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UAM Airspace Research Roadmap Rev 1.2

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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

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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. 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 possible. 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.

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 National Airspace System (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 complimentary 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 Definition

This section will define UAM airspace by describing the assumptions, constraints, and system actors that shape the system. In the next section, the operational progression of the UAM airspace system will be described.

One of the first constraints applied to the UAM airspace system definition comes from the desire to understand how the paradigm of an Extensible Traffic Management (xTM) system can be applied to UAM operations. The xTM paradigm is characterized by a cooperative control environment that is part of a federated and automated service-based Air Traffic Management (ATM) System [2]. Other examples of the xTM paradigm include small Unmanned Aircraft System (UAS) Traffic Management (UTM) [3, 4] and Upper Class E Traffic Management (ETM) [5].

The UAM airspace system will include aspects of a federated architecture. A federated architecture is one which operates collaboratively, and where governance is divided between a central authority and constituent units, balancing organizational autonomy with enterprise needs [6]. 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.

2.1 Operational Assumptions

The operational assumptions in this section are derived from [7] and expectations from UAM Community (or stakeholders). Reference [7] generally sets constraints on the design for UAM Airspace, while the stakeholder's expectations help to derive finer assumptions within the established constraints to further bound the research.

The following assumptions apply to the definition of the UAM Airspace System:

- 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 UAM airspace system architecture will be federated, with central authority derived largely from the Air Navigation Service Provider (ANSP) (and possibly other entities), and with a distributed constituency of UAM Operators who operate safely and with increasing flexibility as the system evolves [7].
- The UAM Operators will have increased operational independence, flexibility, and access to airspace over current IFR and VFR operations, through use of an array of services and technologies that are either self-provided or from a third-party, such as the Provider of Services to UAM (PSU) and the Supplemental Data and Services Provider (SDSP) [1].
- 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 integrate with conventional air traffic, when UAM operations meet ATC requirements.

- UAM operations will be conducted, potentially using unconventional airspace constructs and airspace management techniques, to minimize or eliminate the burden on Air Traffic Control (ATC).

  Note: Examples of airspace constructs include Vertiports (distinct from existing heliports, or existing areas on an airport surface), Vertiport Operations Area (VOA) and Vertiport Volume (VPV) [8], new routes or waypoints, metering arcs, and cooperative volumes of airspace such as the 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].

2.2 UAM Airspace System Actors

In this document the UAM Airspace system derives its categories of actors from five of the eight members of the ATM Community defined in Appendix A of Ref. [9], enumerated in the list below. The system actors will be presented in groups for each ATM Community member, in alphabetical order of members which does not signify any order of importance or priority [9].

- 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)
  - Remote Supervisor
  - Remotely Supervised Aircraft
  - UAM Operator
- ATM Service Provider
  - Air Traffic Control (ATC)
  - FAA
  - Provider of Services to UAM (PSU)
  - PSU Operator
- 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 [9]. 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, the Pilot-in-Command, Remotely Supervised Aircraft, and Remote Supervisor.

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 with limited autonomy 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 [9]. 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.

Remote Supervisor : The individual who is accountable for operational control of one or more Remotely Supervised Aircraft.

Note: Remotely Supervised Aircraft and the Remote Supervisor are identified as actors, but no requirements have yet been identified for them.

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 [9]. The system actors from this group are the FAA, the Air Traffic Control (ATC), the Provider of Services to UAM (PSU), and the PSU Operator.

Air Traffic Control (ATC) : Personnel and equipment responsible for delivering Air Traffic Management (ATM) services on behalf of the FAA. For UAM operations, Tower, TRACON, En route, and Center controllers are the primary providers of separation services for ATC and the Traffic Managers provide flight and flow services.

FAA : In the United States, the FAA is the transport agency of the United States government regulating all aspects of civil aviation in the NAS, including but not limited to the regulatory areas of ATM, certification of personnel and aircraft, standards for airports and vertiports to ensure aviation safety and minimize environmental impact. The FAA is the organization accountable for delivering ATM services, and is also the regulatory authority.

