal scenarios. Each scenario describes the aspects of the operation that deviate from the nominal operation. These use cases are by no means exhaustive and these will likely be matured through research, test, and realization of UML-1 through -3.

Loss of Navigation—Single Aircraft

This off-nominal scenario examines a loss of navigation, for one or more aircraft, that occur in one of three ways: a failure of the aircraft's navigational equipage, a RFI/EMI interference disrupting the functionality of the navigational infrastructure, or a loss of connectivity with the PSU navigation infrastructure (which is addressed in a use case below). This scenario does not include lost communications. If the problem is an onboard equipment failure, the aircraft's automated systems switch to a redundant navigation system and the PIC informs the fleet operator and the PSU. If the problem is interference, the aircraft's automated systems switch to a redundant navigation option and the PIC informs the fleet operator and the PSU. Assuming the PSU is capable of conformance monitoring, the PSU would provide navigational recommendations through a communication path and notifies other aircraft of the issue and immediately provides additional separation if needed. The PIC decides if the aircraft should land or continue its path based on factors such as distance from UAM aerodrome. Any change of plans is negotiated with the PSU to ensure other operators remained informed. This will include additional services required from the UAM aerodrome so that is may prepare for the aircraft's landing. The fleet operator later files an incident report. The FAA is unlikely to play an active role during this type of emergency but would receive incident reports filed by the fleet operator.

PSU Network Outage

This off-nominal scenario examines a PSU Network loss of communications. This can impact the only PSU in a PSU Network, a subset of PSUs, or all PSUs in a multi-PSU Network such that a PSU can no longer reach fleet operators, aircraft, UAM aerodrome operators, and other key operational stakeholders. For airborne aircraft, the fleet operators and aircraft follow a predetermined SOP that is designed for this type of scenario. V2V communications are functional and fleet operators can communicate with each other and with their aircraft. The airborne aircraft continue to their destinations with current aviation standards. Depending on the level of network failure (one PSU versus many or all PSUs), UOE operations are suspended until network coverage is restored. The affected PSU(s) later file an incident report.

Unplanned Entry into ATC-controlled Airspace

UAM aircraft do not fly in ATC-controlled airspace, except for limited circumstances such as flying into or out of a UAM aerodrome co-located with an airport or preplanned operations involving UAM aircraft that are appropriately equipped and have filed operations plans. As a general rule, when a UAM aircraft has an unplanned entry into ATC-controlled airspace, the goal is to get the UAM aircraft out of the ATC-controlled airspace and back into the UOE as soon as possible. If the unplanned entry occurs, the PSU alerts the aircraft's automated systems, aircraft crew, and fleet operator of the incursion, and the fleet operator communicates with FAA (ATC) to notify them that they have entered the controlled airspace. ATC immediately deconflicts the airspace, notifies other traffic, and provides separation/clearance to the UAM aircraft. While in ATC-controlled airspace, aircraft carry out any instructions provided by ATC upon the PIC's command. Using conformance monitoring capabilities, the PSU moves other traffic out of the way from incursion upon reentry of the aircraft into the UOE. The UAM aerodrome does not play a role in this scenario.

Individual Aircraft Failure

This off-nominal scenario examines a situation that begins when a single aircraft has a critical system failure requiring an immediate landing due to a situation potentially impacting the control of the aircraft (e.g., loss of control due to propeller damage). This scenario impacts the affected aircraft and detects the critical error, initiates pre-identified procedures and notifies the PIC, Fleet operator, and PSU. The PIC acknowledges the critical failure, monitors initiated actions and can initiate additional actions to ensure the safety of the occupants, nearby aircraft, bystanders, and the aircraft itself. The PIC, if onboard, or the aircraft automated systems flies the aircraft to the nearest predetermined emergency landing location (note, this can be an existing UAM aerodrome, predetermined landing site, or safest viable landing location). The fleet operator notifies emergency services and personnel are dispatched to that location to assist the passengers and the aircraft as required. Upon landing, the PSU notifies other airborne aircraft, the fleet operators and SDSPs, and the UOE resumes normal operations. The fleet operator files an incident report. This scenario assumes that each aircraft in coordination with the PSU maintains a continually updated identified immediately available landing site.

