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UAM Airspace Research Roadmap Rev 2.0

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Change Log

Version	*Date*	*Purpose*
1.0	Sep 2021	Baseline
1.1	Mar 2022	• Incorporated NASA stakeholder comments and input throughout • Added Secured Airspace research element • Added subproject application, with progress visualization
1.2	Jun 2022	• Updated per NASA/FAA Comment review • Definitions section added and expanded • System Actors updated • Added Vertiport and Weather research elements • Added requirement IDs
2.0	Feb 2023	Updated per NARI AEWG Airspace WG review

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1 Introduction

Advanced Air Mobility (AAM) encompasses a range of innovative and technological changes to aviation (electric aircraft, increasingly automated aircraft, increasingly automated airspace operations, etc.) that are transforming aviation's role in everyday movement of people and goods. The Urban Air Mobility (UAM) concept covers a subset of the AAM concepts, namely those that provide air-taxi services to the public over densely populated cities and the urban periphery, including flying between local, regional, intra-regional, and urban locations. UAM envisages a future in which advanced technologies and new operational procedures enable practical, cost-effective air transport as an integrated mode of movement of people and goods in metropolitan areas. In this document, UAM operations are further scoped by those which are enabled by revolutionary new electric Vertical Takeoff and Landing (eVTOL) aircraft designs that are now becoming feasible.

To safely support UAM operations at scale in the National Airspace System (NAS), NASA's Air Traffic Management-Exploration (ATM-X) UAM Airspace Subproject is conducting research that evolves the UAM air traffic management system towards a highly automated and operationally flexible system of the future. The scope of this research includes the conduct of UAM operations in relationship to other NAS operations, the supporting technologies and information exchanges, and the architecture of the associated systems and services.

The UAM Maturity Level (UML) scale [1] was developed by NASA to provide insight into UAM operational, technical, and regulatory evolution in the NAS. The UML framework is used herein to help understand the future NAS by stepwise introduction of new operational capabilities. Although the NAS evolves continuously, certain accumulated changes represent a phase change to UAM operations (e.g., demand-capacity balancing, time-based flow management, unpiloted operations). This document establishes a complementary framework to study this phased progression, and to help NASA deliver validated requirements, assumptions, and system architectures for the transformation of the aviation system of systems that will be brought about by UAM.

The complexity of the UAM airspace progression requires a plan to effectively organize, integrate, and communicate NASA's research and development in the area. The UAM airspace system research roadmap, or just roadmap, is a system engineering methodology to manage what is known, what is developed, and what is planned for in NASA's UAM airspace research & development (R&D) lifecycle.

To establish this methodology for UAM airspace, the entire UAM system of systems must be considered. To operationalize a concept, the ultimate need to be interoperable with other NAS ecosystems must always be met. Through the application of the UAM airspace research roadmap, NASA will take proactive steps to adopting an integrated and holistic R&D approach early in the lifecycle. While not all elements and components of the UAM airspace system will be directly addressed by NASA R&D, it is important to have a complete view that unifies assumptions and requirements across the system of systems.

2 UAM Airspace System

This section will define the UAM airspace system, the system actors, and the constraints and assumptions that are applied in this document. Definitions are *italicized* upon first usage and provided in the Glossary (Appendix B).

2.1 System Definitions

The system of interest is the *UAM Air Traffic Management (ATM) System*, colloquially referred to as *UAM airspace*. It is composed of multiple *capabilities* which combine to achieve the safety and performance of UAM traffic management in the airspace. This is enabled through the provision of facilities and seamless services, done in collaboration with all parties [2]. Each capability is characterized by a combination of specific functions, services, and other features which are generally referred to as *components*.

The UAM airspace system is initiated and driven by the *system actors* that interface externally to, and act upon, the system. The system actors exchange information with the system and with each other. See Fig 1 to relate these definitions to the identified system of interest.

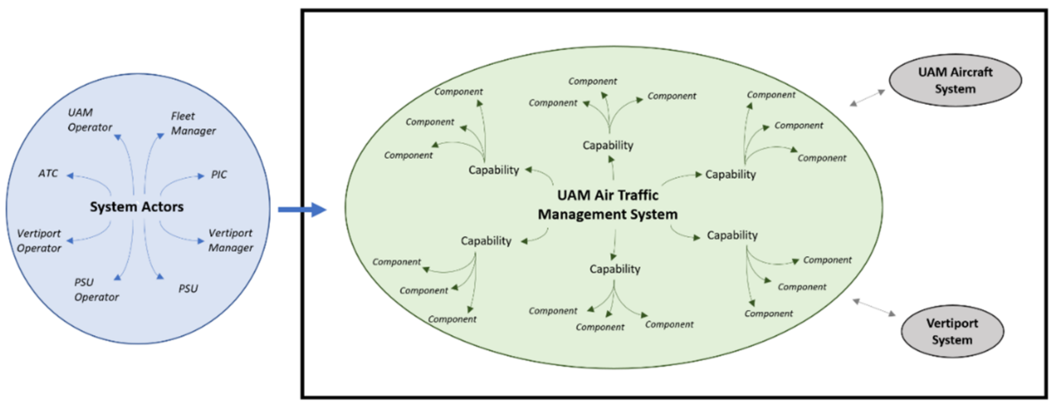

Figure 1. System of Interest and System Actors

The system actors are generally composed of a combination of *humans* and *automation*, as illustrated in Fig 2 below. The system actors will act according to well-defined roles and responsibilities (R&R) which can be described in terms of *authority*, *responsibility*, and *accountability*. Authority is the power to act and is generally bestowed by an organization or by law [3], and there should be no ambiguity around which system actor is authorized for a particular role. Responsibility is the obligation to act correctly, each according to their role. A system actor is accountable for the failure to fulfill their role, which is to say that their actions must be explained.

Automation can be either *automatic* or *autonomous*, and the automation component of a system actor may be composed of both automatic and autonomous subsystems. Automatic systems perform their function according to a predefined process, and the human in command can be assured that outcomes will be as expected a priori.

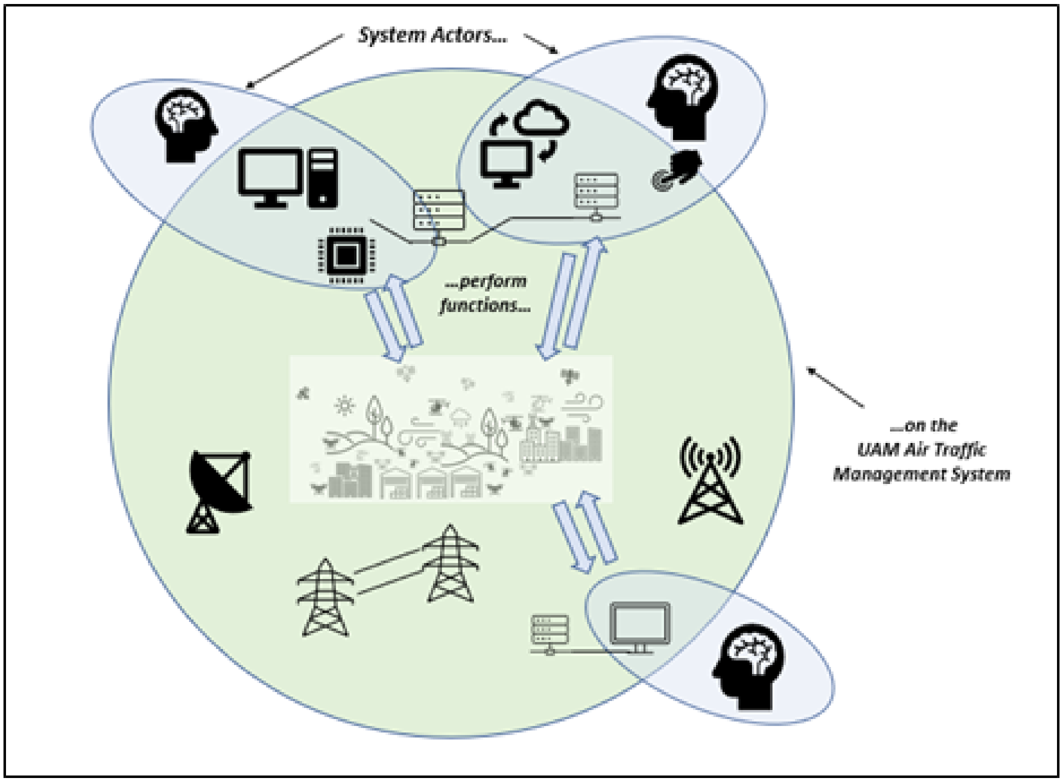

Figure 2. System Actors

Autonomous systems are capable of independently determining a new course of action in the absence of a predefined plan and have been authorized to do so. Autonomous systems make decisions based on their knowledge and understanding of the operational environment and situation.

How a system actor achieves the intended function can often be modeled as a *control system*, which manages, commands, directs, or regulates system behavior using *control loops* [4]. A control loop is a series of control operations that derive from receiving reference inputs and system state feedback, deciding on a desired state, and acting to reach that state. As a complex arrangement of interacting control systems, in which the system actors exercise the authority imbued in their roles, UAM airspace is fundamentally a *command and control* system.

An important characteristic of the command and control design is the level of authority and ability that a human has over the control loop. *Human in the loop* is used to describe a configuration where the human must act for the system to perform its intended function. *Human on the loop* describes a configuration in which the automation has the authority to act without human interaction or additional authority. In such configurations, the human still can change the behavior of the system but may also choose to allow autonomous control. *Human over the loop* describes a configuration in which the human can guide overall system behavior, but the automation has the authority to act without the human or any additional authority. *Human out of the loop* describes a configuration in which the human is unable to intervene or provide guidance to the control system, except possibly to grant or revoke the authority for the automation to act.

The level of authority and ability that the automation components have over the control loop can also be characterized. *Automation in the loop* refers to a configuration where the automation is required, and must act in order for the system to achieve the intended function. *Automation on the loop* refers to a configuration where the automation can intervene and is authorized to act under appropriate conditions, and when necessary to achieve the intended function. *Automation over the loop* refers to a configuration where automation forewarns the human on the need to act. The intended function of the automation in these cases is to provide guidance to the human and has no authority to act. *Automation out of the loop* refers to a configuration where the automation has no ability to affect the operational function and is used primarily to collect or provide data to humans or other automation systems.

The design of a control system is constrained by the possible outcomes if it fails. A *safety-critical system* is a system whose failure or malfunction may lead to catastrophic outcomes, such as death or serious injury to people, loss or severe damage to property, or environmental harm. A *safety-enhancing system* is a system whose failure or malfunction may lead to minor outcomes at most. A *mission-critical system* is one whose failure or malfunction may lead to serious impact on business operations or upon an organization and can lead to social turmoil and near-catastrophic outcomes.

2.2 UAM Airspace System Actors

The system actors are derived from five of the eight members of the ATM Community defined in Appendix A of [2], enumerated in the list below in no particular order of importance or priority.

- Aerodrome Community
- Airspace User
- ATM Service Provider
- ATM Support Industry
- Regulatory Authority

The system actors for UAM Airspace are defined to be all-encompassing of the UAM operational concept. In specific UAM use cases, two or more system actors may coincide. The system actors for UAM are enumerated below for convenience, organized first by ATM Community member, and then in alphabetical order.

- Aerodrome Community
  - Vertiport Manager
  - Vertiport Operator
- Airspace User

  - Fleet Manager
  - Pilot-in-Command (PIC)
  - UAM Operator

- ATM Service Provider
  - Air Traffic Control (ATC)
  - FAA
  - Provider of Services to UAM (PSU)
  - PSU Operator
  - Communication Service Provider (CSP)
  - Surveillance Service Provider (SSP)
  - Meteorological Service Provider (MSP)

- ATM Support Industry
  - Supplemental Data Service Provider (SDSP)

- Regulatory Authority
  - FAA
    * FAA Aircraft Certification (AIR)
    * FAA Flight Standards (AFS)
    * FAA Air Traffic Organization (ATO)
    * FAA Aviation Safety (AVS)

2.2.1 Aerodrome Community

The UAM aerodrome community includes aerodromes, the aerodrome operator and other parties involved in the provision and operation of the physical infrastructure needed to support the take-off, landing and ground handling of aircraft [2]. For UAM Airspace, the system actors from this community are vertiport managers, and vertiport operators.

Vertiport Manager: The individual(s) and/or automation responsible for managing operations at one or multiple vertiports and support the safe takeoff, landing, and surface operations of each incoming and outgoing flight.

Vertiport Operator: The entity accountable for the overall management of vertiport operations including approvals, compliance, credentialling, which may represent the organization that is executing the operations (e.g., a Fixed Base Operator).

Note: The numerous aerodrome activities not directly related to aircraft flight operations (e.g., passenger processing, baggage handling, catering services, customs and immigration) are outside the scope of the ATM operational concept. In some cases, the vertiport manager will be part of the vertiport operator organization but there may be situations where they are different organizational entities and thus defined separately.

2.2.2 Airspace User

Organization operating the aircraft in the NAS. For UAM Operations scoped by this document, the specific airspace users are the air taxi operators operating in and around urban areas on relatively short-haul flights. This may include aircraft with and without on-board pilots. Other civil and non-civil airspace users are important to NAS integration, but this document only considers air taxi operators. The system actors from this group are the UAM Operator, the Fleet Manager, and the Pilot-in-Command..

Fleet Manager: The individual(s) and automation responsible for maintaining operational control for a network of UAM aircraft providing air taxi services to the public on behalf of the UAM Operator.

Note: Operational control, with respect to a flight, means the exercise of authority over initiating, conducting, or terminating a flight. (14 CFR § 1.1)

Pilot-in-Command (PIC): The Pilot-in-Command (PIC) is defined in 14 CFR § 1.1 as the person who:

1. Has final authority and responsibility for the operation and safety of the flight;
2. Has been designated as pilot in command before or during the flight; and
3. Holds the appropriate category, class, and type rating, if appropriate, for the conduct of the flight.

Furthermore, 14 CFR § 91.3 establishes that the PIC is directly responsible for and has final authority for safe operation of the UAM aircraft.

Note: An aircraft requiring a dedicated PIC responsible for the flight may be commanded by a remote PIC from another place not on-board the aircraft (e.g., ground, another aircraft, space). When the distinction is necessary, the terms onboard PIC or remote PIC will be used. When there is no qualifier, then PIC includes both onboard and remote.

Remotely Supervised Aircraft: Programmed and fully autonomous UAM aircraft, with the ability to operate under limited human supervision and largely independent of external control [2]. The remotely supervised aircraft is responsible for control actions that ensure safe operation with management and guidance from an individual who is accountable for operational control.
Note: Requirements for Remotely Supervised Aircraft have not yet been identified. The relationship between the PIC and the Remotely Supervised Aircraft will be further defined and analyzed in future versions.

Remote Supervisor: The individual who is accountable for operational control of one or more Remotely Supervised Aircraft. The remote supervisor is also directly responsible for and has final authority for the safe operation of the aircraft.
Note: Requirements for Remote Supervisor have not yet been identified. The relationship between the PIC and the Remove Supervisor will be further defined and analyzed in future versions.

UAM Operator: The entity or organization accountable for the overall management and execution of one or more UAM operations (14 CFR § 1.1). As operators of air taxi services which typically will operate a fleet of UAM aircraft, the UAM Operator is often referred to as the Fleet Operator. Other configurations of the UAM Operator are possible, for example a single UAM aircraft owner/operator.

2.2.3 ATM Service Provider

Organizations and personnel (e.g., controllers, engineers, technicians) and automation systems engaged in the provision of ATM services to the Airspace Users [2]. The system actors from this group are the FAA, the Air Traffic Control (ATC), the Provider of Services to UAM (PSU), the PSU Operator, the Communication Service Provider (CSP), the Surveillance Service Provider (SSP), and the Meteorological Service Provider (MSP).

Air Traffic Control (ATC): Personnel and equipment responsible for delivering Air Traffic Management (ATM) services on behalf of the FAA. For UAM operations, Tower, Terminal Radar Approach Control (TRACON), Air Route Traffic Control Centers (ARTCC) and Air Traffic Control System Command Center (ATCSCC) controllers and personnel are the primary providers of separation services for ATC and the Traffic Managers provide flight and flow services.

FAA: The FAA is the regulatory agency for civil aviation in the NAS, including but not limited to delivering ATM services, certification of personnel and aircraft, and standards for airports and vertiports to ensure aviation safety and minimize environmental impact.

Provider of Services to UAM (PSU): The individual(s) and/or automation responsible for managing the provision of information services associated with airspace operations to the UAM Operator. Agents of the UAM operator may interact with the PSU include Fleet Managers, and PICs.

Note: According to the conventions applied to system actors in this document, this may have been referred to as the "PSU Manager". However, the term PSU is used without the qualifier due to how it is overwhelmingly used in practice.

PSU Operator: An entity or organization accountable for providing information services associated with airspace operations to the UAM Operators and their agents. The PSU Operator also provides the ability to securely share information with other UAM Operators over the PSU Network, and to support ongoing maintenance of the services. The PSU Operator may be a State-owned self-financing corporation, a privatized organization, a regional organization, or an independent private sector organization [2].

Communication Service Provider (CSP): broad title for a variety of service providers in broadcast and two-way communications services. A CSP offers telecommunications services over a network infrastructure that support a range of functions for UAM Operations. The CSP will leverage a range of communications infrastructure, as well as transformational digital technologies such as artificial intelligence, analytics and automation [5]. The CSP may be a State-owned self-financing corporation, a privatized organization, or an independent private sector organization.

Note: Requirements for the CSP have not yet been identified. The relationship between the CSP and the Supplemental Data Service Provider will be further defined and analyzed in future versions.

Surveillance Service Provider (SSP): An entity or organization providing services in aircraft detection and resolution of key flight attributes such as position, flight level, speed, and intent. An SSP offers surveillance services based on a variety of measurement, processing, and inferential techniques. Cooperative and non-cooperative surveillance. The SSP may be a State-owned self-financing corporation, a privatized organization, or an independent private sector organization.
Note: Requirements for the SSP have not yet been identified. The relationship between the SSP and the Supplemental Data Service Provider will be further defined and analyzed in future versions.

Meteorological Service Provider (MSP): An entity or organization providing services in weather observations and predictions on the airfield and aloft. An MSP delivers consistent, timely and accurate weather information for the UAM airspace system, leveraging a network of sensors and computational resources. The MSP may be a State-owned self-financing corporation, a privatized organization, or an independent private sector organization.

Note: Requirements for the MSP have not yet been identified. The relationship between the MSP and the Supplemental Data Service Provider will be further defined and analyzed in future versions.

2.2.4 ATM Support Industry

The ATM support industry offers systems and services used by ATM service providers to provide communications, navigation, and surveillance/air traffic management (CNS/ATM) facilities and seamless services that achieve the ATM operational concept. For UAM Operations scoped by this document, only Information Service Providers are considered. For UAM Airspace, the system actor is the Supplemental Data Service Provider whose definition is taken verbatim from that of the Information Service Provider [2].

Supplemental Data Service Provider (SDSP): Government or private sector organizations that are not ATM Service Providers per se but that are engaged in the collection and dissemination of air navigation related information of an operational nature. This includes environmental information (e.g., charts, navigation databases); ground, airborne and space-based meteorological data; and aviation weather observations and forecasting. For simplicity, this actor refers to both the accountable organization and the human(s) and/or automation responsible for delivering the service.

Note: Other categories of ATM Support Industry which do apply to UAM Airspace but are not considered here are a) R&D Organizations; b) Standards Development

Organizations; and c) Equipment and Vehicle Manufacturers.
Note: The distinction between SDSP, CSP, SSP and the MSP will be further defined and analyzed in future versions.