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 including Fleet Managers, Remotely Supervised Aircraft, Remote Supervisors, 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 (Adapted from Ref. [9]).

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 [9].

Supplemental Data Service Provider (SDSP) : government or private sector organizations that are not PSUs 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 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.

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 [9]. 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 [10].

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 Level of Automation

All the human actors in the previous section will rely on some level of automation. As such, automation systems to support the human actors are not listed. The allocation of role and responsibilities between human and automation will not be prescribed in this document, but rather is intentionally left out for discretionary implementations. The vision is that the level of automation will increase to enable higher density operations while minimizing or eliminating the burden on ATC.

Three levels of automation, defined in [1] to largely apply to aircraft automation, are applied to any automation system (onboard or offboard the aircraft) throughout this document. Two additional higher levels of automation (highly-integrated automated network and system-wide automated optimization) are to be integrated at higher UAM maturity levels that are not covered in this document.

Assistive Automation : Assistive automation applies to a reliance on lower-level automated functions (e.g., highly augmented flight controls) with limited integration and that human agents retain full-responsibility for operational safety.

Comprehensive Safety-Assurance Automation : Comprehensive Safety-Assurance automation provides the capability for safety-critical monitoring and interventions mitigating a wide range of specific hazards within the system (e.g., ground collision avoidance, traffic collision avoidance, etc.), significantly improving the safety of the system, but with human agents still retaining full-responsibility for operational safety.

Collaborative and Responsible Automation : Collaborative and Responsible Automation applies to automation which is assured to perform specified functions such that human monitoring and mitigation of potential failures of those functions is no longer necessary.

Highly-Integrated Automated Network : Highly-Integrated Automated Networks applies to automation in which real-time human involvement is no longer required for safe operation of the system.

System-Wide Automated Optimization : System-Wide Automated Optimization applies to automation in which continuous human monitoring or intervention is not expected in the system for either safety or efficiency.

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, assistive automation will 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, 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 (e.g., cooperative volumes of airspace) 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 [9] 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) [8]. There will be enhanced communication, navigation, and surveillance (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.

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. Comprehensive safety assurance automation will provide services that support safe separation for the UAM traffic, but human actors will remain responsible for operational safety. 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 Simple 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 [9]. 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, with support of collaborative and responsible automation providing more 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. 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 [8]. 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. 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 and mixed 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 remotely piloted 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. Version 1.0 was baselined in September 2020 [12], and version 2.0 is expected in December 2022. NASA research activities will be the primary, but not necessarily 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 [9], and the FAA's NAS Enterprise Architecture [13]. 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.

Next, for each capability, each component is described so that any high-level requirements or assumptions that may be associated with it are easily understandable. The progression of the UAM airspace system is then modeled by considering the set of requirements needed to enable the operations in each UML. In this way, each UML is modeled to represent a new set of requirements added to the UAM airspace system. The additional requirements will generally increase the functional performance of the components and therefore increase the associated capabilities.

The requirements will be discussed in the next section. The full decomposition of capabilities and components is shown below in Fig. 1.