All Aircraft Land

If there is a situation that warrants all aircraft in the UOE to immediately land (within a single metropolitan area), the following occurs. An "all land" order comes from the FAA, which triggers the sequence of events. The FAA is responsible for initiating this order. It may take this action based on information internal to the FAA or received from an external source. If applicable to ATM airspace, ATC would immediately clear ATC-controlled airspace. Within the UIOE, this order is transmitted to all PICs, fleet operators, PSUs, SDSPs, UAM aerodromes, and emergency landing site managers. As a normal precaution within the UOE, the PSUs dynamically take stock of how many available landing spaces there are at each UAM aerodrome and, if applicable, emergency landing areas to maintain the capability to issue new routes to these spots for all airborne aircraft contracted with them for services and ground stops to all others. This information is coordinated across PSUs so in the event of implementation, multiple PSUs do not assign aircraft to the same landing spot. The PIC carries out the instructions and flight profiles provided by their PSU. The aircraft's automated systems execute the new operations plan upon the PIC's command. UAM aerodrome and emergency landing site managers prepare all available landing sites and assist with that process. It is not anticipated that ATC managed traffic will land within the UOE, but if a PIC, fleet operator, or PSU desires to land an aircraft requiring transit through ATC airspace, they will pre-coordinate entry with ATC prior to entering that airspace.

Appendix E: Acronyms List

The follow list provides a list of the acronyms used in this document and their associated terms.

Table E1: Acronyms List

Acronym	Term
AAM	Advanced Air Mobility
AGL	Above Ground Level
ARMD	Aeronautics Research Mission Directorate
ASTM	American Society for Testing and Materials
ATC	Air Traffic Control
ATM	Air Traffic Management
CBR	Community-Based Rules
CFR	Code of Federal Regulations
CNSI	Communication, Navigation, Surveillance, Information
COR	Contracting Officer's Representative
CTOL	Conventional Takeoff and Landing
DAA	Detect-and-Avoid
DHS	Department of Homeland Security
DoC	Department of Commerce
DoD	Department of Defense
DoT	Department of Transportation
DST	Decision Support Tool
EMI	Electromagnetic Interference
EPA	Environmental Protection Agency
ETA	Estimated Time of Arrival
eVTOL	electric Vertical Takeoff and Landing
FAA	Federal Aviation Administration
FCC	Federal Communications Commission
FIMS	Flight Information Management System
FOQA	Flight Operational Quality Assurance
GA	General Aviation
GCTC	Global Cities Technology Challenge
GPS	Global Positioning System
HEC	high-end computing
hVTOL	hybrid Vertical Takeoff and Landing
IASMS	In-time Aviation Safety Management System

Acronym	Term
ILS	Instrument Landing System
IoT-A	Internet of Things-Architecture
IP	Internet Protocol
ISSA	In-time System-wide Safety Assurance
LAANC	Low Altitude Authorization and Notification Capability
LOC	Localizer
MOQA	Maintenance Operational Quality Assurance
MRO	Maintenance, Repair, and Overhaul
NAS	National Airspace System
NASA	National Aeronautics and Space Administration
NCAR	National Center for Atmospheric Research
NEPA	National Environmental Policy Act
NFPA	National Fire Protection Association
NOAA	National Oceanic and Atmospheric Administration
NOTAM	Notice to Airmen
NTIA	National Telecommunications and Information Administration
NWS	National Weather Service
OV	Operational View
PBN	Performance-based Navigation
PIC	Pilot in Command
PSU	Provider of Services to UAM
RF	Radio Frequency
RFI	Radio Frequency Interference
RNAV	Area Navigation
RPIC	Remote Pilot in Command
RTCA	Radio Technical Commission for Aeronautics
SAA	Special Activity Airspace
SDSP	Supplemental Data Service Provider
SIC	Second in Command
SOP	Standard Operating Procedure
STOL	Short Takeoff and Landing
SUA	Special Use Airspace
sUAS	small Unmanned Aircraft System
TBO	Trajectory-Based Operations
TLOA	Touchdown and Lift-off Area
TSA	Transportation Security Agency
U4-UOE	UAM Operations Environment at UML-4
UAM	Urban Air Mobility