2.2.5 Regulatory Authority

The Regulatory Authority is responsible for certain aspects of the overall performance of the aviation industry — most significantly, aviation safety — and other areas, including the environmental impact and international trade [2]. For UAM Operations, the FAA is the organization with regulatory authority of the aviation industry and has already been defined above. There are multiple organizations within the FAA that play a part in providing that regulatory authority. A few of these are identified below for the reader's information but the document will generally apply the term "FAA" throughout.

FAA Air Traffic Organization (ATO): One of the eight Lines of Business (LOBs) for the FAA. The Air Traffic Organization (ATO) is the operational arm of the FAA. It is accountable for providing safe and efficient air navigation services to 29.4 million square miles of airspace [6].

FAA Aviation Safety (AVS): One of the 8 Lines of Business (LOB) for the FAA. Aviation Safety (AVS) is an organization responsible for the certification, production approval, and continued airworthiness of aircraft; and certification of pilots, mechanics, and others in safety-related positions. AVS is also responsible for:

- Certification of all operational and maintenance enterprises in domestic civil aviation
- Certification and safety oversight of approximately 7,300 U.S. commercial airlines and air operators
- Civil flight operations
- Developing regulations

FAA Aircraft Certification (AIR): Within the FAA's Aviation Safety LOB, the Aircraft Certification organization is comprised of the engineers, scientists, inspectors, test pilots and other experts responsible for oversight of design, production, airworthiness certification, and continued airworthiness programs for all U.S. civil aviation products and foreign import products.

FAA Flight Standards (AFS): Within the FAA's Aviation Safety LOB, the Flight Standards organization sets the standards for certification and oversight of airmen, air operators, air agencies, and designees. Services provided by AFS to promote safety of flight of civil aircraft and air commerce include; accomplishing certification, inspection, surveillance, investigation, and enforcement; setting regulations and standards, and; managing the system for registration of civil aircraft and certification of airmen.

2.3 Constraints

Constraints are the restrictions placed on the definition of the UAM airspace system to establish scope for this research roadmap. Constraints impose a choice between alternatives and are useful when a clear choice does not exist. In the absence of constraints, the research requirements may become too vague to be useful. Reference [7] generally sets constraints on the design for UAM airspace system. The primary constraints applied to the UAM airspace system definition come from the UAM Concept of Operations [7], which applies the paradigm of Extensible Traffic Management (xTM) [1]. As a result, UAM airspace is characterized by a cooperative control environment that is part of a federated and automated service-based Air Traffic Management (ATM) System [11].

- The UAM airspace system architecture includes greater federation than the current NAS, with central authority derived largely from the Air Navigation Service Provider (ANSP) [7]. Federated architectural elements are ones where governance is divided between a central authority and constituent units, balancing organizational autonomy with enterprise needs [12]. The role of the central authority is to ensure the well-being of the enterprise, while constituent units have the flexibility to pursue individual strategies and independent processes.
- The UAM airspace system actors comprise a distributed constituency of operators and service providers, who satisfy defined roles and responsibilities safely and with increasing flexibility as the system evolves [7]. The airspace system will be cooperatively managed by a complex set of system actors, following a common set of community-based rules (§ 5.3). These rules and the resulting behaviors will lead to the safe, orderly, and expeditious flow of air traffic [13].
- The UAM Operators will have increased operational independence, flexibility, and access to airspace operations, through use of an array of qualified or certified services and technologies [1].
- The UAM airspace system will be increasingly dependent on automation to enable higher density operations while minimizing or eliminating the burden on controllers and pilots.

2.4 Assumptions

Assumptions are aspects of the UAM airspace system that are reasonably believed to be true. They are derived from stakeholder's expectations, experience, or knowledge at hand.

Assumptions are also captured in Section 5, where "**will**" is used to indicate an assumption. The following assumptions apply to the definition of the UAM Airspace System as a whole.

[1] Other examples of the xTM paradigm include small Unmanned Aircraft System (UAS) Traffic Management (UTM) [8, 9] and Upper Class E Traffic Management (ETM) [10]

- Automation that is used to support a safety-critical intended function will have appropriate oversight. Similarly, automation that supports safety-enhancing or mission-critical functions will be regulated appropriately.

- The UAM airspace system will move through a series of progressive stages, from the current NAS to a NAS with integrated UAM operations accommodating a community of airspace users and ATM service providers to safely manage the airspace at scale.

- The systems and services that support the UAM Operator in complying with regulatory and community-based rules and requirements will evolve towards being highly automated [1].

- Aircraft will be equipped to meet the performance requirements of the airspace in which they are operating.

- UAM operations will be conducted in all classes of airspace except Class A.

- UAM Aircraft will operate in and out of controlled and uncontrolled airports, including those with and without dedicated vertiports.

  Note: Airport is defined as any area of land or water that is used, or intended for use, for the landing and takeoff of aircraft (14 CFR § 152.3).

- UAM operations will be enabled by airspace constructs and airspace management techniques which minimize or eliminate additional workload for Air Traffic Control (ATC).

  Note: Examples of proposed solutions for such enabling airspace constructs include Vertiports (distinct from existing heliports, or existing areas on an airport surface), Vertiport Operations Area (VOA), Vertiport Volume (VPV) [14], new routes or waypoints, metering arcs, and UAM Corridors [7].

- As the demand for UAM services increases, new capabilities involving increases in automation, new procedures, airspace designs, and regulatory changes will be needed to enable higher density operations

- UAM aircraft will initially have an onboard Pilot in Command (PIC), with remote PIC becoming more commonplace as level of automation increases and novel operational changes are established [1].

- The rules and processes that govern the behavior of the system actors, including the automation, lead to safe and expeditious flow of traffic, equitable, and transparent access to the UAM airspace system.

- The UAM aircraft is an electric Vertical Takeoff and Landing (eVTOL) design.

3 UAM Airspace System Progression

The UAM airspace system will move through a series of progressive stages, with each stage defined by a set of capabilities that have been enabled in the NAS. While any prediction of how these stages may progress will be uncertain, some reasonable path or set of paths can be established and refined as the research advances.

The progression of the NAS through the UMLs from an airspace system perspective is summarized below in operational terms so that progression of the enabling capabilities can be derived later. This progression is largely drawn from the FAA NextGen UAM Concept of Operations v1.0 [7] and existing UML definitions [1] but is adapted based on numerous other inputs. With some exceptions, UML-1 and UML-2 defined below correspond to "Initial UAM Operations" [7, §3.1], and UML-3 and UML-4 correspond with "ConOps 1.0 Operations" [7, §3.2].

3.1 UML-1: Pre-Operational

UML-1 represents the (current) pre-operational stage that precedes the first operational approval of commercial UAM eVTOL operations in the NAS. These will be on-board piloted operations and largely experimental, although late in this stage there may be a period of non-experimental flights in the NAS (e.g., under Part 91) using certified UAM aircraft while commercial operations are not yet approved by the FAA. Existing and approved infrastructure will be used to demonstrate UAM operations, and to collect field data that will advance UAM operations to the next stage. Depending on the features of the experiment, the Safety Risk Management (SRM) process may be developed to permit certain experimentation (e.g., in controlled airspace). Traffic densities will be low, and interactions with existing ATC will be known and controlled through the appropriate safety management system (SMS) processes. These experimental trials will primarily take place under Visual Meteorological Conditions (VMC), and as on-board piloted operations under Visual Flight Rules (VFR) or Instrument Flight Rules (IFR). When certified eVTOL vehicles are introduced to support air taxi operations, the UAM airspace system will undergo a phase shift out of UML-1 and into the UML-2 stage.

3.2 UML-2: Initial

UML-2 represents initial commercial air taxi operations using newly certified eVTOL aircraft designs under existing airspace and regulations. These operations are expected to take place in carefully chosen early adopter markets where operational challenges can be addressed without significant regulatory accommodations. These operations will likely rely on commercial pilot certification and ratings, operating under VFR or IFR with Part 91 and Part 135 approvals. UAM operations will be planned to minimize interactions with existing ATM operations at low traffic densities [1]. Existing infrastructure will be leveraged by the UAM Operator, initially with existing low-complexity route networks. Landing and departure locations (e.g., heliports) are expected to be shared among UAM Operators in some cases, and in others private facilities may be exclusive to a single UAM Operator.

Note: "Low" traffic density is generally used to indicate that commercial traffic is present but with a small number of UAM aircraft aloft (i.e., less than 100), and small numbers of landing and takeoff locations (e.g., nominally ten or less) [1]. The actual traffic densities that are perceived as "Low" may vary significantly depending on numerous factors.

While the human actors retain responsibility for operational safety, safety-enhancing automation may be leveraged by the PIC and the UAM Operator to safely increase operational tempo without overwhelming ATC communications and workload limits. These systems will be designed to enable scaling of the operations in the future, and extensive data collection will take place to mature them to the next step. Technology maturation will be on a path towards, among other things, assisting humans in the safe and strategic management of shared airspace resources being utilized by UAM operations. Information exchanges may be established that permit cooperative behaviors that lead to overall system benefit.

Automated technologies will be exercised to build the experience and data necessary to apply towards fundamental operational changes. The demand for air taxi operations will increase beyond the capacity of existing NAS constraints and increased operational flexibility will be required to meet the demand. When the initial regulatory, procedural, and technological solutions mature to the point that they can be operationalized, in certain regions the UAM airspace system will undergo a phase shift out of UML-2 and into the UML-3 stage.

3.3 UML-3: Transition and Growth

UML-3 represents a transitional period, with the introduction of novel regulatory and airspace constructs designed to overcome the capacity constraints of UML-2. This period also comes with the certification or qualification of safety-critical technology onboard and offboard the UAM aircraft, which begins to change the roles of the actors in conflict management functions [2] and which are required to operate in novel ways.

New infrastructure and airspace constructs needed to enable vertiport operations will be a primary addition to the NAS, with the introduction of new system actors from the Aerodrome Community; the Vertiport Operator and the Vertiport Manager. The concept of a Vertiplex will start to emerge as regional vertiport control capabilities for multiple vertiports in a vicinity are managed from a centralized vertiport operational control center (VOCC) [14]. There will be enhanced CNS services to support UAM operations, especially to support vertiport operations.

Fundamental operational changes will build upon the integrated operations in UML-2, maintaining interoperability with the existing and evolving NAS. This will be enabled in part by comprehensive safety-assurance systems and services that have matured through data collection and operational experience during UML-2 and are now able to be used to mitigate ATC and PIC communications and workload increases to acceptable levels.

This period will experience significant operational growth from UML-2, with the introduction and expansion of vertiports and higher demand in metropolitan areas [1]. The UAM Operator will take greater responsibility and have greater operational flexibility than in UML-2. Some changes to policy or regulation are expected, for example, the establishment of new airspace constructs, exemptions to existing rules, the use of waivers to permit operations, or even changes to 14 CFR Part 93 prescribing special air traffic rules in certain areas.

To aid in the responsibility to minimize the risk of collision between aircraft, airspace systems and services will be capable of supporting complex strategic conflict management of the UAM traffic to minimize the risk of collision between all cooperative (UAM and non-UAM) operations. These technologies will enable greater operational complexity, and more equitable and efficient management of shared airspace resources. Within this period, the UAM airspace system will also begin to interoperate with the UTM system in ways that leverage and constrain procedures and technologies in both domains.

This increased operational flexibility also comes at a time of increasing levels of automation onboard the UAM aircraft, involving early examples of capabilities such as Simplified Vehicle Operations (SVO) and remote PIC [1]. Technology aiding pilots to see-and-avoid will make VFR operations safer at higher tempos and may permit limited operations below VMC.

The solutions put in place for UML-3 may be tailored to many of the specific regional conditions and operational use cases that proliferate across the NAS. Similarly, individual testing, certification, and SMS processes may be employed to gain the tailored operational approvals. These pathfinders will lead to enough understanding about how to integrate UAM operations into the NAS, that a unified national approach can be established.

The combination of infrastructure, airspace, and aircraft advancements in UML-3 will open the door to changes in roles and responsibilities, specifically (but not only) around conflict management [2]. The operational experience gained, and the data that is collected throughout UML-3 will be critical to enabling the next stage. When the regulatory, procedural, and technological solutions mature to the point that it is possible for actors other than ATC to provide separation services for UAM aircraft in ways that are substantially different than is done under existing IFR and VFR modes of flight, the UAM airspace system will undergo a phase shift out of UML-3 and into the UML-4 stage.

3.4 UML-4: New Predetermined Separator

UML-4 represents a period of integration across the UAM and ATM communities, enabled by regulatory changes to operate differently than the NAS has accommodated previously under IFR and VFR. The UAM Operators will be able to operate under more complex meteorological conditions, supported by automation providing complex safety-critical functions, and with increased digital exchanges including with ATC. The data collection and operational experience gained during UML-3 will have matured the automation and helped to define an expected level of design and operational safety that supports FAA approval for advanced operations.

While the technological solutions that take hold in UML-4 are uncertain, it can be expected that aircraft, airspace, and even infrastructure will become highly automated. However, because of the inevitable and somewhat frequent need to communicate with ATC for off-nominal, contingency, and emergency operations, most system actors will rely on a human component and legacy infrastructure and systems. Completely automated actors are not likely for UML-4 and are beyond the scope of this document.

The airspace constructs that will have emerged are used routinely in conjunction with third party systems and services to ensure safe, efficient, and equitable access to the airspace for the UAM Operator. Depending on the solutions that are established in UML-3, these airspace constructs may take many potential forms, from highly structured to highly flexible. Vertiports will be large multi-landing locations with a parking capacity to accommodate the tempo and may offer extensive service support capabilities such as refueling or charging and vendor services. Although vertiports in urban centers are not likely to have the space needed to offer extended services, high service vertiports may be located at the periphery of urban centers, including at airports [14]. The route and vertiport networks will be highly complex, but also resilient to disruption through accurate predictions of weather and traffic conditions. The initial CNS enhancements that have matured during UML-3 will provide advanced CNS services to support these highly complex operations. Cooperative conflict management concepts will be applied to UAM operations, within the parameters of established airspace constructs and supporting infrastructure, which utilize shared flight intent and data exchanges across the UAM and ATM communities. All hazards, including non-broadcasting or non-participating airspace users, will be managed as part of the operational design. There may be additional requirements to ensure safety, such as additional surveillance infrastructure and more complex information management.

Many of the regulatory and non-regulatory rules and requirements that enable these concepts will have been achieved by consensus in industry. Performance standards will enable mixed operations with appropriate equipage to co-exist cooperatively in the same airspace, allowing for operational flexibility and equitable access for all airspace users who satisfy the performance requirements. This period will see regular SVO, and uncrewed UAM aircraft will become commonplace at operational tempos that are comparable to those of piloted aircraft.

4 System Engineering Methodology

A system engineering methodology is needed to manage the system engineering artifacts associated with conducting airspace research and development over multiple complex dimensions in scope and time. The methodology described here is designed for the discovery and maturation of high-level requirements in the UAM system of systems, by supporting the researcher in organizing and defining their research and the incorporation of the research results when they are available. This also supports the project manager, in tracking progress towards goals and maximizing success with available resources. The roadmap is a living document, with iterations driven by research results. Periodically, versions will be released to update the community and encourage internal and external collaboration NASA research activities will be a primary, but not only, driver for updates and iterations. The roadmap process will culminate in a mature set of assumptions, requirements, constraints, and architecture for UAM airspace systems and services.

4.1 Roadmap Decomposition

The process begins by identifying a discrete set of capabilities, which cover the UAM airspace system. These UAM airspace capabilities are derived from several sources, including the global ATM Concept [2], and the FAA's NAS Enterprise Architecture [15]. Each capability is then decomposed into an exhaustive list of constituent components. The components are generally functional, and work in combination to deliver the parent capability.

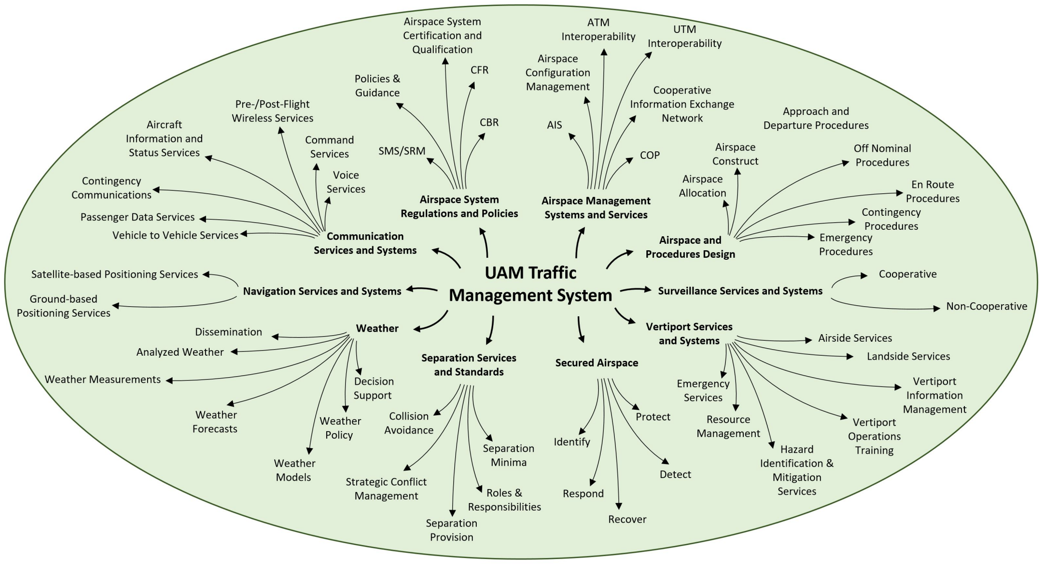

Figure 3. UAM Airspace Capability and Component Tree Decomposition

Note: There are operational capabilities beyond airspace needed for UAM that are not captured here, especially those related to the aircraft and infrastructure. The level of automation and types of piloting configurations for the UAM aircraft have also not been assessed in this airspace research roadmap, though it is ultimately needed for the research.

4.2 Roadmap Requirements and Assumptions

To identify the requirements set associated with each UML, candidate requirements and assumptions are identified at a high level for each capability, and then listed progressively across the UMLs. These requirements and assumptions are derived from existing research, source documentation, system constraints and subject matter expertise. The goal of the process is to increase the traceability to research results and other sources, and in doing so mature the candidate requirements.

The requirements that are tabulated in §5 are termed the *roadmap requirements* and are generally one of the following types

- **Operational Requirements** define the operational attributes of a system needed for the effective and/or efficient provision of system operations to users. These requirements focus on what actions actors in the system must take or how the system functions are performed.

- **Functional Requirements** define what functions need to be performed to accomplish the mission objectives. These requirements typically focus on converting inputs to outputs.

The roadmap requirements herein have been identified and matured through a subset of the research to date, and are expected to be modified, expanded, and further matured as more research results are acquired or constraints are identified by the UAM Community. To the extent possible, the roadmap requirements are solution-agnostic.

The roadmap requirements are written around the system actors defined in Section 2.2 and will take the form [System Actor] **should/shall** [perform a function]. The context of the keywords "should" and "shall" are described below

> **should** is used to indicate a desired goal at the boundary of existing research, is non-binding, and is used to guide evaluation activities [16, Appendix C]. As the research matures, these can be revised to become "shall" requirements.

> **shall** is used to indicate a requirement that has been demonstrated through research system implementations to be a potential minimum requirement in the UAM system of systems.

The roadmap requirements are at various levels of maturity. Future versions of this document will include measures of requirement maturity, which will enable research gaps to be more easily identified effectively targeted. As the roadmap requirements mature as research progresses, the closer the associated knowledge, innovation and capabilities are ready for Technology Transfer and the operational implementation [17].