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.*

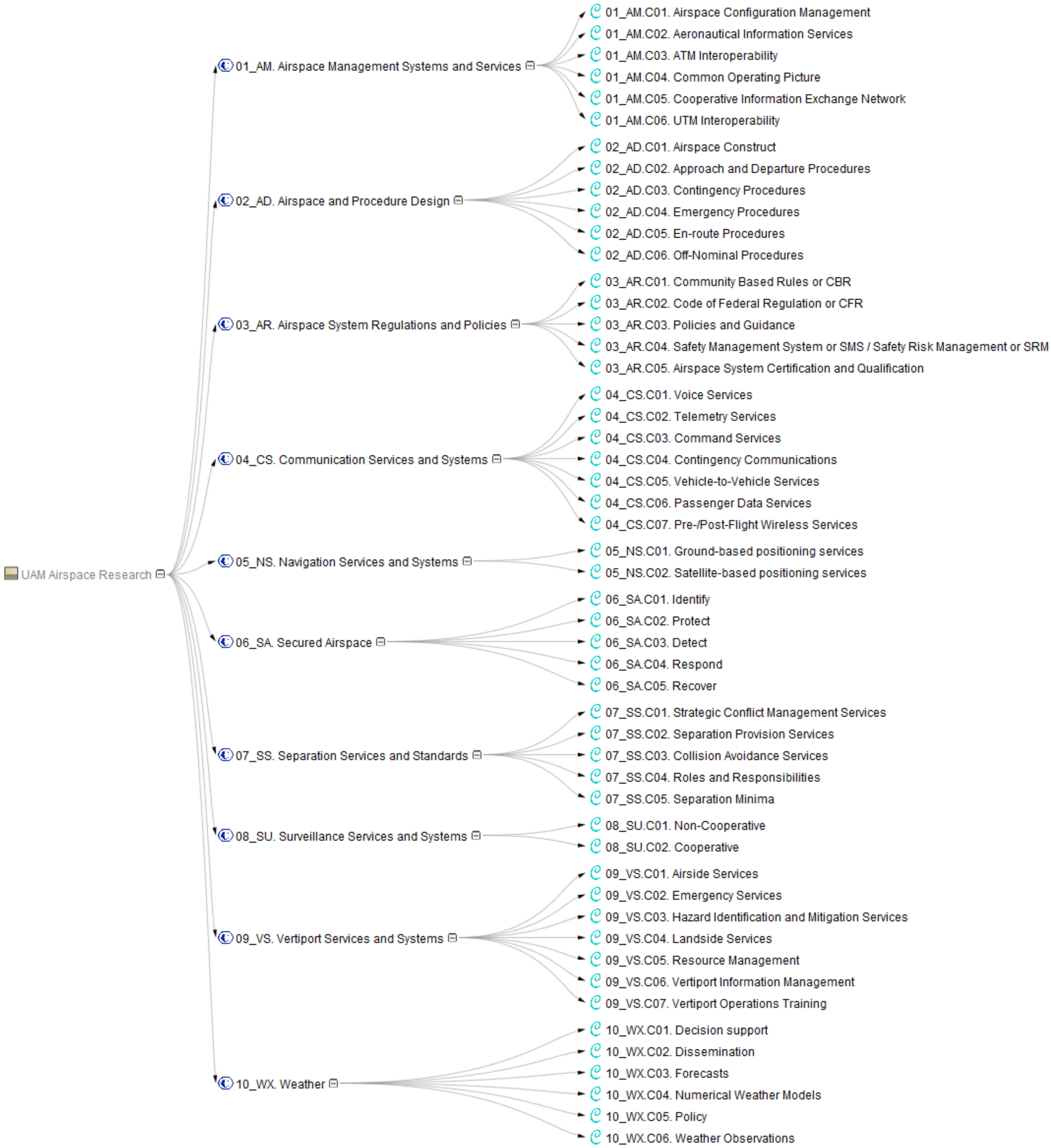

Figure 1. UAM Airspace Capability and Component Tree Decomposition

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 new requirements are generally based on existing research or traced from existing documentation but are also based on desired system constraints or are simply derived from 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.

Note: The current version of this document (v1.2) is in a development stage and relies on significant subject matter expertise for consistency and completeness. The targeted baseline version (v2.0) is expected to include more traceability to research and documentation.

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 an action]. 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 [14, 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.

Note: The roadmap requirements are at various levels of maturity. The more mature the "shall" requirements are, the closer they are to being ready for tech transfer and eventual operational implementation. Future versions of this document will include measures of requirement maturity, which will enable research gaps to be more easily identified and tech transfers to be more effectively targeted.

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., [10] and [1], or from expectations of the UAM Community (see § 2.1). 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 [14, 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
- 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 autogenerated by the MBSE model;
- *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

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 [9, §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 [9].