Acronym	Term
UAS	Unmanned Aircraft System
UCAT	UAM Coordination and Assessment Team
UML	UAM Maturity Level
UOE	UAM Operating Environment
US	United States
USS	UAS Service Supplier
UTM	UAS Traffic Management
V2V	Vehicle-to-Vehicle
VFR	Visual Flight Rules
VTOL	Vertical Takeoff and Landing

Appendix F: Glossary

This glossary of terms is a quick reference to define terms that were either defined in the body of the document or require further expansion. While not an exhaustive list of all terms, those defined below are those that are the most important to understand and illustrate the concepts of UAM at UML-4. This glossary will be expanded upon and refined as concepts mature, research is completed, testing is performed, and UML-1 through -3 are realized.

Advanced Air Mobility (AAM): Safe, sustainable, affordable, and accessible aviation for transformational local and intraregional missions. AAM includes UAM as well as many other missions, including different forms of passenger transport, cargo transport, and aerial work missions. These missions may be performed with many types of aircraft (e.g., manned or unmanned; conventional takeoff and landing (CTOL), short takeoff and landing (STOL), or VTOL), over/between many different locations (e.g., urban, rural, suburban), and to/from far more locations than typical commercial aviation (e.g., novel UAM aerodromes, existing underutilized small/regional airports). Local and intraregional missions are likely less than approximately 75 nautical miles and 300 nautical miles, respectively, though these ranges are not strict upper limits.

Aircraft Crew: A human or humans partially responsible for the safe flight of the aircraft who share this responsibility with some automated system(s). An aircraft crew member is not a traditional pilot, but rather performs the role of aircraft operator, multi-aircraft operator, or aircraft steward. An aircraft operator may be either onboard or off-board, a multi-aircraft operator is located off the aircraft, and an aircraft steward is located onboard. One aircraft crew member is designated the PIC (or RPIC) at a time, though the PIC or RPIC may change during flight. Typically, the aircraft crew work on behalf of the fleet operator to support UAM operations. A fleet operator can utilize a traditional pilot, a single aircraft crew member, or a combination of aircraft crew members as required for safety in light of their particular business model. For example, the use of an onboard aircraft crew may bolster public acceptance by providing human interaction throughout the UAM experience.

Barrier: Challenge(s) across the entire UAM ecosystem that must be addressed to enable the UAM vision. Barriers include, but are not limited to, challenges that have no currently known solution pathway.

Detect and Avoid (DAA): Systems that provide situational awareness to an aircraft that enable the identification of other air traffic or hazards and the ability to take appropriate action to mitigate collision risk. DAA systems are typically categorized as onboard or ground-based depending on where the hardware of the system is located.

En Route Area: The airspace where aircraft can cruise during flight that is away from the terminal areas.

Federated: A group of systems and networks operating in a standard and connected environment. In the UAM ecosystem, a federated network leverages commercial services and enables a flexible and extensible construct that can adapt and evolve as the trade space changes and matures.

Fleet Operator: The fleet operator of the aircraft who hires the aircraft crew (if the aircraft fleet operator is not also the aircraft crew) and in some instances performs dispatch duties. A fleet may consist of one aircraft.

Flight Information Management System (FIMS): FIMS is an interface for data exchange between FAA systems and UTM/UAM participants. FIMS enables exchange of airspace constraint data between the FAA and the PSU Network. The FAA also uses this interface as an access point for information on active UAM operations. FIMS also provides a means for approved FAA stakeholders to query and receive post-hoc/archived data on UAM operations for the purposes of compliance audits and/or incident or accident investigation. FIMS is managed by the FAA and is a part of the UAM ecosystem

High-Density Route: An area of the UOE that is designated for high-density traffic. What differentiates these routes from other parts of the UOE is that they may be limited to aircraft that meet certain performance characteristics in other to enable safe, seamless high-density operation.