In addition to the requirements, section 5 also includes assumptions. These are referred to as *roadmap assumptions* and are generally derived from higher-level or authoritative sources (e.g., [6] and [1], or from expectations of the UAM Community (see § 2.4). The roadmap assumptions are written using the keyword "**will**", described below

> **will** is used to indicate a statement of fact, or an assumption taken for granted, and are binding in that an expectation of certainty is established [16, Appendix C].

The set of UAM airspace research requirements and their progression to UML-4 is highly complex and interrelated. Most of the requirements that will be needed for operationalizing and evolving the concept and associated technologies have not yet been identified or are in an early stage and need extensive validation. In this case, To Be Resolved (**TBR**) is used to indicate best estimates, a lack of known requirements, assumptions, or constraints, or simply areas where further development is needed. As with requirements, **TBRs** will be updated, added, and resolved during roadmap iterations. In many cases, **TBRs** will be replaced with research requirements.

5 Roadmap Requirements Tables

In the following subsections, each capability from the decomposition is defined, and its components are described in detail. For each capability a table of requirements is provided, indexed by component and UML. The roadmap requirements tables are only defined for UML-2 and above since requirements on the pre-operational phase do not guide NASA's UAM airspace research efforts.

Roadmap requirements are placed in the UML in which they are expected to first apply to UAM operations. Once introduced in a UML, any requirements on the actors to provide a capability are assumed to be available from that point forward. As such, the tables are understood cumulatively and are written without repetition of requirements in later UMLs.

The list of capabilities covered by the roadmap is expected to expand during its lifecycle. The capabilities that have been identified to-date are listed below

- Airspace Management Systems and Services Architecture
- Airspace and Procedure Design
- Airspace System Regulations and Policies
- Communication Services and Systems
- Navigation Services and Systems
- Secured Airspace
- Separation Services and Standards
- Surveillance Services and Systems
- Vertiport Operations
- Weather

Every requirement in the tables has unique identifier following this (*autoID UML-#.Cap*) convention, where:

- *autoID* is the unique ID;
- *UML-#* is the UML where this requirement appears;
- *Cap* is two-letter-code capability identifier, defined for the capabilities below
  - **AM**: Airspace Management Systems and Services
  - **AD**: Airspace and Procedure Design
  - **AR**: Airspace System Regulations and Policies
  - **CS**: Communication Services and Systems
  - **NS**: Navigation Services and Systems
  - **SA**: Secured Airspace
  - **SS**: Separation Services and Standards
  - **SU**: Surveillance Services and Systems
  - **VS**: Vertiport Services and Systems
  - **WX**: Weather

5.1 Airspace Management Systems and Services Architecture

All airspace is managed, to varying degrees, where "managed" means that a strategic or tactical decision as to the level of service to be provided will have been taken by the appropriate authority [2, §2.2.6]. Airspace Management is the process by which airspace organizations establish and configure airspace structures to accommodate different types of air activity, the volume of traffic, and differing levels of service. Competing interests for the use of airspace will make airspace management a highly complex exercise, necessitating a process that equitably balances those interests [2].

The Airspace Management research capability provides the ability for UAM Operators to share airspace resources safely and equitably, enabled by a combination of cooperative CBRs [7] and a Common Operating Picture that allows users to follow those rules consistently and predictably. Airspace management systems, services, and procedures will be part of how the UAM Operator is able to work cooperatively with other UAM Operators, conventional and unconventional airspace users (e.g., ATM, GA, UTM), and ATC, with the goal of safely scaling UAM operations beyond the capacity of the as-is NAS. It is expected that there will be a safe and efficient emergence of new services for UAM Operators to meet increasing demand, and interoperability between UAM and non-UAM operations will use a common set of rules and practices and the incorporation of new airspace and procedure designs. Airspace Management is decomposed into six (6) general functions, enumerated below, and described in greater detail below.

- Airspace Configuration Management
- Aeronautical Information Services
- ATM Interoperability
- Common Operating Picture
- Cooperative Information Exchange Network
- UTM Interoperability

Potential related technology solutions in this area of research include some that are still in the concept stage, such as the PSU and the FAA-Industry Data Exchange Protocol (FIDXP), which are an extension of the UAS Service Supplier (USS) and Flight Information Management System (FIMS) from UTM [8]. Other solutions include extending fielded operational systems such as System Wide Information Management (SWIM), the Federal Notice to Air Missions (NOTAM) System (FNS), and the National Airspace Data Interchange Network (NADIN).

Airspace Configuration Management: The airspace users and ATM service providers will play a routine role in establishing the airspace organization and configurations in use, in accordance with the needs of the local community. The operational state of the airspace organization will need to be easily learned and understood by the UAM community and will be a fundamental part of the Common Operating Picture. Roles and responsibilities amongst the actors around establishing capacity limits, activating, or deactivating routes and other airspace constructs, and other airspace planning functions will shift as UAM Airspace progresses towards UML-4.

Aeronautical Information Services: Aeronautical Information Services are established within defined areas of coverage and are responsible for the provision of aeronautical data and aeronautical information necessary for the safety, regularity, and efficiency of air navigation [18]. This component includes secure aeronautical information exchange between the FAA, the PSU Operators, and the UAM Operators. Depending on the operations ATC may need the ability to request UAM operational data on demand and may also need to provide air traffic information to the PSU network for distribution to UAM Operators, PICs, UAM aircraft, and public interest stakeholders [7]. The interface for this information exchange is managed and operated by the FAA ATO and is a part of the UAM ecosystem. Aeronautical information provided by these services will play a vital role for various FAA entities to obtain information on UAM operations including, but not limited to, inquiries into accident/incident investigations, vehicle registrants, authorizations, and waivers. FAA data sources available to the PSU Operator and UAM Operator include, but are not limited to, flight data (including safety critical traffic information), airspace restrictions and constraints, approach and departure procedures, navigational information, obstruction information, active Special Activity Airspaces (SAAs), active Temporary Flight Restrictions (TFRs) and other NOTAMs.

ATM Interoperability: Airspace Management will minimize the interactions that would stress pilot and ATC workload at scale. The provision of Aeronautical Information Services and the Common Operating Picture will be foundational to ensuring that ATM and UAM operations are complimentary and working toward a shared goal of safe and efficient accommodation of demand. Other operational information exchanges between UAM and ATM systems may also be needed to support the management of the common airspace. For example, in the NAS today ATC manages the real-time access of airspace users to controlled airspace through the issuance of clearances, UAM operations will not be able to gain access at scale without changes to that management system. A management system that leverages exclusionary airspace with defined CBRs and PSU support for demand management and scheduling could be one basis for providing the airspace user access at scale.

Common Operating Picture: The concept of Common Operating Picture is based upon the military notion of a Common Operational Picture [19], is a key function of the ATSCC and is part of the FAA's overall vision of the future [18, 20]. The Common Operating Picture is a single set of relevant operational information shared by multiple entities in the distributed system of command and control. Airspace and Procedures are designed under the assumption that all related activity within the airspace will be known to the UAM/ATM system in varying degrees [2, § 2.2.6]. UAM Airspace management will be cooperative, requiring the airspace users, ATM service providers, and aerodrome community to have access to a sufficiently common real-time model of the operating environment, tailored to their needs, upon which cooperative decisions may be made in a distributed fashion. The PIC, Fleet Manager, Vertiport Manager, and ATC will each use a Common Operating Picture, tailored to their operational needs, to make cooperative decisions that satisfy the CBRs. For UAM, the most important elements to be included in the Common Operating Picture, many of which are derived from the Aeronautical Information Services [19] are:

- wind and temperature field predictions and measurements
- traffic state
- traffic intent
- weather hazard
- terrain and obstruction
- NAS configuration (e.g., runway configuration, approach-in-use)
- data on any other dynamic hazards such as special activity airspace
- landing facility status.

The acceptance, management, and discovery of this information by the UAM Operators will be central to establishing an effective Common Operating Picture. Existing NAS infrastructure such as SWIM provide similar functionality and may be extended to meet some or all of the needs of the UAM Community.

Cooperative Information Exchange Network: A trusted digital network will be needed by the UAM Operators to exchange information required for safety and performance, and to satisfy the CBRs. The network will need to support interoperability of multiple UAM Operators at scale. The network will be essential to the establishment of a Common Operating Picture for all airspace users and will include such information as position and intent information. During contingency and emergency events, the network will provide essential information to the users and service providers to safely resolve the situation. This capability will also provide a means for the Fleet Managers and the PSUs to discover flight information that is relevant to the operations being planned and managed.

UTM Interoperability: UAS may likely interact with UAM traffic especially near vertiports that coincide with UAS operations or may also land at UAM vertiports. As Beyond Visual Line of Sight (BVLOS) operations become more routine and require UTM participation, UAS Service Suppliers (USSs) may be able to share operation intent data with PSUs to reduce the likelihood of unsafe interactions. Small UAS are currently authorized to operate in controlled airspace via the Low Altitude Authorization and Notification Capability (LAANC) or other waivers, which could potentially lead to interactions between the two types of operations [21]. In the near term, ATC may have knowledge of the operations and could advise UAM Operators. In the future, USSs servicing these operations could play a role in storing and exchanging information for UAM operations.

Table 1: Airspace Management Systems and Services Requirements

	UAM Maturity Level		
Component	**UML-2: Initial**	**UML-3: Transition and Growth**	**UML-4: New Predetermined Separator**
Airspace Configuration Management	ATC **will** manage the configuration of the airspace for all airspace users. (275 UML-2.AM)	The FAA **shall** enable ATC to update and distribute airspace constraints to the PSU. (72 UML-3.AM) ATC **will** establish capacity constraints on shared airspace resources. (98 UML-3.AM) ATC **will** establish the airspace organization and configuration in use. (99 UML-3.AM)	The Vertiport Operator **should** establish arrival and departure capacity constraints on the vertiport. (37 UML-4.AM) The Vertiport Operator **should** establish vertiport arrival and departure configurations. (100 UML-4.AM) The UAM Operator **should** establish capacity constraints on shared airspace resources. (330 UML-4.AM) The UAM Operator **should** establish the airspace organization and configuration. (332 UML-4.AM)
Aeronautical Information Services	The UAM Operators, and PSU Operators **should** collect data on potential new Aeronautical Information Services. (272 UML-2.AM) Fleet Managers **will** use available Aeronautical Information Services for planning and executing UAM operations. (273 UML-2.AM) The UAM Operators, and PSU Operators **should** collect data on new potential Airspace Authorization services. (377 UML-2.AM)	The UAM Operator **shall** ensure that relevant aeronautical information is available for their Fleet Managers and PICs. (91 UML-3.AM) The FAA **will** approve the PSU Operator to provide Airspace Authorization services to the UAM Operator. (94 UML-3.AM) The FAA **will** approve the PSU Operator to provide Aeronautical Information Services to the UAM Operator. (97 UML-3.AM)	**TBR** (331 UML-4.AM)

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Table 1: Airspace Management Systems and Services Requirements (cont.)

	UAM Maturity Level		
Component	**UML-2: Initial**	**UML-3: Transition and Growth**	**UML-4: New Predetermined Separator**
ATM Interoperability	When ATC is the designated separator; The Fleet Manager and PIC **will** receive services from ATC. (19 UML-2.AM) The UAM Operators, and PSU Operators **should** collect data that supports changes to procedure and policy around conflict management. (269 UML-2.AM) UAM Operators **will** follow all existing ATM procedures. (274 UML-2.AM) The Fleet Manager **should** consider ATM operations in their operational planning. (426 UML-2.AM) The Fleet Manager **should** leverage available ATM data exchanges. (427 UML-2.AM) The PIC **shall** obtain authorization from ATC to operate in controlled airspace. (428 UML-2.AM)	The FAA **will** enable the authentication and authorization of the PSU. (71 UML-3.AM) The FAA **will** enable the PSU to notify ATC of off-nominal and contingency UAM operations. (73 UML-3.AM) The UAM Operator **should** use novel techniques that reduce workload to receive authorization to operate in controlled airspace. (74 UML-3.AM) The FAA **shall** have on-demand access to operational data on active, pending, and past UAM operations. (75 UML-3.AM) The PSU **will** enable the authentication and authorization of its subscribers. (451 UML-3.AM)	The PSU **shall** coordinate airspace allocation actions with ATC when necessary. (119 UML-4.AM) The PSU **shall** coordinate airspace configuration actions with ATC when necessary. (333 UML-4.AM)

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Table 1: Airspace Management Systems and Services Requirements (cont.)

	UAM Maturity Level		
Component	**UML-2: Initial**	**UML-3: Transition and Growth**	**UML-4: New Predetermined Separator**
Common Operating Picture	The UAM Operators, and PSU Operators **should** collect data on potential new services to build the Common Operating Picture. (32 UML-2.AM) The Fleet Manager **will** use tools for creating and modifying the flight plan. (191 UML-2.AM) The UAM Operators, and PSU Operators **should** collect data on potential new services for establishing and managing planned flight intent. (276 UML-2.AM)	The UAM Operator and Vertiport Operator **shall** integrate aeronautical information into a Common Operating Picture. (33 UML-3.AM) The UAM Operator and Vertiport Operator **shall** use standardized data sources to develop the Common Operating Picture. (34 UML-3.AM) The PSU, UAM Operator, Vertiport Operator **shall** discover the information needed to build a Common Operating Picture. (36 UML-3.AM) The PSU **shall** make all the following information (**TBR**: includes operational intent and telemetry) discoverable to other PSUs, UAM Operators, Vertiport Operators. (92 UML-3.AM) The Fleet Manager **should** make cooperative information available to the PSU. (302 UML-3.AM)	**TBR** (334 UML-4.AM)

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Table 1: Airspace Management Systems and Services Requirements (cont.)

		UAM Maturity Level	
Component	**UML-2: Initial**	**UML-3: Transition and Growth**	**UML-4: New Predetermined Separator**
Cooperative Information Exchange Network	The UAM Operators, and PSU Operators **should** collect data that supports the potential new PSU Network capabilities. (270 UML-2.AM)	The PSU **should** support cooperative decision making amongst UAM Operators. (93 UML-3.AM) The PSU **shall** communicate with the PSU Network using a standard protocol to ensure interoperability amongst connected PSUs. (179 UML-3.AM) The PSU **shall** share operational intent to the PSU Network on behalf of the UAM Operators. (180 UML-3.AM)	The PSU **should** facilitate equitable allocation of existing capacity of share resources. (122 UML-4.AM)
UTM Interoperability	The Fleet Manager **should** consider UTM operations in their operational planning. (60 UML-2.AM) The Fleet Manager **should** leverage available UTM data exchanges. (425 UML-2.AM)	The PSU **should** discover UTM operational information from available UTM data exchanges. (77 UML-3.AM) The PSU **should** share operational information on available UTM data exchanges. (79 UML-3.AM)	**TBR** (158 UML-4.AM)

5.2 Airspace and Procedure Design

The Airspace and Procedure Design capability is the ability to devise strategies, rules, and procedures by which the airspace will be structured to accommodate the different types of air activity, volume of traffic, and differing levels of service and rules of conduct [2, §2.2.5]. For UAM, this will follow a set of organizational principles, such as accommodating dynamic flight trajectories where practicable, applying structured route systems where necessary, and being easily learned and understood by the UAM (and where needed, ATM) community.

This capability includes the design and definition of airspace constructs within the NAS that support the strategic and tactical decisions needed in the UAM operational environment, interoperating with the ATM operational environment. Examples of such constructs include corridors [7], certain aspects of vertiports, etc.

Airspace and Procedure Design is decomposed into seven (7) discrete functional areas for research and operational evolution.

- Airspace Allocation
- Airspace Construct
- Approach and Departure Procedures
- Contingency Procedures
- Emergency Procedures
- En Route Procedures
- Off Nominal Procedures

Example solutions and technologies in this area include the UAM Corridors [7], Letters of Agreement (LOA), and approach/departure procedure design from National Campaign.

Airspace Allocation: It is relatively straightforward to achieve equitable and efficient access to airspace at low levels of demand, but as demand increases sharing resources becomes more difficult and subject to a number of complicated tradeoffs [22]. In [7], one of the overarching assumptions is that the FAA may intervene to support demand-capacity balancing as the number of UAM operations increases. Mechanisms for ensuring equitable and efficient use of capacity-constrained resources, such as congestion pricing, airspace markets, multi-lateral negotiations, algorithm-based resource sharing, will be needed to be robust against strategic (gaming) behavior. Additionally, efficiency and fairness tradeoffs will need to be explored to identify optimum solutions in order to preserve equitable and open access while avoiding a tragedy of the commons [23].

Airspace Construct: Identification and definition of new or novel airspace structures in controlled and uncontrolled airspace that are utilized by UAM Operators to execute their UAM mission. Airspace constructs for UAM are central to the introduction of UAM into the NAS, providing ATC with the ability to accommodate new traffic flows within their airspace with minimal impact on their workload and eventually providing the UAM Operator new regulatory constraints as technology evolves. The required procedures and interfaces with ATC that are required to transition into airspace constructs within controlled airspace will need to be defined through mechanisms (i.e. Letter of Agreement) that allow for minimal workload. If regulatory relief is sought which relies on the airspace constructs, it is expected to also rely on safety-critical systems and infrastructure both on- and off-board the UAM aircraft. The establishment of airspace constructs will need to take into consideration the environments in which the operations are being conducted, including the potentiality of hazards as well as the underlying land usage. Depending on the nature of the airspace constructs, how they will (or will not) be depicted on aviation charts will also need to be determined.

Approach and Departure Procedures: Identification and definition of preplanned and published procedures providing ingress and egress to the surface, as well as the roles of the UAM Operator, PSU, Vertiport Operator, ATC, and PIC. These procedures will be heavily influenced by the performance and capabilities of the aircraft types for which they are developed, and mixed-use operations will present challenging tradeoffs to consider. Supporting a wider range of aircraft performance will generally require more physical airspace to accommodate safely and at scale. Approach and departure procedures for vertiports on the airport surface (e.g., ramp, taxiway, runway, parking garage) will need especially careful treatment to be usable at scale, due to issues around aircraft speeds, active runway interactions, and wake turbulence from aircraft departing close to the vertiport. Approach and departure procedures are expected to be impacted by multiple environmental conditions, including weather and predicted demand. Existing heliports may serve as vertiports, which would come along with interoperability challenges to address. Overcoming these challenges may lead to extending solutions, and providing benefits to, both UAM operators and conventional airspace users.

Contingency Procedures: Identification, definition, and application of procedures for managing the airspace during unforeseen incidents that result in impacts to airspace or capacity. Contingency operations are generally rare, but credible, large-scale system or service outages which are disruptive to nominal operations and must be managed. This category includes procedures to handle conditions similar to those which may lead to Irregular Operations (IROPS), which are well-understood for many local airport operations [24]. Examples of such conditions include excessive flight delays, widespread cancellations, CNS outages, lost link with uncrewed aircraft, diversions due to weather, unplanned airspace or landing restrictions, air traffic congestion, accidents or aircraft damage, and active security concerns [25]. Contingency operations are reactive to the incident after it occurs, but the response of the system actors is practiced through training and experience.

Emergency Procedures: Identification, definition, and application of procedures for managing the airspace for predominantly single aircraft events which require the arrangement of additional services (e.g., fire and rescue, Search and Rescue, passenger emergency). During emergency operations, aircraft in distress are provided priority and other aircraft are managed in response to the needs of the emergency aircraft. For the PIC, “aviating” becomes the sole task to bring the aircraft down safely. Emergency landing sites may be established ahead of time, or requirements on emergency landings may be identified, to help increase safety under such conditions.

En-route Procedures: Identification and definition of nominal pre-planned and published procedures providing access to controlled and uncontrolled airspace for the conduct of airborne UAM flight, as well as the roles of the UAM Operator, PSU, ATC, and PIC. En-route procedures are expected to be impacted by multiple environmental conditions, including weather and predicted demand. Associated performance requirements also affect how these procedures are defined and used.