The Airspace Management research capability provides the ability for UAM Operators to share airspace resources safely and equitably, enabled by a combination of cooperative Community Business Rules (CBR) [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., UTM), and ATC, with the goal of safely scaling UAM operations beyond the capacity of the as-is NAS, without overburdening the pilot or ATC. To meet this goal, interoperability between UAM and non-UAM operations using a common set of rules and practices, and the systems and services that support them, will need to be ensured for safe and efficient integration of UAM Operations. 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 [3]. 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 [15]. 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, airspace restrictions and constraints, approach and departure procedures, navigational information, obstruction information, active Special Activity Airspaces (SAAs), active Temporary Flight Restrictions (TFRs) and other Notices to Airmen (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 that the ATM system is not overburdened. 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 [16], is a key function of the Air Traffic Control System Command Center (ATSCC) and is part of the FAA's overall vision of the future [15][17]. 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 [9, §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, are [16]

- 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 telemetry (i.e., current position, velocity vector) and intent (i.e., planned route). 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. As Beyond Visual Line of Sight (BVLOS) operations, UAS (UAS) become more routine and require UTM participation, 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 [18]. 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 (NEW)	ATC **will** manage the configuration of the airspace for all airspace users. (275 UML-2.AM)	ATC **will** establish the airspace organization and configuration in use and in accordance with the CBRs. (99 UML-3.AM)	The UAM Operator **should** establish the airspace organization and configuration in use, in accordance with the CBRs. (332 UML-4.AM)
		The FAA **shall** provide a means for ATC to make updates and distribute airspace constraints to the PSU. (72 UML-3.AM)	The UAM Operator **should** establish capacity constraints on shared airspace resources in accordance with the CBRs. (330 UML-4.AM)
		ATC **will** establish capacity constraints on shared airspace resources in accordance with the CBRs. (98 UML-3.AM)	The Vertiport Operator **should** set arrival and departure configurations and constraints at the vertiport. (100 UML-4.AM)
			The Vertiport Operator **should** establish capacity constraints on shared airspace resources in accordance with the CBRs. (37 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**
Aeronautical Information Services (NEW)	UAM Operators **will** use available Aeronautical Information Services. (273 UML-2.AM) The UAM Operators, and PSU Operators where applicable, **should** collect data on potential new Aeronautical Information Services that may be certified or qualified for use. (272 UML-2.AM)	The UAM Operator **shall** ensure that all relevant aeronautical data and aeronautical information necessary to ensure safety, regularity, and efficiency is available for their Fleet Managers and PICs. (91 UML-3.AM) The FAA **will** approve the PSUs to provide Airspace Authorization services to the UAM Operator. (94 UML-3.AM) The FAA **will** approve the PSU to provide Aeronautical Information Services to the UAM Operator. (97 UML-3.AM)	**TBR** (331 UML-4.AM)
ATM Interoperability (NEW)	UAM Operations **will** follow all existing ATM procedures. (274 UML-2.AM) The UAM Operator, Fleet Manager, and PIC **will** receive services from ATC where applicable. (19 UML-2.AM) The UAM Operators, and PSU Operators where applicable, **should** collect data that supports anticipated changes to how the UAM traffic may be managed. (269 UML-2.AM)	The FAA **will** provide a means for authentication and authorization of the PSU. (71 UML-3.AM) The FAA **will** provide a means for the PSU to notify ATC of off-nominal and contingency UAM Operations. (73 UML-3.AM) The UAM Operator **shall** have the ability to obtain authorization from ATC to operate in controlled airspace in a manner that minimizes workload for ATC and the PIC. (74 UML-3.AM) The FAA **shall** have access to active, pending, and past UAM Operations. (75 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 (NEW)	The UAM Operators, and PSU Operators where applicable, **should** collect data on services that may be certified or qualified for use in building the common operating picture. (32 UML-2.AM) The UAM Operators, and PSU Operators where applicable, **should** collect data on services that may be certified or qualified for use in establishing and managing planned flight intent. (276 UML-2.AM) The Fleet Manager **will** use flight planning tools for creating the initial flight plan. (191 UML-2.AM) The Fleet Manager **will** use flight planning tools for updating the flight plan. (271 UML-2.AM)	UAM Operators **should** make cooperative information available to the PSU. (302 UML-3.AM) The PSU **shall** make all the following information (**TBR**: includes operational intent and telemetry) available to other PSUs, Fleet Managers, Vertiport Managers, and PICs to discover based on their area and time of interest. (92 UML-3.AM) The UAM Operator and Vertiport Operator **shall** have the ability to discover the information needed to build a Common Operating Picture in the area and time of interest. (36 UML-3.AM) The UAM Operator and Vertiport Operator **shall** integrate aeronautical information into a common operating picture that is relevant to their operations. (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)	**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 (NEW)	The UAM Operators, and PSU Operators where applicable, **should** collect data that supports the certification or qualification of the PSU Network. (270 UML-2.AM)	The PSU **should** support cooperative decision making amongst the UAM Operators and their PSUs. (93 UML-3.AM) The PSU **shall** communicate with the PSU Network using a standard protocol to ensure interoperability amongst the UAM Operators and the PSUs. (179 UML-3.AM) The PSU **shall** file operational intent on behalf of the UAM Operator to the PSU Network in accordance with the CBRs. (180 UML-3.AM)	The PSU **should** make cooperative decisions with other PSUs to equitably allocate existing capacity of shared airspace resources. (122 UML-4.AM)
UTM Interoperability (NEW)	The UAM Operator **shall** consider UTM operations in their operational planning, leveraging available data exchanges (e.g., LAANC, USS). (60 UML-2.AM)	The PSU **shall** have the ability to discover UTM Operations information relative to an area and time of interest from the USS Network. (77 UML-3.AM) The USS **shall** have the ability to discover UAM Operations information relative to an area and time of interest from the PSU Network. (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 [9, §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 six (6) discrete functional areas for research and operational evolution.