Performance Authorization: An FAA regulatory approval for fleet operators to perform a specific UAM operation. A performance authorization substantiates the fleet operator's ability to meet performance capabilities in their intended area of operation. The FAA grants a performance authorization when a fleet operator's proposed assets (including potentially both ground and air assets) are sufficient to meet an established level of performance in the airspace in which they intend to operate. Performance authorization requests must be submitted by the fleet operator, not a PSU or other entity, regardless of whether the PSU or SDSP will provide services or capability/technology packages to support the fleet operator's ability to meet the performance requirements.

Pillar: The integration of UAM into the NAS is complex; NASA has broken down the challenges into five areas, termed "pillars," where technical progress needs to be made.

Pilot in Command (PIC): An individual, human person who has final authority and responsibility for the operation and safety of flight, has been designated as PIC by the fleet operator, and holds the appropriate licenses and qualifications to conduct the flight. A PIC may be on or off-board the aircraft.

Provider of Services to UAM (PSU): Public or private (e.g., third-party) entities that provide ATC and flight safety services under rules and regulations established by the FAA. Services provided by PSUs include routing, traffic deconfliction, operational constraints, modifications, notifications, and information. A PSU is analogous to a USS in the UTM paradigm and is contracted by the fleet operator (i.e., airspace user).

PSU Network: The amalgamation of PSUs connected to each other and exchanging information. Each PSU is required to share certain information with the other PSUs to provide a complete operating picture and situational awareness.

Second in Command (SIC): A human onboard the aircraft with secondary and tertiary operational responsibility behind aircraft automated systems and the PIC. In instances where an onboard SIC exists, it is assumed that the PIC is operating in a remote capacity. The SIC has more responsibility than an aircraft steward and is fully trained and qualified for the assigned roles and responsibilities. A SIC does not require the same qualifications as a PIC. The SIC is a necessary role to build the safety case for a single PIC with operational control for more than one aircraft at a time.

Strategic Deconfliction: First-level conflict management to deconflict the intended routes of UAM operations to provide separation and avoid collision during flight. Strategic is used here as "in advance of tactical." Strategic deconfliction efforts typically prior to departure and will typically be provided by the PSU Network.

Supplemental Data Service Provider (SDSP): Data sources external to the PSUs that supplement the decision-making and information-sharing of the PSU and fleet operator. These can include weather sources and ground risk assessments, among others. PSUs can access SDSPs via the PSU Network for essential or enhanced services (e.g., terrain and obstacle data, specialized weather data, surveillance, constraint information). SDSPs may also provide information directly to PSUs or fleet operators through non-PSU Network sources (e.g., public or private internet sites).

Tactical Deconfliction: Second-level conflict management to deconflict UAM operations during flight to maintain separation and avoid collisions. Whereas strategic deconfliction occurs prior to departure, tactical deconfliction occurs during flight.

Terminal Area: The immediate vicinity around a UAM aerodrome or airport where departures and landings occur.

Urban Air Mobility (UAM): Our vision of UAM is a safe, efficient, convenient, affordable, and accessible air transportation system for passengers and cargo that revolutionizes mobility around metropolitan areas. This vision includes everything from small package delivery drones to passenger-carrying air taxis that operate above populated areas.

UAM Aerodrome: A specifically defined area that is intended for the arrival, departure, and ground movement of UAM aircraft.[31] Because of the VTOL/eVTOL nature of many UAM aircraft, most UAM aerodromes look more like today's heliports with landing pads as opposed to long runways.

UAM Aerodrome Operators: UAM aerodrome operators are entities responsible for ensuring the safety of individual TLOA, as well as any ground services (embarkation, disembarkation, maintenance, etc.) provided at a UAM aerodrome. UAM aerodrome operators may be private or public entities.

UAM Maturity Level (UML): A NASA-developed framework categorizing anticipated evolutionary stages of a UAM transportation system from the beginning state to a highly developed state where UAM is a ubiquitous capability, similar to automobiles today. This framework includes six maturity levels, with UML-1 representing the earliest maturity level and UML-6 representing full ubiquity. The ConOps focuses on UML-4, an intermediate state, where hundreds of operations could be occurring at any given time within a single metropolitan area.