Off Nominal Procedures: Identification, definition, and application of procedures for managing planned operations that are significantly impacted by an unplanned event. This generally involves tactical adjustments to the strategic plan to mitigate disruptive events. Examples include adjusting to convective weather, or non-critical equipment issues requiring deviation from planned route, speed, or altitude.

Table 2: Airspace and Procedure Design

	UAM Maturity Level		
Component	**UML-2: Initial**	**UML-3: Transition and Growth**	**UML-4: New Predetermined Separator**
Airspace Allocation	The UAM Community **should** collect data on new strategic traffic managements techniques that optimizes efficiency and fairness in the presence of operator preference variability and dynamic traffic demand. (453 UML-2.AD)	The UAM Community **should** establish strategic traffic management techniques optimizes efficiency and fairness in the presence of operator preference variability and dynamic traffic demand. (454 UML-3.AD)	**TBR** (455 UML-4.AD)

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Table 2: Airspace and Procedure Design (cont.)

	UAM Maturity Level		
Component	**UML-2: Initial**	**UML-3: Transition and Growth**	**UML-4: New Predetermined Separator**
Airspace Construct	The Fleet Manager and PIC **will** ensure that all performance requirements are met when utilizing existing routes and procedures. (38 UML-2.AD) The UAM Community **should** establish Letters of Agreement (LOA) with the FAA to ease access to controlled airspace classes. (40 UML-2.AD) The UAM Operator **should** collect data on the use of potential new airspace constructs. (42 UML-2.AD) The Fleet Managers **will** utilize UAM routes that have been largely deconflicted from conventional traffic. (192 UML-2.AD)	The PSU **shall** provide services to the UAM Operator to participate cooperatively in the shared airspace construct. (80 UML-3.AD) The FAA **should** approve airspace constructs that support increasing the tempo of UAM operations. (101 UML-3.AD) The PSU **shall** provide services to the Fleet Manager to enable regulatory compliance within the shared airspace construct. (299 UML-3.AD) The FAA **should** approve airspace constructs that support the predictability of UAM operations. (300 UML-3.AD) The FAA **should** approve airspace constructs that can adapt to the dynamic need of UAM operations. (301 UML-3.AD) The FAA **will** approve UAM routes that include established diversion and emergency landing areas along the various Routes. (379 UML-3.AD) The FAA **should** approve airspace constructs that include design for appropriate off-nominal conditions. (380 UML-3.AD) The FAA **should** approve airspace constructs that include design for appropriate contingency conditions. (446 UML-3.AD)	**TBR**: More research into the UML-3 requirements is needed to resolve. The characteristics of airspace constructs utilized by UAM operations, especially in relation to ATM and UTM traffic, depend on the regulatory approach taken and the associated airspace.constructs in UML-3. (159 UML-4.AD)

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Table 2: Airspace and Procedure Design (cont.)

	UAM Maturity Level		
Component	**UML-2: Initial**	**UML-3: Transition and Growth**	**UML-4: New Predetermined Separator**
Approach and Departure Procedures	The Fleet Manager **shall** operate with approach and departure procedures that minimize exposure to hazards. (41 UML-2.AD)	The FAA **will** approve approach and departure procedures that apply new separation standards. (103 UML-3.AD) The FAA **will** approve approach and departure procedures for UAM operations that ensure smooth flow and separation of aircraft at airspace boundary points. (195 UML-3.AD) The FAA **will** approve approach and departure procedures that include design for off-nominal conditions. (198 UML-3.AD) The FAA **will** approve approach and departure procedures that include design for contingency conditions. (445 UML-3.AD)	Fleet Managers and Vertiport Operators **will** negotiate approach authorizations and procedures through the PSU network. (389 UML-4.AD) The UAM Operator **will** be responsible for providing all necessary approach information to their fleet. (390 UML-4.AD) PIC or RPIC **should** communicate directly with vertiport managers during lost link to receive guidance on approach authorization and procedures. (391 UML-4.AD) The UAM Operator **will** continue controlling the vehicle within the VOA; while the Vertiport Operator **will** have increasing responsibility as the vehicle approaches the destination vertiport. (392 UML-4.AD)
Contingency Procedures	The FAA **will** approve contingency procedures that accommodate the appropriate aircraft performance characteristics. (61 UML-2.AD) The Fleet Manager, PIC, and ATC, **shall** resolve contingency conditions under existing flight rules and procedures. (193 UML-2.AD)	The FAA **will** provide a means to authorize contingency procedures that include the UAM Operator, Vertiport Operator, Fleet Manager, Vertiport Manager, PIC, or ATC. (194 UML-3.AD)	**TBR** (145 UML-4.AD)

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Table 2: Airspace and Procedure Design (cont.)

	UAM Maturity Level		
Component	**UML-2: Initial**	**UML-3: Transition and Growth**	**UML-4: New Predetermined Separator**
Emergency Procedures	The PIC and ATC **shall** resolve emergency conditions under existing flight rules and procedures. (267 UML-2.AD)	The FAA **will** establish emergency procedures that include how to alert ATC and how to execute clearing procedures or other appropriate actions. (297 UML-3.AD)	**TBR** (328 UML-4.AD)
En-route Procedures	The Fleet Manager **should** operate with en route procedures that minimize exposure to hazards. (196 UML-2.AD)	The FAA **will** approve en route procedures that apply new separation standards. (104 UML-3.AD)	**TBR** (144 UML-4.AD)
		The FAA **should** approve en route procedures that include design for appropriate contingency conditions. (199 UML-3.AD)	
		The FAA **should** approve en route procedures that include design for appropriate off-nominal conditions. (298 UML-3.AD)	
Off Nominal Procedures	For operations in controlled airspace, the FAA **will** approve off-nominal procedures that accommodate the appropriate aircraft performance characteristics. (268 UML-2.AD)	The UAM Operator **shall** establish a plan to resolve off-nominal conditions with the PIC, Fleet Manager, or Vertiport Manager, without ATC involvement. (150 UML-3.AD)	The PIC or RPIC **will** take any intervention during off-nominal conditions with the support of a sufficient autonomy level in the UAM vehicles. (329 UML-4.AD)

5.3 Airspace System Regulations and Policies

The Airspace System Regulations and Policy operational capability includes regulations, certifications, processes, and other policies which apply to the airspace in which UAM aircraft operate. The UAM operations will adhere to a range of regulations available to them, depending on the nature and objectives of the operation. In UML-4 it is assumed that significant changes to regulation and policy have been approved by the FAA, allowing for, among other things, new separation modes with new predetermined separators, and BVLOS operations in a variety of separation modes. Procedure changes such as LOAs, use of existing policy such as waivers, and policy changes, such as exemptions and changes to the Code of Federal Regulations [26] are included here.

Community Based Rules (CBRs): UAM common rules of behavior to create safe and scalable outcomes of distributed decision-making by flight operators and supporting services. Development, adoption, and implementation of CBRs will require collaboration across multiple stakeholders, including operators, support services (industry), and regulatory authorities (most prominently the FAA). FAA approval will be required for some CBRs, supported by documentation, testing, and in some cases formal authorization, acceptance or qualification. The existence of CBRs does not in any way alter the FAA's regulatory and oversight authority for the NAS. It is expected that CBRs will continue to be established and modified as UAM operations mature, adapting to changing regulatory landscape, scaling to the UAM operational environment and in response to disagreement between stakeholders regarding their application. As such, CBRs may need to be developed that establish processes for the development, approval and administration of CBRs. The CBRs are foundational to the cooperative and highly automated operating environment for UAM. They will be established in both human readable and machine readable (executable) forms.

Code of Federal Regulation (CFR): The FAA Regulations (FAR) are found under the Code of Federal Regulations (CFR), Title 14 Aeronautics and Space [27]. Title 14 is decomposed into Volumes, Chapters, and then Parts. Some of the more relevant parts for UAM operations, and where potential changes may be necessary, are expected to be found in Parts 61, 91, 89, 77, and 135. Operational approval to the UAM Operator is expected to be provided by an approved Operations Specification under Part 135. Letters of Agreement (LOA) are developed under Part 91. For a UML-4 airspace system to be realized, where it is assumed that ATC will have limited or no involvement in nominal conflict management of UAM operations, significant changes to the CFR are required.

Policies and Guidance: Official guidance or acceptable practices on how to find compliance with a specific CFR. Examples of Policies and Guidance include the Aeronautical Information Manual (AIM), FAA Orders 7110.65 and 7210.3, NOTAMs and operation specifications developed by the UAM Operator and approved by the FAA. Supplemental procedures such as LOA, Certificates of Authorization (COAs), and waivers may also be developed for local implementation.

Safety Management System (SMS) / Safety Risk Management (SRM) : Safety Management System (SMS) is the formal, top-down, organization-wide approach to managing safety risk and assuring the effectiveness of safety risk controls [28]. It includes systematic procedures, practices, and policies for the management of safety risk. SMS is becoming a standard throughout the aviation industry worldwide and is widely recognized across both public and private sectors as the next step in the evolution of safety in aviation. The SMS is established for the FAA by Order 8000.369C [29], and FAA Order 8040.4B [30] and the FAA SMS Manual 2019 [31] may provide additional guidance. The Safety Risk Management (SRM) process is the key tool used by the FAA to meet their SMS mission. SRM is required to apply to all investments that have an impact on the National Airspace System and is part of Acquisition Management System (AMS) policy [26]. Whenever there is a change to the NAS, the SRM process is invoked. NASA and other research supporting SRM and safety-related analyses for standards development has been valuable in Remotely Piloted Aircraft Systems (RPAS) integration and the same research support for these two areas can be expected for UAM. For more information see Reference [32].

Airspace System Certification and Qualification: The UAM airspace system will include a range of system components that are used in part to provide services to the UAM Operator. Depending on the level of criticality of the systems and associated services, the systems will require various levels of certification and qualification by the FAA and other organizations. There may be novel features in the UAM operational environment that must be managed, for example frequent software updates to automation. It is expected that SMS will be applied wherever system certification and qualification are required. While it is unclear how the FAA will certify or qualify technologies and services used by the UAM Operator, industry has an opportunity to develop standards that may be used as a method of compliance in whatever process emerges.

Table 3: Airspace System Regulations and Policies

	UAM Maturity Level		
Component	**UML-2: Initial**	**UML-3: Transition and Growth**	**UML-4: New Predetermined Separator**
Community Based Rules (CBRs)	The UAM Community **will** establish CBRs to ensure safe, equitable and resilient operations. (62 UML-2.AR)	UAM Operators **shall** ensure that all fleet and flight operations are executed in accordance with CBRs. (139 UML-3.AR) PSU Operators **shall** ensure that all services are provided in accordance with CBRs. (429 UML-3.AR) Vertiport Operators **shall** ensure that all vertiport operations are executed in accordance with CBRs. (430 UML-3.AR) UAM Operators and Vertiport Operators **shall** cooperate to ensure that all flow operations are executed in accordance with CBRs. (431 UML-3.AR) The UAM Community **will** establish CBRs to ensure operational intent is shared among UAM Operators. (432 UML-3.AR) The UAM Community **will** establish CBRs to enable the PSU to provide services to the UAM Operator. (436 UML-3.AR) The UAM Community **will** establish CBRs to ensure position and intent information is shared among UAM Operators. (437 UML-3.AR)	The UAM Community **will** establish CBRs to enable the UAM Operator to establish the airspace organization and configuration. (433 UML-4.AR) The UAM Community **will** establish CBRs to enable the UAM Operator to establish capacity constraints on shared airspace resources. (434 UML-4.AR) The UAM Community **will** establish CBRs to enable the Vertiport Operator to establish arrival and departure capacity constraints on the vertiport. (435 UML-4.AR) The UAM Community **will** establish CBRs to enable the Vertiport Manager to assess and mitigate risk at the vertiport. (444 UML-4.AR)

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Table 3: Airspace System Regulations and Policies (cont.)

	UAM Maturity Level		
Component	**UML-2: Initial**	**UML-3: Transition and Growth**	**UML-4: New Predetermined Separator**
Community Based Rules (CBRs) cont.		The UAM Community **will** establish CBRs to ensure position and intent information is discoverable among UAM Operators. (438 UML-3.AR)	
		The UAM Community **will** establish CBRs to ensure the allocation of shared airspace resources through Demand and Capacity Balancing services. (439 UML-3.AR)	
		The UAM Community **will** establish CBRs to enable the PSU to allocate the capacity of the shared airspace resources to the UAM Operator. (440 UML-3.AR)	
		The UAM Community **will** establish CBRs to ensure safe and efficient flow of UAM operations through the use of Traffic Synchronization services. (441 UML-3.AR)	
		The UAM Community **will** establish CBRs to ensure the cooperative development of a strategic plan. (442 UML-3.AR)	
		The UAM Community **will** establish CBRs to ensure safe execution of the cooperative strategic plan. (443 UML-3.AR)	

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Table 3: Airspace System Regulations and Policies (cont.)

	UAM Maturity Level		
Component	**UML-2: Initial**	**UML-3: Transition and Growth**	**UML-4: New Predetermined Separator**
Code of Federal Regulation (CFR)	The UAM Operator **will** design operations within existing regulations. (65 UML-2.AR)	**TBR**: The regulatory changes necessary for new airspace constructs needs further research and are dependent upon the specific form of the airspace constructs that are required. (151 UML-3.AR)	**TBR**: The regulatory changes necessary for integrated airspace constructs, and for delegation of the entire conflict management function to the UAM Operator and/or PIC/RPIC, needs further research. (160 UML-4.AR)
Policies and Guidance	The UAM Community **will** modify procedural changes such as LOA and use of waivers and exemptions to create standardized regulations. (66 UML-2.AR) UAM Operations **will** follow all applicable FAA policies. (424 UML-2.AR)	**TBR**: Policy and guidance will follow from FAR/CFR and CBRs, where more research is needed. (152 UML-3.AR)	When UAM operation takes place in controlled airspace even nominally, ATC **will** communicate with the onboard PIC or RPIC as specifically mandated by the 14 CFR 91.215. (147 UML-4.AR)
Safety Management System (SMS) / Safety Risk Management (SRM)	UAM Operators, PSU Operators, Vertiport Operators, FAA, and the UAM Community **should** collect data that supports potential new safety assurance processes. (43 UML-2.AR) The UAM Community **will** apply a SRM process to assess risks of proposed changes to the NAS, including identifying necessary safety mitigation. (201 UML-2.AR)	UAM Operators, PSU Operators, Vertiport Operators **shall** implement SMS. (81 UML-3.AR)	**TBR** (85 UML-4.AR)

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Table 3: Airspace System Regulations and Policies (cont.)

	UAM Maturity Level		
Component	**UML-2: Initial**	**UML-3: Transition and Growth**	**UML-4: New Predetermined Separator**
Airspace System Certification and Qualification	The UAM Operator **will** comply with any existing certification or qualification requirements under existing FAA policy and regulations. (63 UML-2.AR)	**TBR**: How the FAA will certify or qualify technologies and services for use by the UAM Operator needs to be better understood. How industry standards will be used as methods of compliance in the qualification process for third-party services and systems also needs to be better understood. (153 UML-3.AR)	**TBR** (148 UML-4.AR)

5.4 Communication Services and Systems

The Communications Services and Systems operational capability includes the usage of verbal and/or digital exchange between the actors/entities which are required to enable the safe, efficient, and scalable execution of operations as defined by regulations and policies. Communications include discrete control instructions, advisories, clearances, data exchange models, aircraft health status, lost link status, etc. Communications may be conveyed by a combination of terrestrial, airborne, and satellite means. The Communications capability is decomposed into components by enumeration of data services (e.g., Voice, Telemetry, Command and Control, etc.) that may be provided between actors (e.g., UAM Operator, PIC, Vertiport Operator, etc.), which may eventually trace to lower-level performance requirements on the link technologies that support them. The performance requirements for each data service may vary depending on where UAM aircraft are operating (e.g., en route versus vertiport proximity), and environmental factors may pose challenges for services provided over Radio Frequency (RF) including spectrum scarcity, and interference and propagation in the urban environment.

Voice Services: For on-board piloted UAM aircraft, voice communications between the pilots, UAM Operators, and possibly Vertiport Operators may be required to ensure safety of operations during the early phases of UAM where on-board automation will be relatively immature. As new airspace procedures evolve and aircraft and airspace management automation improve, the PIC would utilize voice communications during off-nominal events only. Voice communications between ATC and PICs will be routinely required during the earlier UMLs to enable access to controlled airspace, but as UAM operations scale up, these voice exchanges will be used strictly for contingency situations. There will be a persistent need for near-instantaneous voice communication between ATC and the PIC for safety-related advisories and alerts (e.g., CTAF, guard frequencies), especially in contingency and emergency situations. For uncrewed aircraft carrying passengers, voice communications between the remote PIC (or remote flight crew) and passengers would be available in the event of an emergency or distress. Voice communication with ATC or shared vertiports for many short flights within a local area using standard Very High Frequency (VHF) communications could have an impact on controller workload as well as RF congestion. Consideration may be necessary for frequency spectrum management to determine limitations and reserve necessary frequencies for certain situations.

Aircraft Information and Status Services: Aircraft will periodically provide telemetry data describing its position and overall operating status such that it is available to the UAM Operator, Fleet Manager, and PSU as needed. Telemetry will also be made available to other PSUs through the PSU Network as needed. Telemetry services may be used for advisory purposes, as well as flow control especially in and out of vertiports.

Command Services: A UAM Operator in conjunction with the PIC may update the flight plan of any aircraft, potentially at any time during the operation. This service may also be used to provide approach authorization and guidance as the aircraft approaches its destination vertiport. Reliability and security are key performance parameters for command services.

Contingency Communications: During contingency scenarios, additional data bandwidth may be needed for highly reliable, low-latency communications. The additional bandwidth could be used to provide enhanced data service on in an effort to help mitigate contingencies. These contingency communications may be used to provide additional or enhanced information about the current state of the aircraft not included in the nominal telemetry data service or automated diagnostics to aid with situational awareness. The contingency communications would allow for faster update rates, larger bandwidth, added features, and higher priority designations to mitigate contingency conditions [33].

Vehicle-to-Vehicle Services: Direct communications links between aircraft may be used to carry multiple data types including additional voice services and cooperative separation data. These links may also be used to relay other data services such as position and intent information during lost link events, and intent for uncontrolled vertiports. Reliability and security are key performance parameters for command services.

Passenger Data Services: The passenger data service will provide the passengers with support for their on-device personal applications augmented by information pertaining to UAM passenger services. This will be an in-cabin service and will transition to the passenger's home carrier network once they disembark the aircraft. Ensuring that these services will not interfere with other CNS services is an important consideration [34].

Pre-/Post-Flight Wireless Services: Before takeoff, UAM aircraft will require wireless data links to report their status, receive flight plans, flight clearances, and receive airspace and weather data. Additional services may include pre-flight briefings between passengers and remote PICs, over-the-air software, firmware updates, and additional route updates as needed prior to takeoff. After each flight, aircraft may upload vehicle performance data to the UAM Operator for prognostics and maintenance purposes and may receive pad and parking information.

Table 4: Communication Services and Systems

	UAM Maturity Level		
Component	**UML-2: Initial**	**UML-3: Transition and Growth**	**UML-4: New Predetermined Separator**
Voice Services	The PIC and ATC **shall** have the ability to communicate by voice in all classes of airspace as required by regulation. (20 UML-2.CS) The Fleet Manager **should** have two-way communication by voice with the PIC. (44 UML-2.CS) The PIC **shall** have two-way communications by voice to proximate PICs. (124 UML-2.CS) The Vertiport Manager **shall** have two-way communication by voice to the PIC. (202 UML-2.CS) The Vertiport Manager **shall** use a pre-defined frequency to communicate with the PIC in the Vertiport Operations Area. (447 UML-2.CS)	The Fleet Manager **shall** have two-way communication by voice to the PIC. (154 UML-3.CS)	When operating with a remote PIC, the Fleet Manager, or remote PIC **shall** have a two-way capability to communicate by voice with on-board passengers during all phases of flight. (125 UML-4.CS) When the UAM vehicle is parked, docked, or moving at the gate, ramp, or parking area, or assisted by a tow vehicle on the vertiport property, the PIC **will** communicate primarily with the Vertiport Manager, while the UAM Operator **will** receive arrival and departure updates. (394 UML-4.CS)

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Table 4: Communication Services and Systems (cont.)