- 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 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. 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. For example, operations may not be permissible in areas that are sensitive to transiting aircraft, or sensitive to the environmental effects generated by the aircraft themselves. 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 pre-planned 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 (e.g., hospitals), which would require interoperability and may lead to unified solutions leveraged by more than just UAM Operators, potentially enabling operations for conventional airspace users not previously possible.

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. Contingency operations are reactive to the incident after it occurs, but the response of the system actors is practiced through training and experience. Examples of contingency procedures include lost link, ATC-limited, and ATC-zero operations.

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.

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 Construct	The UAM Operators **will** leverage existing routes and procedures, satisfying all existing performance requirements. (38 UML-2.AD) The UAM Operator **will** use UAM routes that have been largely deconflicted from conventional traffic. (192 UML-2.AD) The UAM Operator **should** collect data that supports qualifying the predictability of UAM Operations using novel airspace constructs. (42 UML-2.AD) The UAM Operators **should** establish Letters of Agreement (LOA) with the FAA to ease access to and reduce risk in controlled airspace classes. (40 UML-2.AD)	The FAA **should** approve airspace constructs that allow the UAM Operator to execute missions at increased tempo. (101 UML-3.AD) The FAA **should** approve airspace constructs when needed to increase predictability. (300 UML-3.AD) The FAA **should** approve the use of flexible airspace constructs when possible. (301 UML-3.AD) The FAA **should** approve airspace constructs that provide structure where increased predictability is necessary. (102 UML-3.AD) The PSU **shall** provide services to the UAM Operator when needed, to participate cooperatively and in accordance with CBRs in the shared airspace construct. (80 UML-3.AD) The PSU **shall** provide services to the UAM Operator when needed, to enable regulatory compliance within the shared airspace construct. (299 UML-3.AD) For vertiport development on federally obligated airports, the infrastructure or equipment **will** be depicted on the Airport Layout Plan (ALP). (359 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 UAM Operator **shall** operate with approach and departure procedures that minimize exposure of existing ATM operations to hazards. (41 UML-2.AD)	The FAA **will** approve approach and departure procedures that take advantage of new separation standards. (103 UML-3.AD) The FAA **will** approve approach and departure procedures which include design for off-nominal conditions. (198 UML-3.AD) The FAA **will** approve procedures for UAM operations that ensure smooth flow and separation of aircraft at airspace boundary points (e.g. approach or departure fix). (195 UML-3.AD)	**TBR** (143 UML-4.AD)
En-route Procedures	The UAM Operator **should** operate with en route procedures that minimize exposure of existing ATM operations to hazards. (196 UML-2.AD)	The FAA **will** approve en route procedures that take advantage of new separation standards. (104 UML-3.AD) The FAA **should** approve en route procedures which include design for appropriate off-nominal conditions. (298 UML-3.AD) The FAA **should** approve en route procedures which include design for appropriate contingency conditions. (199 UML-3.AD)	**TBR** (144 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**
Contingency Procedures	The FAA **will** approve contingency procedures that accommodate the appropriate aircraft performance characteristics. (61 UML-2.AD) The UAM Operator, Fleet Manager, PIC, and ATC, **shall** participate in the resolution of contingency conditions as expected under existing flight rules and procedures. (193 UML-2.AD)	The FAA **will** approve contingency procedures that include any of the UAM Operator, Vertiport Operator, Fleet Manager, Vertiport Manager, PIC, or ATC. (194 UML-3.AD)	**TBR** (145 UML-4.AD)
Emergency Procedures (NEW)	The PIC and ATC **shall** resolve emergency conditions as expected under existing flight rules and procedures. (267 UML-2.AD)	**TBR** (297 UML-3.AD)	**TBR** (328 UML-4.AD)
Off Nominal Procedures (New)	The FAA **will** approve go-around 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, and Vertiport Manager as applicable, without involvement of ATC wherever possible. (150 UML-3.AD)	**TBR** (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 Letters of Agreement (LOAs), use of existing policy such as waivers, and policy changes, such as exemptions and changes to the Code of Federal Regulations [19] 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 [20]. 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, 135, and possibly 139. 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, Notice to Air Missions (NOTAMs) and Operation Specifications developed by the UAM Operator and approved by the FAA. Supplemental procedures such as Letters of Agreement (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. 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 [21], and FAA Order 8040.4B [22] and the FAA SMS Manual 2019 [23] 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 [19]. 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 RPAS integration and the same research support for these two areas can be expected for UAM. For more information see [11].