UAM Operations Environment (UOE): The UOE is a flexible airspace volume encompassing the areas of high UAM flight activity. UOE is a UTM-inspired construct and is not a separate airspace class. The UOE is deliberately designed for each local area to accommodate UAM flights. The UOE may extend into portions of actively ATC-controlled airspace (i.e., the Class B, C, or D airspace surrounding an airport) to enable UAM flights to access this airspace without burdening ATC. Such access may be necessary for UAM flights to access a UAM aerodrome collocated with a commercial airport.)

U4-UAM Operations Environment (U4-UOE): The UOE at UML-4. UAM aircraft at UML-4 operate predominantly in the U4-UOE.

Urban Canyon: Locations in the urban setting between buildings, such as where a street is flanked by tall buildings. Weather in urban canyons can differ from the surrounding areas outside, particularly with respect to temperature, wind patterns, and air quality.

[31] International Civil Aviation Organization, *International Standards and Recommended Practices: Aerodromes—Annex 14 to the Convention on International Civil Aviation*, November 1, 1951, https://www.icao.int/APAC/Meetings/2015%20WAWG1/an14_1ed_1951.pdf.

Appendix G: Contributing Stakeholders

The below list includes organizations whose research, interviews, and input (through various mediums) contributed to this ConOps. NASA thanks the following:

1. A^3 by Airbus
2. Aerospace Industries Association (AIA)
3. Airmap
4. Airvant Solutions
5. AiRXOS
6. Akin Gump
7. Amazon
8. American Institute of Aeronautics and Astronautics
9. Arizona Commerce Authority
10. Assure—FAA's Center of Excellence for UAS Research
11. Aurora Flight Sciences
12. Aviators Code Initiative
13. Boeing
14. City of Los Angeles
15. City of San Diego
16. Commercial Drone Alliance
17. Community Air Mobility Initiative (CAMI)
18. Congressional Research Service
19. Cora Aerospace
20. Crown Consulting
21. Dallas/Fort Worth International Airport (DFW)
22. Deloitte
23. DLR
24. Duke University
25. EmbraerX
26. Embry-Riddle Aeronautical University
27. ETH Zurich
28. Eurocontrol
29. European Cooperation in Science and Technology
30. FAA
31. Federal Communications Commission (FCC)
32. Gannett Fleming
33. Giuas
34. Google
35. Hogan Lovells
36. Hughes Aerospace
37. International Council of the Aeronautical Sciences
38. Iowa State University
39. Kitty Hawk IO
40. KPMG
41. L3Harris
42. Lockheed Martin
43. Lockheed Martin Corporation
44. Lone Star UAS Center of Excellence & Innovation
45. Los Angeles Department of Transportation
46. Los Angeles World Airports (LAWA)
47. Massachusetts Institute of Technology
48. MDPI
49. MITRE
50. Nanyang Technological University, Singapore
51. National Aeronautics and Space Administration (NASA)
52. National Air Traffic Controllers Association (NATCA)
53. National Business Aviation Association (NBAA)
54. National Institute of Aerospace (NIA)
55. National Institute of Standards and Technology (NIST)
56. North Carolina Department of Transportation
57. Northeast UAS Airspace Integration Research (NUAIR)
58. Northern Plains UAS Test Site
59. Northrop Grumman Corporation
60. Pipistrel
61. Queensland University of Technology (Australia)
62. Rand Corporation
63. RMIT University (Australia)
64. Rockwell Collins
65. Roland Berger
66. SAE International
67. SAIC
68. Stanford University
69. Starburst Aerospace
70. Technical University of Munich
71. Texas A&M University-Corpus Christi (TAMUCC)
72. Texas UASWERX
73. U.S. House of Representatives: The Committee on Science, Space, and Technology
74. The MITRE Corporation
75. The University of Newcastle (Australia)
76. TruWeather

77. Uber
78. Uber Elevate
79. University of California, Berkeley University of Michigan
80. University of North Dakota
81. University of Wisconsin
82. US Air Force
83. US Department of Defense (DOD)
84. US Department of Justice (DOJ)
85. US Department of Transportation (DOT)
86. US Government Accountability Office (GAO)
87. US National Cooperative Highway Research Program
88. US Office of Inspector General
89. Vertical Flight Society (VFS)
90. White House Presidential Innovation Fellows
91. Wisk
92. World Bank Group
93. World Economic Forum

Appendix H: Bibliography

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