	UAM Maturity Level		
Component	**UML-2: Initial**	**UML-3: Transition and Growth**	**UML-4: New Predetermined Separator**
Aircraft Information and Status Services	The UAM Operator **should** collect data on potential new telemetry services. (45 UML-2.CS) The Vertiport Operator **should** collect data on potential new telemetry services. (46 UML-2.CS) The PSU Operator **should** collect data on potential new telemetry services. (449 UML-2.CS)	The Fleet Manager and PIC **shall** receive telemetry information from the UAM Aircraft. (82 UML-3.CS) The Vertiport Manager **shall** receive telemetry information from the UAM Aircraft. (105 UML-3.CS) The Fleet Manager and PIC **shall** receive position and intent information from the PSU Network. (303 UML-3.CS) The Fleet Manager and PIC **shall** share position and intent information with the PSU Network. (304 UML-3.CS) The PSU **shall** share position and intent information with ATC on demand. (307 UML-3.CS)	**TBR**: The Fleet Manager is expected to need telemetry information from the vehicle and share with the PSU Network, especially within proximity of the vertiport. (161 UML-4.CS)

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Table 4: Communication Services and Systems (cont.)

	UAM Maturity Level		
Component	**UML-2: Initial**	**UML-3: Transition and Growth**	**UML-4: New Predetermined Separator**
Command Services	The UAM Operator **should** collect data on potential new command services. (64 UML-2.CS)	The Fleet Manager **shall** communicate flight path updates to the PIC and the UAM Aircraft for flights under active command. (106 UML-3.CS)	The Vertiport Manager **shall** receive approach information on UAM arrivals. (127 UML-4.CS) **TBR**: How or when authorization to land or depart is required, including the ability of the Vertiport Manager or the PIC to request or execute a missed approach, is the subject of ongoing research. (338 UML-4.CS) The Vertiport Manager **shall** receive departure information on UAM departures. (450 UML-4.CS)

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Table 4: Communication Services and Systems (cont.)

	UAM Maturity Level		
Component	**UML-2: Initial**	**UML-3: Transition and Growth**	**UML-4: New Predetermined Separator**
Contingency Communications	The UAM Operator **should** collect data on potential new communication services for contingency operations. (57 UML-2.CS)	**TBR** (140 UML-3.CS)	When the link is not degraded, the Fleet Manager and the remote PIC **should** have access to enhanced telemetry and sensor data for real-time diagnostics and command. (128 UML-4.CS) The RPIC **should** communicate with the Fleet Manager, Vertiport Manager, or ATC to resolve contingency and emergency operations. (336 UML-4.CS) The onboard PIC **should** have access to enhanced telemetry and sensor data for real-time diagnostics and command during contingency and emergency operations. (337 UML-4.CS) The UAM Operator **should** maintain safe operations when a navigation source has been compromised. (395 UML-4.CS) The PIC **should** detect and alert the Fleet Manager when a navigation source has been compromised. (396 UML-4.CS) Under UAM contingency management, ATC **should** communicate by voice directly with the PIC involved as well as communicate via data with the PSU to aid in mitigating surrounding airspace construct. (448 UML-4.CS)

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Table 4: Communication Services and Systems (cont.)

	UAM Maturity Level		
Component	**UML-2: Initial**	**UML-3: Transition and Growth**	**UML-4: New Predetermined Separator**
Vehicle-to-Vehicle Services	The UAM Operator **should** collect data on potential new Vehicle-to-Vehicle services. (47 UML-2.CS)	The UAM Aircraft **should** provide a means for Vehicle-to-Vehicle exchange of cooperative information to aid in tactical conflict management. (107 UML-3.CS)	The Fleet Manager **shall** utilize Vehicle-to-Vehicle services for the exchange of cooperative information to aid in separation assurance and collision avoidance. (86 UML-4.CS)
Passenger Data Services	**TBR** (277 UML-2.CS)	**TBR** (306 UML-3.CS)	**TBR** (335 UML-4.CS)
Pre-/Post-Flight Wireless Services	The Fleet Manager **should** receive performance information from the PIC when the UAM Aircraft is on the ground. (48 UML-2.CS)	The PIC **should** report the readiness of the UAM Aircraft to the Fleet Manager. (108 UML-3.CS) The Fleet Manager **should** upload flight plan information to the UAM Aircraft pre-flight. (109 UML-3.CS) The Fleet Manager **should** download flight plan information for the UAM Aircraft post-flight. (305 UML-3.CS)	The RPIC **should** obtain pre-flight briefings to ensure completion of pre-flight activities. (129 UML-4.CS)

5.5 Navigation Services and Systems

The Navigation Services and Systems operational capability includes technologies, processes and infrastructure necessary to plan, record, and enable control of the movement of a vehicle from one place to another by providing accurate, reliable and robust position determination capability and time synchronization. Operations in the Vertiport Operations Area (VOA) and high traffic volume UAM airspace construct will require navigation systems to have high accuracy, integrity (ability to provide a warning when the service is not functioning within its performance boundaries), continuity (ability to tolerate short interruptions of a single navigation source), and availability (availability of the navigation services in the operating area during times where the UAM operations are permitted) [33]. Navigational performance requirements should scale with the expected traffic density of the airspace, should be compatible with the UAM airspace construct requirements, and should be more demanding inside the vertiport operations area's airspace than the enroute. The navigation system must also meet requirements for accuracy, integrity, availability, continuity, and resiliency to cybersecurity attacks for all phases of flight.

Ground-based Positioning Services(e.g. ILS, DME/VOR, RF beacons, etc.) : This component includes Position, Navigation, and Timing (PNT) services which utilize beacons, timing sources, or other information sources located on the ground to provide positioning, timing, and guidance data to UAM aircraft. These services may be especially useful during operations near urban areas where satellite-based services may be degraded or unavailable. Some ground-based positioning services such as VHF Omni-Directional Ranges (VORs), Distance Measuring Equipment (DMEs) and RF beacons are being phased out by the FAA and may no longer be available in the future. The services of the future will need to be robust to additional RF interference and propagation challenges posed by the urban environment. Future services such as the use of optical or other sensors to estimate the aircraft position based on the correlation between sensor inputs and ground-references or alternate signal receptions should be matured through research. Navigation services specific to approaches and departures around the vertiports is an especially important area for research.

Satellite-based Positioning Services(e.g. GPS, Galileo, etc.) : These sources provide position and timing data to UAM aircraft over a wide area and at higher altitudes, making them ideal for en route positioning services. Furthermore, these systems may be augmented by secondary services (e.g., GBAS, SBAS) to improve various performance metrics such as accuracy and integrity.

Table 5: Navigation Services and Systems

		UAM Maturity Level	
Component	**UML-2: Initial**	**UML-3: Transition and Growth**	**UML-4: New Predetermined Separator**
Ground-based Positioning Services	**TBR** (58 UML-2.NS)	The UAM Operator **should** use backup navigation sources when the primary source fails. (141 UML-3.NS)	The UAM Aircraft **should** employ ground-based landing assist services for urban vertiports. (130 UML-4.NS) The UAM Aircraft **should** employ ground-based PNT services for urban vertiports. (131 UML-4.NS)
Satellite-based Positioning Services	The UAM Aircraft **shall** utilize at least one satellite-based PNT service. (21 UML-2.NS)	The UAM Aircraft **should** employ real-time accuracy and integrity verification of external PNT source(s). (110 UML-3.NS)	The UAM Aircraft **should** use multiple PNT services to support operations in GPS-denied environments. (132 UML-4.NS)

5.6 Secured Airspace

Since the cyber threat landscape changes continually, cybersecurity awareness and cyber threat mitigation must be systemic to the emerging UAM environments, while balancing cybersecurity risks with the operational needs of UAM Operators and service providers. The Secured Airspace capability defines cybersecurity architectures, and conceptual solutions for technologies that provide operational resiliency, through the confidentiality, integrity, and availability of information for the UAM operational environment. The Secured Airspace capability will include secure procedures and technologies for the UAM operational environments by leveraging the National Institute of Standards and Technology (NIST) Cybersecurity Framework [35], which provides the following set of guidelines for mitigating cybersecurity risks across organizations:

Identify: Assess the UAM environment to identify cybersecurity and physical threats, vulnerabilities, and impacts. Develop an understanding to managing cybersecurity risk to systems, cloud-based resources, people, hardware and software assets, data, and capabilities, and the assets' criticality. Identify the current and trending vulnerabilities, threats, and impacts should the threat be realized to assess the risk. Provide an understanding of the identified critical functions and resources that support those critical functions, and the related cybersecurity risks, which enables UAM Operators and service providers to focus and prioritize operational needs, consistent with a risk management strategy.

Protect: Develop and implement the appropriate safeguards to ensure delivery of critical UAM infrastructure services. Protect the privacy, confidentiality, integrity, and availability of UAM component systems and data. Should a threat be realized, protecting the UAM systems and data to maintain a sufficient level of operations through verified response and recovery plans and prevent adverse impacts. Establish guidelines for managing data consistent with the UAM Operator's and service provider's risk strategy to protect the confidentiality, integrity, and availability of information.

Detect: Develop and implement the technologies to identify the occurrence of a cybersecurity event. Enable detection through monitoring and consistency checking of protective measures of UAM information systems and assets to verify the effectiveness of protective measures. Establish a process for deploying detection capabilities and the handling/disposition of detected cybersecurity events for UAM operational environments. Detect anomalies within UAM systems in a timely manner and provide an understanding of the potential impact of the events.

Respond: Develop and implement the appropriate activities regarding a detected cybersecurity incident. Develop response processes and procedures which are executed, to ensure a timely response to detected cybersecurity events. Contain events using a verified response procedure during or after a cybersecurity incident. Develop processes to respond to and mitigate new known or anticipated threats or vulnerabilities on UAM operations with UAM service operators and service providers. Provide a communications mechanism that includes coordination with internal and external UAM Operators and service providers. Evolve response strategies and plans based on lessons learned.

Recover: Develop and implement the appropriate activities to provide resiliency and to restore any capabilities or services that were impaired due to a cybersecurity incident. Develop coordinated restoration activities with internal and external parties within the UAM environment. Restore the UAM operational services to a proper working state using a verified recovery procedure so that systems dependent on those services can function properly. Communicate the recovery activities and status services to UAM service operators and providers. Evolve recovery strategies and plans based on lessons learned with UAM service operators and providers.

Table 6: Secured Airspace

	UAM Maturity Level		
Component	**UML-2: Initial**	**UML-3: Transition and Growth**	**UML-4: New Predetermined Separator**
Identify	UAM Operators, PSU Operators, Vertiport Operators, the FAA, and other UAM Community stakeholders **should** maintain a database of their operational hardware and software to inform the cybersecurity risk management processes. (241 UML-2.SA) Any unreasonable risk to safety-critical systems **should** be removed or mitigated to acceptable levels through design, and any functionality that presents an unavoidable and unnecessary risk **should** be eliminated where possible. (397 UML-2.SA)	UAM Operators, PSU Operators, Vertiport Operators, the FAA, and other UAM Community stakeholders **should** provide logging of data exchanges within the UAM environment to enable anomaly detection and inform the cybersecurity risk management processes. (226 UML-3.SA) UAM Operators, PSU Operators, Vertiport Operators, the FAA, and other UAM Community stakeholders **shall** maintain an inventory of software components and an inventory of data flow connections to inform the cybersecurity risk management processes. (231 UML-3.SA) UAM Operators, PSU Operators, Vertiport Operators, the FAA, and other UAM Community stakeholders **should** identify a governance organization that defines and enforces cybersecurity policies for the UAM environments. (232 UML-3.SA)	UAM Operators, PSU Operators, Vertiport Operators, the FAA, and other UAM Community stakeholders **shall** identify a governance organization that defines and enforces cybersecurity policies for the UAM environments. (246 UML-4.SA) UAM Operators, PSUs, Vertiport Managers, the FAA, and other UAM Community stakeholders **should** collect information on potential attacks, and this information **should** be analyzed and shared across the UAM environment. (399 UML-4.SA)

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Table 6: Secured Airspace (cont.)

	UAM Maturity Level		
Component	**UML-2: Initial**	**UML-3: Transition and Growth**	**UML-4: New Predetermined Separator**
Identify cont.		A vulnerability analysis **should** be generated for each known vulnerability assessed or new vulnerability identified during cybersecurity testing. The disposition of the vulnerability and the rationale for the how the vulnerability is managed **should** also be documented. (398 UML-3.SA)	

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Table 6: Secured Airspace (cont.)

	UAM Maturity Level		
Component	**UML-2: Initial**	**UML-3: Transition and Growth**	**UML-4: New Predetermined Separator**
Protect	UAM Operators, PSU Operators, Vertiport Operators, and other industry stakeholders resources **shall** utilize authentication techniques for system access. (227 UML-2.SA) Data transmission between UAM Operators, PSU Operators, Vertiport Operators, the FAA, and other UAM Community stakeholders **should** be encrypted. Cryptographic techniques **should** be current and non-obsolescent for the intended application. (228 UML-2.SA) The distribution of UAM Operator vehicle command services data **shall** be encrypted. (229 UML-2.SA) The distribution of UAM Operator vehicle surveillance information **should** be encrypted. (278 UML-2.SA) Proper data marking following Federal-level guidance Controlled Unclassified Information (CUI) policy and practice **should** be considered for all data. (378 UML-2.SA)	Multi-factor authentication techniques **shall** be utilized for system access to UAM Operators, PSU Operators, Vertiport Operators, and other industry stakeholders' resources. (233 UML-3.SA) UAM Operators, PSU Operators, Vertiport Operators, and other industry stakeholders resources **should** ensure that their information systems enforce authorizations for controlling the flow of information. (234 UML-3.SA) UAM Operators, PSU Operators, Vertiport Operators, and other industry stakeholders resources **shall** ensure that information with privacy or proprietary restrictions are encrypted in transit and at rest. (235 UML-3.SA)	A coordinated identity management approach for personnel, vehicles and services **should** be implemented across the UAM Operators, PSU Operators, Vertiport Operators, the FAA, and other UAM Community stakeholders. (244 UML-4.SA) UAM Operators, PSU Operators, Vertiport Operators, and other industry stakeholders resources **should** ensure that information with privacy or proprietary restrictions are stored in immutable databases or ledgers. (245 UML-4.SA) UAM Operators, PSU Operators, Vertiport Operators, and other industry stakeholders resources **should** treat all networks and systems external to their local networks as untrusted and use appropriate techniques to mitigate potential threats. (400 UML-4.SA)

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Table 6: Secured Airspace (cont.)

		UAM Maturity Level	
Component	**UML-2: Initial**	**UML-3: Transition and Growth**	**UML-4: New Predetermined Separator**
Detect	Cybersecurity detection processes and procedures **should** be maintained and tested to provide awareness of anomalous events within UAM Operators, PSU Operators, Vertiport Operators, the FAA, and other UAM Community stakeholders' resources. (230 UML-2.SA)	UAM Operators, PSU Operators, Vertiport Operators, and other industry stakeholders information system and assets **shall** be monitored to identify cybersecurity events and verify the effectiveness of protective measures. (236 UML-3.SA)	**TBR** (247 UML-4.SA)

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Table 6: Secured Airspace (cont.)

	UAM Maturity Level		
Component	**UML-2: Initial**	**UML-3: Transition and Growth**	**UML-4: New Predetermined Separator**
Respond	**TBR** (242 UML-2.SA)	UAM Operators, PSU Operators, Vertiport Operators, the FAA, and other UAM Community stakeholders **should** implement incident response plans outlining the appropriate activities regarding a detected cybersecurity incident. (237 UML-3.SA) UAM Operators, PSU Operators, Vertiport Operators, the FAA, and other UAM Community stakeholders **should** develop metrics to periodically assess the effectiveness of their response process. (401 UML-3.SA)	UAM Operators, PSU Operators, Vertiport Operators, the FAA, and other UAM Community stakeholders **should** provide a communications mechanism that includes coordination with internal and external UAM service operators and service providers, in the event of a detected cybersecurity incident. (239 UML-4.SA) UAM Operators, PSU Operators, Vertiport Operators, the FAA, and other UAM Community stakeholders **shall** implement incident response plans outlining the appropriate activities regarding a detected cybersecurity incident. (402 UML-4.SA) UAM Operators, PSU Operators, Vertiport Operators, the FAA, and other UAM Community stakeholders **should** periodically conduct and participate in organized, cyber incident response exercises. (403 UML-4.SA)

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Table 6: Secured Airspace (cont.)

	UAM Maturity Level		
Component	**UML-2: Initial**	**UML-3: Transition and Growth**	**UML-4: New Predetermined Separator**
Recover	**TBR** (243 UML-2.SA)	UAM Operators, PSU Operators, Vertiport Operators, the FAA, and other UAM Community stakeholders **should** implement recovery plans outlining the approach to restore any capabilities or services that were impaired due to a cybersecurity incident, including incidents leading to loss of access to data, such as successful ransomware attacks. (238 UML-3.SA)	UAM Operators, PSU Operators, Vertiport Operators, the FAA, and other UAM Community stakeholders **should** implement coordinated contingency plans in the event of loss of services. (240 UML-4.SA)

5.7 Separation Services and Standards

The Separation Services and Standards operational capability includes technologies, standards, and services providing functions that limit, to an acceptable level, the risk of collision between aircraft and hazards. A hazard is anything from which an aircraft must be separated, which includes other aircraft, terrain, weather, wake turbulence, buildings and structures, incompatible airspace activity, etc. Separation minima are the minimum displacements between an aircraft and a hazard that maintain the risk of hazardous encounter at an acceptable level of safety. Any situation involving aircraft and hazards in which the applicable separation minima may be compromised is referred to as a conflict [2]. Generally, conflicts are detected or determined by predicting the UAM aircraft and potential hazard's future states. The achievable separation minima are highly dependent upon the nominal and off-nominal (degraded) performance of the Communication, Navigation, and Surveillance systems.

Parts of the function of conflict management, as defined by the ICAO Global Air Traffic Management Operational Concept [2, §2.7], will be allocated to the UAM Operators, including PIC and aircraft capabilities, and may include support from the PSUs [7]. These self-provided and third-party services are directly reliant on the roles & responsibilities of the actors and entities in the UAM airspace system of systems, as well as the separation minima that are agreed and approved via rigorous application of SMS. Intent sharing amongst the actors is an important component of conflict management and will be present in various forms throughout the process.

Strategic Conflict Management Services: Strategic conflict management is the first layer of conflict management and is achieved through the airspace organization and management, demand and capacity balancing and traffic synchronization services. Properly applied, strategic conflict management services enable the services in the second layer – separation provision – to provide an acceptable level of safety and performance.

Separation Provision Services: Separation provision is the second layer of conflict management and is an iterative tactical process of keeping aircraft away from hazards by at least the appropriate separation minima [2]. Separation provision consists of conflict detection, resolution, and monitoring. Tactical actions taken as part of separation provision are considered routine and within nominal operations. When UAM Operators are receiving separation services from ATC, it will be according to the same rules as any other aircraft for which ATC is responsible. A set of criteria defining Well Clear may be established, related to the applicable separation minima in the sense that satisfying the well clear criteria always satisfies the separation minima.

Collision Avoidance Services: Collision avoidance is the third layer of conflict management and must activate when the separation mode has been compromised. Collision avoidance is not part of separation provision, and collision avoidance systems are not included in determining the calculated level of safety required for separation provision. Collision avoidance systems will, however, be considered as part of ATM safety management. Maneuvers for collision avoidance may be aggressive where the safety of flight is compromised and are considered off-nominal events. The collision avoidance functions and the applicable separation mode must be compatible, although the collision avoidance function may need to induce actions that take a limited set of conditions into account [2].

Roles & Responsibilities: Separation provision is assured through an approved set of rules, procedures and conditions of application associated with the separation mode and associated separation minima. These are dependent upon the roles of the system actors, with clearly defined responsibilities. One responsibility of primary importance is that of the predetermined separator[2]. This is the unambiguous agent responsible for keeping aircraft separated from hazards. The predetermined separator must be defined for all hazards. While it is possible that different predetermined separators are separating the same aircraft for different hazards, any separation provision action taken must be acceptable with regard to all potential conflicts. User operations are minimally restricted when the predetermined separator is the airspace user. Oftentimes the operational environment will require a separation provision service provider, and the associated restrictions, to achieve minimum safety and performance levels. The role of separator may be delegated, but the delegation must be temporary and unambiguous.

Separation Minima: Separation minima are based on minimum displacements between an aircraft and a hazard that maintain the risk of collision at an acceptable level of safety but may not be as simple as a single constant minimum value. The separation minima are designed to satisfy both safety and performance goals and will be tailored to the specific operational environment wherever possible. The separation mode is an approved set of rules, procedures and conditions of application associated with the separation minima. The separation minima will be performance-based and will take into account the safety level required, the nature of the activity and hazard, the qualifications and roles of the actors, and other conditions of application such as weather conditions, traffic density, and CNS performance. As part of these performance-based definitions, it is possible that Near Mid-Air Collision (NMAC) volumes are also re-defined. The performance of both strategic conflict management services and Separation Provision services is dependent upon the applicable separation minima.

Table 7: Separation Services and Standards

Component	*UAM Maturity Level* **UML-2: Initial**	**UML-3: Transition and Growth**	**UML-4: New Predetermined Separator**
Strategic Conflict Management Services	ATC and the Fleet Manager **will** strategically manage conflicts for UAM operations using existing flight rules, procedures, and technologies. (204 UML-2.SS) The UAM Operator **should** collect data on potential new Traffic Synchronization services. (281 UML-2.SS) The UAM Operator **should** collect data on potential new Trajectory Generation services used for strategic conflict management. (282 UML-2.SS) The UAM Operator **should** collect data on potential new Demand Capacity Balancing services. (286 UML-2.SS)	The PSU **should** identify when the UAM Aircraft is out of conformance with the cooperative strategic plan. (69 UML-3.SS) The UAM Operator **should** employ Traffic Synchronization services to establish and maintain safe and efficient flow UAM operations. (83 UML-3.SS) The UAM Operator **shall** employ Demand Capacity Balancing services to share airspace resources with other UAM Operators. (205 UML-3.SS) The Fleet Manager **will** leverage the properties of the airspace constructs, en-route, approach, and departure procedures as part of the strategic plan. (208 UML-3.SS) The PSU **shall** allocate the capacity of the shared airspace resources to the UAM Operator. (311 UML-3.SS) The Fleet Manager and the PSU **shall** use shared intent as inputs to strategic plan services. (313 UML-3.SS)	**TBR**: While Strategic Conflict Management services are introduced in UML-3, additional requirements for UML-4 such as increased level of automation are yet to be determined. (206 UML-4.SS)

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Table 7: Separation Services and Standards (cont.)

	UAM Maturity Level		
Component	**UML-2: Initial**	**UML-3: Transition and Growth**	**UML-4: New Predetermined Separator**
Separation Provision Services	The PIC **shall** ensure that their aircraft remains Well-Clear by "see and avoid" under VFR. (22 UML-2.SS) The UAM Operator **should** employ services that provide see and avoid guidance to the PIC. (51 UML-2.SS) The UAM Operator **should** collect data on potential new services that assist the aircraft in conforming with the strategic schedule. (279 UML-2.SS) The UAM Operator **should** collect data on potential new services that assist the aircraft in regaining well clear when it has been lost. (280 UML-2.SS) The UAM Operator **should** collect data on potential new Trajectory Generation services used for separation assurance. (283 UML-2.SS) The UAM Operator **should** collect data on potential new services that assist the aircraft in maintaining well clear. (284 UML-2.SS) The UAM Operator **should** collect data on potential new services that assist the aircraft in achieving appropriate spacing from other aircraft. (285 UML-2.SS)	The PIC **should** use safety-enhancing services that assist the UAM Aircraft in maintaining well clear. (112 UML-3.SS) The PIC **should** employ approved safety-enhancing services that assist the UAM aircraft in conforming with the strategic plan. (113 UML-3.SS) ATC **will** provide separation services when requested by the Fleet Manager or PIC. (209 UML-3.SS) The Fleet Manager **shall** monitor the conformance of the UAM operations under their control to the active flight intent. (212 UML-3.SS) The PIC **shall** ensure that the UAM Aircraft is conforming to the expected flight path. (213 UML-3.SS) The PIC **should** use onboard situation awareness tools to assist in visual separation. (216 UML-3.SS) When well-clear has been lost, the PIC **should** use safety-enhancing services that assist the UAM Aircraft in regaining well clear. (308 UML-3.SS)	The PIC **should** use safety-critical services that help the UAM Aircraft maintain well clear. (134 UML-4.SS) The UAM Operator **should** employ approved mission-critical services that assist the UAM aircraft in conforming with the strategic plan. (214 UML-4.SS) The UAM Operator **should** use approved flight intent as input to their separation provision intervention capability. (221 UML-4.SS) When well-clear has been lost, the PIC **should** use safety-critical services that assist the UAM Aircraft in regaining well clear. (340 UML-4.SS) The PIC **should** employ mission-critical services that assist the UAM aircraft in achieving appropriate spacing from other aircraft. (341 UML-4.SS)

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Table 7: Separation Services and Standards (cont.)

	UAM Maturity Level		
Component	**UML-2: Initial**	**UML-3: Transition and Growth**	**UML-4: New Predetermined Separator**
Separation Provision Services cont.		The UAM Operator **should** employ approved safety-enhancing services to assist the UAM aircraft in achieving appropriate spacing from other aircraft. (314 UML-3.SS) The PIC **should** respond to approved guidance to assist the UAM Aircraft in maintaining well clear. (352 UML-3.SS) The PIC **should** respond to approved guidance intended to help the UAM Aircraft regain well clear when it has been lost. (353 UML-3.SS) The Fleet Manager **shall** make other Fleet Managers aware when any operation under their control has deviated from the active flight intent. (354 UML-3.SS)	
Collision Avoidance Services	The PIC **shall** use "see and avoid" under VFR to avoid collisions once the separation mode has been compromised. (210 UML-2.SS)	The PIC **should** use safety-critical services to avoid a collision hazard, once the separation mode has been compromised. (142 UML-3.SS)	

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Table 7: Separation Services and Standards (cont.)

	UAM Maturity Level		
Component	**UML-2: Initial**	**UML-3: Transition and Growth**	**UML-4: New Predetermined Separator**
Roles & Responsibilities	ATC **will** be the predetermined separator for UAM aircraft operating under IFR or within controlled airspace. (23 UML-2.SS) The PIC **will** be the predetermined separator for the UAM aircraft operating under VFR. (452 UML-2.SS)	The UAM Operators **will** be accountable for the cooperative development of a strategic plan. (217 UML-3.SS) The FAA **will** approve flight rules that allow the PIC to be the predetermined separator below VMC, or under other conditions where VFR would not traditionally apply. (309 UML-3.SS) The PIC and Fleet Manager **will** be responsible for executing the cooperative strategic plan. (310 UML-3.SS)	The FAA **will** approve flight rules that allow ATC to delegate separation responsibility to the PIC, Fleet Manager, or Vertiport Manager, or PSU under appropriate conditions. (89 UML-4.SS) The FAA **will** approve flight rules that allow the predetermined separator to be (**TBR**; an actor who is neither the onboard PIC under VFR nor ATC). (339 UML-4.SS)
Separation Minima	The UAM Operator **should** collect data on potential new performance-based separation standards. (52 UML-2.SS)	The UAM Operator **will** satisfy performance requirements for reduced separation minima. (115 UML-3.SS) The UAM Operator **should** collect data on potential new sensors and automation onboard and offboard the aircraft that assist in separation minima compliance. (220 UML-3.SS)	Under VMC, the RPIC **should** use sensors and automation onboard and offboard the aircraft that assist in separation minima compliance. (215 UML-4.SS)

5.8 Surveillance Services and Systems

The Surveillance Services and Systems operational capability includes technologies and procedures that assist in providing awareness of the contents of the airspace. This includes the validation of self-reported aircraft position data and non-cooperative surveillance to detect sUAS, GA aircraft, non-cooperative UAM aircraft (if any), birds, high-rise construction cranes, and any other objects in the airspace that may present a collision risk.

Non-Cooperative: This includes the use of on-board Detect and Avoid (DAA) sensors and ground-based surveillance assets (e.g., radar, cameras, radiometric tracking, etc.) to detect physical objects in the airspace and to validate the self-reported position of UAM aircraft. In the near term, existing primary radar services provided by ATC could be considered. It is expected that there will often be gaps in non-cooperative surveillance that will need to be filled in order for UAM to operate in the area.

Cooperative: This primarily includes the passing of position and intent data along with the intended navigation precision between aircraft for tactical and strategic deconfliction (e.g., ADS-B) and situational awareness. The data needed by the aircraft and other systems is also used for trajectory and state predictions necessary for demand prediction, scheduling, conformance monitoring, and tracking in case of emergencies. It is expected that there will often be gaps in non-cooperative surveillance that will need to be filled in order for UAM to operate in the area.

Table 8: Surveillance Services and Systems

	UAM Maturity Level		
Component	**UML-2: Initial**	**UML-3: Transition and Growth**	**UML-4: New Predetermined Separator**
Non-Cooperative	ATC **should** provide surveillance using primary radar sources. (53 UML-2.SU)	The FAA **should** approve surveillance services using primary radar sources installed at vertiports. (117 UML-3.SU) The Fleet Manager and the PSU **should** use approved surveillance services at vertiports. (118 UML-3.SU) The UAM Operator **should** equip the UAM Aircraft with sensors to detect non-cooperative aircraft to deliver sufficient performance and safety in the airspace. (224 UML-3.SU)	The Fleet Manager and Vertiport Manager **should** utilize on-board collision avoidance instrument's data as a source of non-cooperative surveillance information. (137 UML-4.SU) The FAA **will** approve the use of radiometric tracking and verification of vehicle position reports. (138 UML-4.SU)

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Table 8: Surveillance Services and Systems (cont.)

	UAM Maturity Level		
Component	**UML-2: Initial**	**UML-3: Transition and Growth**	**UML-4: New Predetermined Separator**
Cooperative	The UAM Operator **will** ensure their aircraft meets FAA standards for appropriate operation in the airspace. (25 UML-2.SU) The PIC **should** use vehicle-to-vehicle surveillance for advisory purposes. (54 UML-2.SU) The Fleet Manager **should** have access to telemetry directly from the vehicle. (55 UML-2.SU) When ATC is the designated separator; ATC **should** use surveillance sources to detect potential surface conflicts. (222 UML-2.SU) The Fleet Manager **should** monitor real-time information of the progress of flights under their supervision. (223 UML-2.SU) When ATC is the designated separator; ATC **will** need to identify UAM aircraft, maintain identity of targets, and perform handoffs between controllers. (225 UML-2.SU)	The UAM Operator **should** provide position and intent information as a surveillance source for other airspace users . (84 UML-3.SU)	The PIC **should** use vehicle-to-vehicle surveillance for cooperative separation assurance. (90 UML-4.SU) The RPIC **should** use cooperative surveillance information in their command and control of the UAM aircraft. (355 UML-4.SU)

5.9 Vertiport Operations

The Vertiport Operations capability provides the ability for Vertiport Operators to deliver safe, secure, efficient, and resilient approach, departure, maintenance, and customer services for UAM operations at the vertiports. A vertiport is an identifiable ground or elevated area, including any buildings or facilities thereon, used for the takeoff and landing of eVTOL aircraft and rotorcraft [14]. A vertiport may be new or existing infrastructure and may be publicly or privately owned. Vertiport design will vary in size, configuration, service offerings, and locations. Service offerings can range from passenger or cargo drop-off/pick-up, parking area with/without refueling or recharging battery services, to maintenance, repair, and overhaul (MRO) operations for fleet management. Two vertiport types are distinguished, depending on the available infrastructure, defined below

- A **vertihub** refers to a vertiport with infrastructure for maintenance, repair, fueling, and parking spaces for the UAM aircraft
- A **vertistop** refers to a vertiport intended solely for takeoff and landing of VTOL aircraft and rotorcraft to drop off or pick-up passengers or cargo. A vertistop may have limited parking available [14].

Vertiports can vary significantly in size and scope. Vertihubs may involve a handful of landing pads, parking spaces, and charging stations, or they may be part of a hub linking with other modes like train and ground transportation, designed to support high volume of activity. Vertistops can be as small as a single pad and may require more restrictive approach procedures when fewer services are available.

Vertiport locations will be selected based on anticipated or actual demand, and can range from being a current heliport supporting mixed UAM and traditional operations, to new purpose-built infrastructure supporting new aircraft types and new modes of operation.

Vertiport operations may require advanced technology and regulatory changes to support UAM operations at scale, and to coordinate with other UAM and ATM system actors. The vertiport is a significant component of the Common Operating Picture, since the Vertiport Operator may be accountable for aspects of the schedule and demand-capacity balancing requirements on approach, as well as the departure schedule. Off-nominal and contingency procedures are especially important at the vertiports, where demand for shared resources is the highest and the phase of flight is most complex. The vertiports also play an important role as a potential focal point for services and safe landing during emergencies. The Vertiport Operations capability is decomposed into the following components.

Airside Services: Those who work airside operations oversee the airfield, ramps, safety, and security of the vertiport. Airside services support the management of UAM aircraft surface movements. Airside locations include all areas accessible to UAM aircraft, including the Touchdown and Liftoff (TLOF) pads, the Final Approach and Takeoff (FATO) zones, and surrounding safety area. It also includes passenger boarding areas and taxiways between all airside locations, and transitions to/from landside areas. It also includes air and ground traffic conflict and detection, and the exchange of information with the PIC to enable safe landing, departing, and taxiing operations [36].

Emergency Services: The vertiports will play a central role during emergencies, coordinating with approach and departure operations that may be impacted by the emergency, and arranging for emergency services as needed for the aircraft in distress. These services will be enabled by highly reliable infrastructure supporting the human decision-makers actively engaged in resolving the emergency, connecting them to any of the variety of actors outside of the UAM system that may be needed (e.g., fire, medical, law enforcement).

Hazard Identification and Mitigation Services: These services leverage vertiport infrastructure, sensors, and automation to identify and mitigate against hazards associated with off-nominal and contingency vertiport conditions which could cause harm, damage, or injury and have been determined to pose a threat to UAM aircraft. Examples of such services include non-cooperative traffic surveillance, vertiport resource availability monitoring, wildlife hazard detection and mitigation, weather collection and reporting, and Foreign Object Debris (FOD) detection and mitigation. The information associated with these services are intended for use by the Vertiport Operator and will generally prompt the Vertiport Manager to implement appropriate off-nominal procedures. This information will generally, but not necessarily, be part of the Common Operating Picture [7].

Landside Services: Those who work in landside operations have a customer-service role overseeing vertiport access facilities, parking and maintenance areas, and properties surrounding the airport. Like airside, landside services also include safety and security operations, such as security checkpoints where the transfer of people and goods from Landside to Airside requires it. Landside services support the logistics of moving people and goods through the facility to board the UAM aircraft. Landside areas include parking lots, fueling stations, access roads, waiting areas [36]. In some cases, areas designated for emergency operations may be used for landside activities.
Note: Landside Services are not considered part of Airspace and are not fully addressed in this document. Assumptions on the performance of these services can impact airspace operations, especially as it impacts the predictability of the approach, departure, and aircraft turnaround.

Resource Management: Shared resources at the vertiport such as TLOF pads, taxiways, gates, parking, fueling infrastructure, and ramp areas will need to be managed as UAM operations scale. The Vertiport Manager's role in coordinating the availability of these resources will play an important role in the development of the shared strategic plan and the Common Operating Picture. In some environments, especially with mixed-use facilities (e.g., helicopter, airport surface), the Vertiport Manager will need to coordinate resource availability with users outside of the UAM airspace system. The Vertiport Manager will prioritize allocation of the vertiport resources under a set of configurable rules and will manage the resources to achieve efficient vertiport surface operation in accordance with the configurable business rules and local, state, and federal rules and regulations [7].

Vertiport Information Management: Vertiport information management refers to the collection and distribution of active and future UAM flight information. People who work in information management store seasonal and arrival/departure information and keep track of the connection with the UAM Operators and the PSUs. This management function is integral to the timeliness of flight arrivals and departures and the organization of the schedule [36].

Vertiport Operations Training: Training standards and practices will be in place to ensure that Vertiport Managers and their staff provide services for safe, secure, efficient, and sustainable Vertiport Operations. Training programs will be offered for airside operations to understand performing ramp handling services, safety management, the risks of the operations, and airside emergency management. Depending on the services provided, the FAA may require a certain level of training for Vertiport Managers [36].

Table 9: Vertiport Operations

	UAM Maturity Level		
Component	**UML-2: Initial**	**UML-3: Transition and Growth**	**UML-4: New Predetermined Separator**
Airside Services	**TBR** (287 UML-2.VS) Vertiport Operators **should** provide takeoff and landing coordination functions. (387 UML-2.VS)	The Vertiport Manager **should** monitor aircraft and ground vehicle conformance to trajectories. (315 UML-3.VS) The Vertiport Manager **should** execute approved off-nominal procedures when an aircraft or ground vehicle trajectory is out of conformance with the expected trajectory. (361 UML-3.VS)	Vertiport Managers **should** assess operational risk and make decisions to mitigate risk at the vertiport operation area. (344 UML-4.VS) The Vertiport Manager **shall** monitor aircraft and ground vehicle conformance to trajectories. (345 UML-4.VS) Vertiport Managers **should** be responsible for (**TBR**) elements of conflict management. (366 UML-4.VS) The Vertiport Manager **shall** execute approved off-nominal procedures when an aircraft or ground vehicle trajectory is out of conformance. (368 UML-4.VS)
Emergency Services	The Vertiport Operator **should** collect data on emergency services available in and around potential vertiport locations. (288 UML-2.VS)	The Vertiport Manager **will** have direct communication with emergency services. (316 UML-3.VS)	**TBR** (367 UML-4.VS)

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Table 9: Vertiport Operations (cont.)

	UAM Maturity Level		
Component	**UML-2: Initial**	**UML-3: Transition and Growth**	**UML-4: New Predetermined Separator**
Hazard Identification and Mitigation Services	The Vertiport Operator **should** collect data on wildlife activity in and around potential vertiport locations. (289 UML-2.VS)	The Vertiport Operator **should** have a wildlife management plan in place. (360 UML-3.VS) The Vertiport Manager **should** identify hazards. (363 UML-3.VS) The Vertiport Operator **should** utilize automated FOD detection systems. (364 UML-3.VS)	Vertiport Managers **shall** monitor their vertiport surface for any Foreign Object Debris that may pose a collision risk for UAM vehicles during the vertiport surface operations. (342 UML-4.VS) Vertiport Managers **shall** monitor their airspace for sUAS operations, birds, construction cranes, and any other objects that may pose a collision risk for UAM vehicles within the vertiport operations area. (388 UML-4.VS)
Landside Services	**TBR** (372 UML-2.VS)	**TBR** (373 UML-3.VS)	**TBR** (369 UML-4.VS)

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Table 9: Vertiport Operations (cont.)

	UAM Maturity Level		
Component	**UML-2: Initial**	**UML-3: Transition and Growth**	**UML-4: New Predetermined Separator**
Resource Management	Vertiport Managers **should** use resource management functions to strategically coordinate at the origin and destination vertiports. (356 UML-2.VS) Vertiport Operators **should** provide resource availability, scheduling, and reservation functions to strategically coordinate at the origin and destination vertiports. (381 UML-2.VS) Vertiport Operators **should** provide a vertiport capacity function if there are systems that rely on this type of information. (382 UML-2.VS) Vertiport Operators **should** provide a vertiport status function if there are systems that rely on this type of information. (383 UML-2.VS) Vertiport Operators **should** provide a vertiport configuration information function. (384 UML-2.VS)	The Vertiport Manager **should** manage arrival, departure, and parking reservations at the vertiport. (317 UML-3.VS) For vertiport development on federally obligated airports, the infrastructure or equipment **will** be depicted on the Airport Layout Plan (ALP). (359 UML-3.VS)	The Vertiport Manager **shall** manage vertiport resources. (343 UML-4.VS)

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Table 9: Vertiport Operations (cont.)

	UAM Maturity Level		
Component	**UML-2: Initial**	**UML-3: Transition and Growth**	**UML-4: New Predetermined Separator**
Vertiport Information Management	Vertiport Managers **should** use the vertiport information management system to view the status of the vertiport. (290 UML-2.VS) In the vertiport arrival reservation, Vertiport Operators **will** include the identifier for the fleet operator that owns the inbound operation. (385 UML-2.VS) Vertiport Managers **should** require knowledge about where the flight is coming from (or going to) or what arrival path (or departure path) the flight may be following in order to properly assess availability or make reservations for the vertiport's resources. (386 UML-2.VS)	Vertiport Managers **should** use the vertiport information management system to make adjustments to the state of the vertiport. (318 UML-3.VS)	**TBR** (370 UML-4.VS)
Vertiport Operations Training	The FAA **will** establish training standards for defined Vertiport Manager roles as necessary. (357 UML-2.VS) The UAM Operators and Vertiport Operators **should** define the roles and responsibilities of the Vertiport Manager that need to be approved by the FAA. (358 UML-2.VS)	The UAM Operators and Vertiport Operators **should** establish training programs for Vertiport Managers. (362 UML-3.VS) Vertiport Managers **should** be trained and approved for service. (365 UML-3.VS)	**TBR** (371 UML-4.VS)

5.10 Weather

The Weather operational research element includes the collection, translation, and usage of weather information exchanged between entities which are required to enable safe, efficient, and scalable UAM operations. As the low-altitude urban airspace in which UAM operations occur is a highly dynamic environment where conditions vary rapidly both spatially and temporally, weather will at times be an impactful (and even a significant) hazard. Thus, adequate weather information at urban scales is necessary to ensure conditions are within regulatory, safety, and operational constraints, inform route planning, and facilitate efficient operations. The specific weather information requirements (e.g., resolution, accuracy, precision, refresh rate) for different parameters (e.g., wind speed and direction at the surface and aloft, turbulence, icing, wind shear, updraft and downdraft intensity, precipitation, ceiling, visibility, barometric pressure, temperature, dew point, etc.) will be highly dependent on a number of factors. These include the forecast horizon, vehicle type and performance, vertiport location and configuration, airspace procedure design, density of operations (defined as the number of vehicles within a volume of airspace), flight operation type, type of environment (e.g., urban, suburban, interurban), and other factors. As operations begin at UML-2, weather requirements will be aligned with current FAA regulations with targeted waivers to test and demonstrate performance-based standards. Specifically, operations will be under Part 91, 121, and 135 using FAA qualified weather sources, except as waived by the FAA to allow operators to use approved Weather SDSPs (also called Weather Information Providers, WIPs) to test, demonstrate, and collect data for the FAA and NASA on data performance standards under real world operations. Starting in UML-3 and by UML-4, weather requirements are expected to transition to performance-based standards, such as those currently being developed by ASTM's Committee on Unmanned Aircraft Systems (F38).

Weather SDSPs will not be required to provide a full set of weather services. Some SDSPs will only provide sensor data, some will only provide machine-to-machine data sets, some only forecaster consulting services, and some the full suite of services from sensors to decision support. In general, a weather SDSP will provide meteorological information (e.g., measurements, analyses, models, forecasts, and/or decision support) that are disseminated across the ecosystem to the appropriate users in accordance with common policies. The UAM Operator and other airspace users will be the primary customers of these data, and are anticipated to subscribe to a variety of weather SDSPs across the service categories to support operational decision making. The following descriptions apply to weather SDSPs or PSUs providing those specific services and the UAM Operators utilizing these services, with the associated requirements provided in Table 10. These weather requirements are sourced from and can be traced to existing documentation, including other elements of this UAM Research Roadmap, and refined with input from UAM community stakeholders.

The weather element consists of the following components:

Analyzed Weather: Analysis of atmospheric conditions in full three-dimensions spatially, both at the surface and aloft, to provide the best estimate of current weather conditions at any location. These analyses are produced to provide weather information at points between sparse measurements. The techniques in which these analyses are produced varies by product and include interpolation, extrapolation, artificial intelligence, statistical models, and/or blending with prior forecast products. Weather analyses have varying degrees of uncertainty dependent on a variety of factors such as the density and accuracy of weather measurements and the presence of local micro-climates. Analyzed weather provides a measure of situational awareness for UAM operators for tactical decision making to help manage risk about potential weather conditions where a lack of real measurements exist. Analyzed weather can be used to assess whether the conditions may be within operating constraints and determine whether the vehicle is able to conform with performance requirements, particularly at locations where there is no representative weather measurement nearby.

Decision Support: Systems that translate weather measurements, models, and/or forecasts into operational constraints and/or actionable advice to support operational decision-making using automation or through human analysis or consulting. These support tools may incorporate vehicle performance, operator preferences, operational constrains, passenger comfort (e.g., ride quality), airspace management procedures, current observations and forecasts together to aid in decision making. Observational and forecast uncertainty may be utilized to assess risk and the range of potential operational impacts across the UAM ecosystem including throughput at vertiports, airspace capacity, type of operation, and energy management for UAM operators. These decision support tools will need to meet certain performance requirements such as the ability to ingest new weather information, traffic demand, airspace status, and other relevant information to generate meaningful information with low latency.

Dissemination: Data networks to distribute pertinent weather information in both textual as well as pictorial formats across the UAM system in a timely manner, such as to alert UAM operators of new hazards when conditions rapidly deteriorate. The volume of micro-scale weather information is going to be massive, prompting the need to develop methods to distill and compress this information for real-time dissemination. These networks will use Community Based Rules (CBRs) and agreed upon standardized data formats across the different components of the UAM system. The networks will be monitored and resilient, to identify, report, and mitigate data outages from any source, and secure from potential outside threats.

Weather Forecasts: Predictions of weather conditions into the future, often incorporating observational data, output from multiple numerical weather models, and can include manual intervention by a human forecaster and interpretation skills by the UAM operator, who has the final authority of the flight. This component includes both nowcasts (short-term forecasts out to two hours) and longer-term forecasts of the meteorological conditions, with nowcasts being more heavily based on current observations and longer forecast horizons on numerical weather model output. Forecasts can have uncertainty metrics to support UAM operations including contingency planning.

Weather Measurements: Measurements of current atmospheric conditions including but not limited to temperature, humidity, pressure, precipitation, visibility, wind speed, and wind direction. Observations can be in situ (e.g., via anemometers, thermometers, barometers), remotely sensed (e.g., via radar, lidar, satellite), or indirectly derived (e.g., visibility from camera). Each observation has an associated accuracy dependent on the sensing method, conditions, and other factors. Observations are typically valid at a specific point or volume and time with their representativeness being highly dependent on the surrounding environment. Meteorological measurements provide situational awareness for UAM operators about the weather for tactical decision making, ensuring conditions are within operating constraints, and determining whether the vehicle is able to meet the weather performance requirements.

Weather Models: Computational models that process weather observations to produce an analysis of current weather conditions and solve mathematical equations based on physics to predict future weather conditions. This includes full numerical weather prediction models that simulate all weather phenomena, as well as computational fluid dynamic (CFD) models such as large eddy simulation (LES) and direct numerical simulation (DNS) that generally run at higher resolution over a smaller domain to model microscale phenomena such as urban canyon and other built-environment effects, and can include machine learning or artificial intelligence models. These models inform UAM operators of three-dimensional weather conditions into the future and serve as tactical and strategic aids.

Weather Policy: A set of common rules and guidelines to be followed regarding the collection, use, and dissemination of weather informational data across all the UAM ecosystem. These guidelines include accepted standards agreed upon by all the relevant stakeholders and will be foundational to the weather sensing, modeling, forecasting, decision support, and dissemination architecture necessary to facilitate high-tempo UAM operations.

Table 10: Weather

	UAM Maturity Level		
Component	**UML-2: Initial**	**UML-3: Transition and Growth**	**UML-4: New Predetermined Separator**
Analyzed Weather	The Fleet Manager **should** use early analyzed weather products to support situational awareness and flight planning. (404 UML-2.WX)	The SDSP **shall** publish analyzed weather that meets performance standards for estimating weather parameters to all subscribers. (405 UML-3.WX) The SDSP **should** publish associated validated uncertainty metrics for analyses of weather parameters using validation methods approved by the FAA to support risk-based decision making. (406 UML-3.WX)	The SDSP **shall** publish associated validated uncertainty metrics for analyses of weather parameters using validation methods approved by the FAA to support risk-based decision making. (407 UML-4.WX)
Decision Support	The Fleet Manager **should** use early decision support and weather translation products to increase safety and efficiency. (291 UML-2.WX)	The SDSP or PSU **shall** incorporate weather information to assess capacity, availability, and safety of shared airspace resources. (322 UML-3.WX) The SDSP or PSU **should** produce uncertainty metrics on anticipated weather impacts on capacity, availability, and safety of shared airspace resources that is validated. (324 UML-3.WX) The SDSP or PSU **shall** provide decision support capability to advise users of relevant weather impacts near vertiports and along routes. (408 UML-3.WX)	The SDSP or PSU **shall** produce uncertainty metrics on anticipated weather impacts on capacity, availability, and safety of shared airspace resources that is validated. (346 UML-4.WX)

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Table 10: Weather (cont.)

	UAM Maturity Level		
Component	**UML-2: Initial**	**UML-3: Transition and Growth**	**UML-4: New Predetermined Separator**
Dissemination	The Fleet Manager **will** obtain weather information from a source approved by the FAA to comply with regulations. (292 UML-2.WX)	The SDSP or PSU **shall** alert Fleet Managers of hazardous weather conditions when they are detected. (323 UML-3.WX) The Fleet Manager **shall** obtain weather information from a source approved by the FAA, including SDSPs and PSUs, to comply with regulations and for additional situational awareness. (325 UML-3.WX) The Fleet Manager **shall** report hazardous weather conditions when they are detected or encountered for shared use among other operators, SDSPs, and PSUs. (409 UML-3.WX)	The Fleet Manager **shall** obtain weather information from a source approved by the FAA, including SDSPs and PSUs, to comply with regulations, for additional situational awareness, and to support high tempo operations. (347 UML-4.WX)
Weather Forecasts	The Fleet Manager **will** use forecast products approved by the FAA to ensure compliance with existing policies and procedures. (296 UML-2.WX) The Fleet Manager **should** use supplementary high-resolution forecasts for enhanced situational awareness and flight planning and to increase safety and efficiency. (410 UML-2.WX)	The SDSP **should** publish associated validated uncertainty metrics for forecasts of weather parameters using validation methods approved by the FAA to all subscribers. (319 UML-3.WX) The SDSP **shall** publish forecasts that meets performance standards for weather parameters to all subscribers. (411 UML-3.WX)	The SDSP **shall** publish associated validated uncertainty metrics for forecasts of weather parameters using validation methods approved by the FAA to all subscribers. (348 UML-4.WX)

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Table 10: Weather (cont.)

	UAM Maturity Level		
Component	**UML-2: Initial**	**UML-3: Transition and Growth**	**UML-4: New Predetermined Separator**
Weather Measurements	The Fleet Manager **will** use weather measurements approved by the FAA to ensure compliance with existing policies and procedures. (293 UML-2.WX) The Fleet Manager **should** use supplementary weather measurements for enhanced situational awareness and flight planning and to increase safety and efficiency. (412 UML-2.WX) The UAM community **should** develop weather sensing networks to improve the safety of early operations and provide data to validate, weather models and standards along with beginning to improve AAM weather forecasts. (413 UML-2.WX)	The SDSP **shall** collect and publish weather measurements meeting sensor and data performance standards for weather parameters to all subscribers. (321 UML-3.WX) The SDSP **should** publish associated validated uncertainty metrics be included with each weather measurement in compliance with CBRs to all subscribers. (414 UML-3.WX) The Fleet Manager **should** take meteorological measurements (e.g., temperature, pressure, wind speed, wind direction) on vehicles and transmit the observations periodically for shared use among other operators, SDSPs, and PSUs. (415 UML-3.WX) The UAM community **should** enhance weather sensing networks to support UML-3 operations and continue validation of standards and models along with providing data to improve forecasts and forecasting methods. (416 UML-3.WX)	The SDSP **shall** collect and publish weather measurements that meets sensor and data performance standards for weather parameters to all subscribers at sufficient density to support high tempo UML-4 operations. (351 UML-4.WX) The SDSP **shall** publish associated validated uncertainty metrics be included with each weather measurement in compliance with CBRs to all subscribers. (417 UML-4.WX)

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Table 10: Weather (cont.)

	UAM Maturity Level		
Component	**UML-2: Initial**	**UML-3: Transition and Growth**	**UML-4: New Predetermined Separator**
Weather Models	The Fleet Manager **should** use operational weather models (i.e., from the National Weather Service) and supplementary high-resolution models to support situational awareness and flight planning. (295 UML-2.WX)	The SDSP **shall** use numerical weather prediction models that meet performance standards for estimating weather parameters. (327 UML-3.WX) The SDSP **should** use computational fluid dynamics models that meet performance standards for estimating weather parameters in regions where conditions are highly complex due to the built environment such as downtown regions. (418 UML-3.WX)	The SDSP **shall** use computational fluid dynamics models that meet performance standards for estimating weather parameters in regions where conditions are highly complex due to the built environment such as downtown regions. (349 UML-4.WX)

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Table 10: Weather (cont.)

	UAM Maturity Level		
Component	**UML-2: Initial**	**UML-3: Transition and Growth**	**UML-4: New Predetermined Separator**
Weather Policy	The UAM operator **will** comply with any operational requirements involving weather under approved FAA policy and regulations (e.g., aircraft equipage and pilot training). (294 UML-2.WX) The FAA **should** begin to draft updated requirements to authorize UAM operators to utilize data from initially qualified SDSPs to satisfy FAA weather related policy and regulations. (419 UML-2.WX) The UAM community **should** collaborate on developing initial weather SDSP standards focused on real-time measurements and analyses, addressing interim relevant definitions, common data formats, and data performance standards. (420 UML-2.WX)	The FAA **should** make public the Initial Operational Capability (IOC) process for qualifying weather SDSPs. (320 UML-3.WX) The UAM community **should** collaborate on developing updated weather SDSP standards based on current state-of-the-art technology and knowledge, as well as introduce standards for weather model, forecast uncertainty, and operational safety in various weather conditions. The updated standard **should** also incorporate changes to adjust for other standards in concurrent development e.g., cyber standards, CBRs, and ensuring compatibility with IOC qualification process. (326 UML-3.WX) The UAM community **should** include weather and microclimate information in establishing and approving airspace constructs to minimize susceptibility to weather hazards. (421 UML-3.WX)	The FAA **should** make public the Final Operational Capability (FOC) process for qualifying weather SDSPs. (350 UML-4.WX) The UAM community **shall** include weather and microclimate information in establishing and approving airspace constructs to minimize susceptibility to weather hazards. (422 UML-4.WX) The UAM community **should** collaborate on developing mature weather SDSP standards for measurements, models, and forecasts, including uncertainty metrics and operational safety in various weather conditions. The updated standard **should** also incorporate changes to adjust for other standards development e.g., cyber standards, CBRs, and ensuring compatibility with FOC qualification process. (423 UML-4.WX)

6 Conclusions and Next Steps

The UAM Airspace research roadmap defined here is expected to be an important tool for the execution of NASA's research over the next ten years, with the goal of evolving UAM airspace to UML-4. It provides a basis for prioritizing and coordinating research efforts, and for integrating results that build towards NASA's research goals. The roadmap also has the potential to serve as a focal point for ongoing and continuous deliberation, as has been the case during its development. It naturally attracts questions and feedback that are beneficial to overall understanding, which is key to NASA's leadership in defining the airspace of the future.

The UAM subproject has begun to leverage the roadmap methodology to plan and execute its research and development efficiently and to maximize the impact of the research results. Processes for requirements tracing and progression tracking have been established through an MBSE model, details can be found in [37] and [38]. This version of the UAM airspace roadmap is a steppingstone along the development path. Time is being spent early on to ensure that the form and purpose of the roadmap is coordinated with the stakeholders it may impact. Next steps will include synthesizing more information from NASA's research and development in UAM airspace.

Finally, characterizing and advancing the maturity of the roadmap requirements through the research will be addressed. A rigorous process with quantitative metrics will be established to guide the integration of learnings from the lower-level requirements, which are coming from multiple research efforts.

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Appendix A: Acronyms

AAM	Advanced Air Mobility
ADS-B	Automatic Dependent Surveillance-Broadcast
AFS	Flight Standards
AIM	Aeronautical Information Manual
AIR	Aircraft Certification
AMS	Acquisition Management System
ANSP	Air Navigation Service Provider
ARTCC	Air Route Traffic Control Centers
ASTM	American Society for Testing Materials
ATC	Air Traffic Control
ATCSCC	Air Traffic Control System Command Center
ATM	Air Traffic Management
ATM-X	Air Traffic Management-Exploration
ATO	Air Traffic Organization
AVS	Aviation Safety
BVLOS	Beyond Visual Line of Sight
CBR	Community Based Rules
CFD	Computational Fluid Dynamic
CFR	Code of Federal Regulation
CNS	Communication, Navigation, and Surveillance
COA	Certificates of Authorization
CSP	Communication Service Provider
CTAF	Common Traffic Advisory Frequency
DAA	Detect and Avoid
DME	Distance Measuring Equipment
DNS	Direct Numerical Simulation
ETM	Class E Traffic Management
eVTOL	Electric Vertical Takeoff and Landing
FAA	Federal Aviation Administration
FATO	Final Approach and Takeoff
FIDXP	FAA-Industry Data Exchange Protocol
FIMS	Flight Information Management System
FNS	Federal Notice to Airmen System
FOD	Foreign Object Debris
GA	General Aviation
GBAS	Ground Based Augmentation System
GPS	Global Positioning System
ICAO	International Civil Aviation Organization
IFR	Instrument Flight Rules
ILS	Instrument Landing System
LAANC	Low Altitude Authorization and Notification Capability
LES	Large Eddy Simulation
LOA	Letters of Agreement
LOB	Lines of Business

MBSE	Model Based Systems Engineering
MRO	Maintenance, Repair, and Overhaul
MSP	Meteorological Service Provider
NADIN	National Airspace Data Interchange Network
NAS	National Airspace System
NASA	National Aeronautics and Space Administration
NIST	National Institute of Standards and Technology
NMAC	Near Mid-Air Collision
NOTAM	Notices to Airmen
PIC	Pilot in Command
PNT	Position, Navigation, and Timing
PSU	Provider of Services to UAM
R&D	Research & Development
RF	Radio Frequency
RPAS	Remotely Piloted Aircraft Systems
RPIC	Remote PIC
SAA	Special Activity Airspace
SBAS	Satellite Based Augmentation System
SDSP	Supplemental Data and Services Provider
SMS	Safety Management System
SRM	Safety Risk Management
SSP	Surveillance Service Provider
STARS	Standard Terminal Automation Replacement System
sUAS	Small UAS
SVO	Simplified Vehicle Operations
SWIM	System Wide Information Management
TBR	To Be Resolved
TFR	Temporary Flight Restrictions
TLOF	Touchdown and Liftoff
TRACON	Terminal Radar Approach Control Facilities
TRL	Technical Readiness Level
UAM	Urban Air Mobility
UAS	Unmanned Aircraft System
UML	UAM Maturity Level
USS	UAS Service Supplier
UTM	UAS Traffic Management
VFR	Visual Flight Rules
VHF	Very High Frequency
VMC	Visual Meteorological Conditions
VOA	Vertiport Operations Area
VOCC	Vertiport Operational Control Center
VOR	VHF Omni-Directional Ranges
VPV	Vertiport Volume
WIP	Weather Information Providers
xTM	Extensible Traffic Management

Appendix B: Glossary

Advanced Air Mobility (AAM): Safe, sustainable, affordable, and accessible aviation for transformational local and intraregional missions. There are generally three broad application categories within AAM: Urban Air Mobility (UAM), Regional Air Mobility (RAM), and Low Altitude Mobility (LAM). These missions may be performed with many types of aircraft (e.g., crewed or uncrewed; conventional takeoff and landing (CTOL), short takeoff and landing (STOL), or vertical takeoff and landing (VTOL); over or between many different locations (e.g., urban, rural, suburban); and to or from far more locations than typical commercial aviation (e.g., novel aerodromes, existing underutilized small/regional airports).

Accountability: The obligation of a human to answer for their actions, or for actions taken by their authority.

Aerodrome: A defined area on land or water (including any buildings, installations and equipment) intended to be used either wholly or in part for the arrival, departure and movement of aircraft.

Aeronautical Information Services: Responsible for the provision of aeronautical data and aeronautical information necessary for the safety, regularity, and efficiency of air navigation.

Air Navigation Service Provider (ANSP): A public or a private legal entity providing Air Navigation Services. It manages air traffic on behalf of a company, region or country.

Air Traffic Control (ATC): A service operated by appropriate authority to promote the safe, orderly, and expeditious flow of air traffic. The primary purposes of the Air Traffic Control system are to prevent a collision between aircraft operating in the system; to provide a safe, orderly and expeditious flow of traffic; and to support national security and homeland defense.

Air Traffic Management (ATM): The dynamic, integrated management of air traffic and airspace including air traffic services, airspace management, and air traffic flow management — safely, economically and efficiently — through the provision of facilities and seamless services in collaboration with all parties and involving airborne and ground-based functions.

Airspace Construct: Novel airspace design elements used to support the safe management of Advanced Air Mobility aircraft through a defined airspace in which aircraft abide by rules, procedures, and performance requirements specific to the airspace construct. Examples include corridors and Urban Air Mobility operating environments.

Architecture (System): The high-level unifying structure that defines a system. It provides a set of rules, guidelines, and constraints that defines a cohesive and coherent structure consisting of constituent parts, relationships and connections that establish how those parts fit and work together. It addresses the concepts, properties and characteristics of the system and is represented by entities such as functions, functional flows, interfaces, relationships, resource flow items, physical elements, containers, modes, links, communication resources, etc. The entities are not independent but interrelated in the architecture through the relationships between them.

Authority: The power or right to give orders and/or make decisions. The authority to act is vested in a predetermined and unambiguous set of decision-makers.

Automatic System: An automation system designed to execute predefined processes without intervention. An automatic (or automated) system refers to hardware and software that automates a predefined process without the need for human intervention. Automatic systems are not "self-directed", but instead require command and control during execution.

Automation: A holistic term used to refer to the hardware and software components (or sub-components) of any system actor.

Automation in the loop: Automation that must act for the system to achieve the intended function. The automation is required to execute necessary actions.

Automation on the loop: Automation that can intervene and act under appropriate conditions. The automation has the authority to act where necessary to perform the intended function.

Automation out of the loop: Automation that has no ability to affect the operational function and is used to collect or communicate information to humans. The intended function of the automation can only impact the long-term operational behavior of the system.

Automation over the loop: Automation that forewarns the human on the need to act. The intended function of the automation is to provide guidance to the human. The automation has no authority to act or effect behaviors other than indirectly through the actions of the human.

Autonomous System: An automation system that may be authorized by the human to make decisions independently and self-sufficiently. An autonomous system can determine a new course of action in the absence of a predefined plan and independently from other system actors.

Capability: (n) An ability, level of expertise, or level of proficiency.

Collision Avoidance: The maneuver of an aircraft after becoming aware of conflicting traffic. This is currently achieved by one of the following means: visual observation, Airborne Collision Avoidance System alert, or traffic information provided by Air Traffic Control.

Command and Control: (n) A set of organizational and technical attributes and processes that employs human, physical, and information resources to solve problems and accomplish missions. Command and control systems are characterized by the exercise of authority in the accomplishment of a defined mission.

Common Operating Picture: A repository for operational intent, current traffic situation data, and other real-time aeronautical information provided by the

Provider of Services for Urban Air Mobility (PSU), with inputs from the air navigation service provider (ANSP), fleet managers, etc.

Communication Service Provider (CSP): Broad title for a variety of service providers in broadcast and two-way communications services. A CSP offers telecommunications services over a network infrastructure that support a range of functions for UAM Operations. The CSP will leverage a range of communications infrastructure, as well as transformational digital technologies such as artificial intelligence, analytics and automation [13]. The CSP may be a State-owned self-financing corporation, a privatized organization, or an independent private sector organization.

Community Based Rules (CBR): Collaborative set of UAM operational business rules developed by the stakeholder community. Rules may be set by the UAM community to meet industry standards or FAA guidelines when specified. These rules will require FAA approval.

Component: Specific functions, services and features used in combination to characterize a capability.

Conflict: A point in time in which the predicted separation of two or more aircraft is less than the defined separation minima.

Contingency Procedures: Identification, definition, and application of procedures for managing the airspace during unforeseen incidents that result in impacts to airspace or capacity. Contingency operations are generally rare, but credible large-scale system or service outages (e.g., radar, navigation, communications), pop-up airspace restrictions, or unplanned aerodrome closures.

Control Loop: A series of control operations to carry out a task and/or perform a system function, including receiving reference inputs and system state feedback, deciding the desired system state, and acting (providing command input to some aspect of the system) to reach a desired state.

Control System: Manages, commands, directs, or regulates the behavior of other devices or systems using control loops.

Cooperative Information Exchange Network: A trusted digital network will be needed by the UAM Operators to exchange information required for safety and performance, and to satisfy the CBRs.

Cooperative Separation: Separation based on shared flight intent and data exchanges between operators, stakeholders, and service providers and supported by the appropriate rules, regulations, and policies for the planned operations. Air Navigation Service Providers (ANSP) do not provide tactical ATC separation services for UAM operations.

Demand Capacity Balancing: Flight intent adjustments during the planning phase to ensure that predicted demand does not exceed the capacity of a resource (e.g., UAM Corridor, aerodrome).

Emergency Procedures: Identification, definition, and application of procedures for managing the airspace for predominantly single aircraft events which require the arrangement of additional services (e.g., fire and rescue, Search and Rescue, passenger emergency). During emergency operations, aircraft in distress are provided priority and other aircraft are managed in response to the needs of the emergency aircraft.

FAA: The FAA is the regulatory agency for civil aviation in the NAS, including but not limited to delivering ATM services, certification of personnel and aircraft, and standards for airports and vertiports to ensure aviation safety and minimize environmental impact.

FAA Air Traffic Organization (ATO): FAA LOB accountable for providing safe and efficient air navigation services to 29.4 million square miles of airspace.

FAA Aircraft Certification (AIR): FAA LOB comprised of the engineers, scientists, inspectors, test pilots and other experts responsible for oversight of design, production, airworthiness certification, and continued airworthiness programs for all U.S. civil aviation products and foreign import products.

FAA Aviation Safety (AVS): FAA LOB responsible for the certification, production approval, and continued airworthiness of aircraft; and certification of pilots, mechanics, and others in safety-related positions. Also responsible for certification of all operational and maintenance enterprises in domestic civil aviation, certification and safety oversight of approximately 7,300 U.S. commercial airlines and air operators, civil flight operations, and developing regulations.

FAA Flight Standards (AFS): FAA LOB responsible for setting the standards for certification and oversight of airmen, air operators, air agencies, and designees. Services provided by AFS to promote safety of flight of civil aircraft and air commerce include accomplishing certification, inspection, surveillance, investigation and enforcement, setting regulations and standards, and managing the system for registration of civil aircraft and certification of airmen.

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 Manager: The individual(s) and automation responsible for maintaining operational control for a network of UAM aircraft providing air taxi services to the public on behalf of the UAM Operator.

Functional Requirements: What functions need to be performed to accomplish the mission objectives. These requirements typically focus on converting inputs to outputs.

Hazard: A condition in which an aircraft must be separated, including other aircraft, terrain, weather, wake turbulence, buildings and structures, incompatible airspace activity, etc.

Hazard Identification Service (HIS): A service to enhance safety by identifying hazards that is defined as conditions or physical items which could cause harm, damage, or injury and have been determined to pose a threat to a specific object such as aircraft. Once hazard has been identified, HIS transmits the hazard information for risk analysis and mitigation.

Human/ Humans: Any individual person that is affecting the system of interest (i.e., UAM airspace). A single system actor may include multiple humans.

Human in Command: The authorized source of the commands that control a given function. Authority may be temporarily delegated, but the human in command always remains accountable.

Human in the loop: A configuration of the system actor in which a human must act for the control system to perform the intended function. The human has direct control over the system.

Human on the loop: A configuration of the system actor in which the human can act so that the control system performs the intended function or may permit the automation to act without intervention. The human retains the ability for direct control at any time.

Human out of the loop: A system in which a human is not able to intervene or provide guidance to the control system, except to grant or revoke the authority to perform its intended function.

Human over the loop: A configuration of the system actor in which the human can guide overall system behavior, but the automation has authority to act without human interaction or additional authority. The human maintains operational control over the associated function without the ability for direct control.

Information Service Provider (ISP): Government or private sector organizations that are not ATM service providers per se but that are engaged in the collection and dissemination of air navigation related information of an operational nature. This includes environmental information (e.g. maps, navigation databases); ground, airborne and space-based meteorological data; and aviation weather forecasting.

Intended function: The function being performed by the system actor. The intended functions working together enable a capability.

Meteorological Service Provider (MSP): An entity or organization providing services in weather observations and predictions on the airfield and aloft. An MSP delivers consistent, timely and accurate weather information for the UAM airspace system, leveraging a network of sensors and computational resources. The MSP may be a State-owned self-financing corporation, a privatized organization, or an independent private sector organization.

Mission-critical automation: Automation whose failure or malfunction may lead to serious impact on business operations or upon an organization and can lead to social turmoil and catastrophic effects.

Model Based System Engineering (MBSE): The formalized application of modeling to support system requirements, design, analysis, verification and validation activities beginning in the conceptual design phase and continuing throughout development and later life cycle phases.

Off-nominal procedures: Identification, definition, and application of procedures for managing planned operations that are significantly impacted by an unplanned event. This generally involves tactical adjustments to the strategic plan to mitigate disruptive events.

Operational Intent: Operation specific information including, but not limited to, UAM operation identification, the intended UAM Corridor(s), aerodromes, and key operational event times (e.g., departure, arrival) of the UAM operation.

Operational Requirements: The operational attributes of a system needed for the effective and/or efficient provision of system operations to users. These requirements focus on what actions actors in the system must take or how the system functions are performed.

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. 14 CFR § 91.3 establishes that the PIC is directly responsible for and has final authority for safe operation of the UAM aircraft. A PIC may be on or off-board the aircraft.

Predetermined Separator: The unambiguous agent responsible for keeping aircraft separated from hazards. Provider of Services to UAM (PSU): The entity responsible for managing the provision of information services to the UAM Operator including Fleet Managers and PICs.

Provider of Services to UAM (PSU) Network: A collection of Providers of Services for Urban Air Mobility (PSUs) with access to each PSU's data for use and sharing with their subscribers.

Provider of Services to UAM (PSU) Operator: An entity or organization accountable for providing information services associated with airspace operations to the UAM Operators and their agents.

Radiometric Tracking: The application of radio frequencies to accurately determine the position and characteristics of an object.

Responsibility: The obligation or duty to carry forward an assigned task to its successful conclusion. A responsible entity has the duty to act.

Roadmap Assumptions: High-level assumptions applied across the UAM airspace components derived from authoritative sources or expectations from the UAM Community. The roadmap assumptions use the keywork "will" to indicate a statement of fact, or an assumption taken for granted, and are binding in that an expectation of certainty is established.

Roadmap Requirements: High-level operational and functional requirements derived from the UAM airspace components across the UMLs. These requirements have been identified and matured through a subset of the research to date, and are expected to be modified, expanded, and further matured as more research results are acquired or constraints are identified by the UAM Community. While they are generally identified or matured based on research around one or more specific solutions, the roadmap requirements themselves are solution-agnostic. Roadmap requirements use the keywords "should" and "shall". "Should" is used to indicate a desired goal at the boundary of existing research, is non-binding and is used to guide evaluation activities. "Shall" is used to indicate a requirement that has been demonstrated through research system implementation to be potential minimum requirement in the UAM system of systems.

Safety-critical: Automation whose failure or malfunction may lead to death or serious injury to people, loss or severe damage to property, or environmental harm.

Safety-enhancing: Automation whose failure or malfunction may lead to minor outcomes, at most. This will typically involve providing advisory information to a human making decisions. Examples include situation awareness applications, and traffic or terrain advisories.

Safety Management System (SMS): The formal, top-down, organization-wide approach to managing safety risk and assuring the effectiveness of safety risk controls. It includes systematic procedures, practices, and policies for the management of safety risk. SMS is becoming a standard throughout the aviation industry worldwide and is widely recognized across both public and private sectors as the next step in the evolution of safety in aviation.

Safety Risk Management (SRM): The process used by the FAA to meet their SMS mission. SRM is required to apply to all investments that have an impact on the National Airspace System and is part of Acquisition Management System (AMS) policy. Separation Minima: The minimum displacements between an aircraft and a hazard that maintain the risk of hazardous encounter at an acceptable level of safety.

Separation Provision: The second layer of conflict management and is an iterative tactical process of keeping aircraft away from hazards by at least the appropriate separation minima. Separation provision consists of conflict detection, resolution, and monitoring.

Shared Strategic Plan: Plan developed as part of the collaborative strategic conflict management process amongst the UAM Operators and their PSUs. It is shared and common to all users and is part of the Common Operating Picture.

Strategic Conflict Management: The first layer of conflict management and is achieved through the airspace organization and management, demand and capacity balancing and traffic synchronization services.

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).

Surveillance Service Provider (SSP): An entity or organization providing services in aircraft detection and resolution of key flight attributes such as position, flight level, speed, and intent. An SSP offers surveillance services based on a variety of measurement, processing, and inferential techniques. Cooperative and non-cooperative surveillance. The SSP may be a State-owned self-financing corporation, a privatized organization, or an independent private sector organization.

System Actor: A system actor is a combination of humans and automation having an external interface to the UAM airspace system. The humans and the automation team together to act on the system in order to achieve an intended function.

Tempo (Operational): The density, frequency, and complexity of operations.

Traffic Synchronization: The management of the flow of traffic through merging and crossing points, such as traffic around major aerodromes or airway crossings. It currently includes the management and provision of queues both on the ground and in the air. Traffic synchronization, as a function, is closely related to both demand/capacity balancing and separation provision and may in the future be indistinguishable from them. Traffic synchronization also concerns the aerodrome "service" part of the concept.

UAM community: UAM community is a joint body of regulatory authorities and industry representatives.

UAM Maturity Level (UML): A NASA-developed framework categorizing anticipated evolutionary stages of an Urban Air Mobility (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 UAM Maturity Level (UML)-1 representing the earliest maturity level and UML-6 representing full ubiquity. The NASA UML-4 ConOps focuses on UML-4, the intermediate state, where hundreds of operations could be occurring at any given time within a single metropolitan area.

UAM Operator: The entity or organization accountable for the overall management and execution of one or more UAM operations (14 CFR § 1.1). As operators of air taxi services which typically will operate a fleet of UAM aircraft, the UAM Operator is often referred to as the Fleet Operator. Other configurations of the UAM Operator are possible, for example a single UAM aircraft owner/operator. UAS Service Supplier (USS): An entity that assists Unmanned Aircraft System (UAS) operators with meeting UAS Traffic Management (UTM) operational requirements that enable safe and efficient use of airspace. A UAS Service Supplier (USS): (1) acts as a communications bridge between federated UTM actors to support operators' abilities to meet the regulatory and operational requirements for UAS operations, (2) provides the operator with information about planned operations in and around a volume of airspace so that operators can ascertain the ability to safely and efficiently conduct the mission, (3) archives operations data in historical databases for analytics, regulatory, and operator accountability purposes. In general, these key functions allow for a network of USSs to provide cooperative management of low altitude operations without direct FAA involvement.

Urban Air Mobility (UAM): UAM is a subset of the Advanced Air Mobility (AAM), a National Aeronautics and Space Administration (NASA), FAA, and industry initiative to develop an air transportation system that moves people and cargo between local, regional, intraregional, and urban places previously not served or underserved by aviation using revolutionary new aircraft. While AAM supports a wide range of passenger, cargo, and other operations within and between urban and rural environments, UAM focuses on the transition from the traditional management of air traffic operations to the future passenger or cargo-carrying air transportation services within an urban environment.

UAM Air Traffic Management (ATM) System: The dynamic, integrated management of UAM traffic and airspace – safely, equitably, and efficiently – through the provision of facilities and seamless services in collaboration with all parties. Also referred to as the UAM airspace system.

Vertihub: A vertiport with infrastructure for maintenance, repair, and overhaul operations for the fleet, parking spaces for longer-haul vertical takeoff and landing aircraft, and a centralized operations control system.

Vertiplex: Multiple vertiports within a geographic area whose arrival and departure operations are highly interdependent.

Vertiport: An identifiable ground or elevated area, including any buildings or facilities thereon, used for the takeoff and landing of VTOL aircraft and rotorcraft.

Vertiport Manager: Manage operations at one or multiple vertiports and support the safe takeoff, landing, and surface operations of each incoming and outgoing flight.

Vertiport Operations Area (VOA): A volume of airspace in which sufficient assurance of communications, navigation, and surveillance must be established through proper aircraft equipage as designated by the Provider of Services for Urban Air Mobility (PSU) network and ground-based infrastructure.

Vertiport Operator: The entity responsible for the safe and efficient management of the vertiport resources. The Vertiport Operator may have authority over the UAM Operator's ability to land and depart.

Vertiport Volume (VPV): A volume of airspace relevant to the Provider of Services for Urban Air Mobility (PSU) network through which air traffic cannot flow unless coordinating with that vertiport.

Vertistop: An area similar to a vertiport, except that no charging, fueling, defueling, maintenance, repairs, or storage of aircraft are permitted.

Well-Clear: A standard intended to facilitate the ability to detect, analyze and maneuver to avoid potential conflicting traffic by applying adjustments to the current flight path in order to prevent the failure of the separation mode, e.g. becoming closer than the separation minimum.