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)	**TBR**: CBRs will likely be under development during UML-2. (62 UML-2.AR)	**TBR**: The regulatory nature of CBRs needs to be developed further before identifying requirements on their role and creation. (139 UML-3.AR)	**TBR** (143 UML-4.AR)
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)
Airspace System Certification and Qualification	**TBR**: 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)
Safety Management System (SMS) / Safety Risk Management (SRM)	UAM Operators, PSUs, Vertiport Operators, FAA, and other UAM Community stakeholders **should** collect data to support the ongoing safety and certification processes. (43 UML-2.AR) A SRM process **will** be applied to assess the risk of any proposed changes to the NAS and to identify necessary safety mitigations. (201 UML-2.AR)	UAM Operators, PSUs, Vertiport Operators, and other UAM Community stakeholders, **shall** employ SMS processes. (81 UML-3.AR)	**TBR** (85 UML-4.AR)
Policies and Guidance	Procedural changes such as LOA and use of waivers and exemptions **will** be modified to create standardized regulations. (66 UML-2.AR)	**TBR**: Policy and guidance **will** follow from FAR/CFR and CBRs, where more research is needed. (152 UML-3.AR)	**TBR** (147 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, 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 the additional Radio Frequency (RF) interference and propagation challenges posed by 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. There will be a persistent need for 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. In addition to ATC workload constraints, congestion on the frequency for ATC will impact the tempo of UAM operations. As aircraft automation improves, on-board pilots would utilize voice communications during off-nominal events only. For remotely piloted aircraft carrying passengers, voice communications between the remote PIC 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 operations.

Telemetry 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 off-nominal conditions, the UAM operator may want access to additional or enhanced information about the current state of his or her aircraft that is not included in the nominal telemetry data service. This additional information may include detailed battery status, raw sensor data, and additional telemetry from the on-board avionics' suite. This information may be requested by the RPIC or an automated diagnostics algorithm provided by the aircraft manufacturer. Reliability and security are key performance parameters for command services. Contingency scenarios which involve degradation or total loss of the communications link need to be considered and accounted for.

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 telemetry and command data during lost link events. Reliability and security are key performance parameters for command services. Dedicating spectrum for this service may present a challenge.

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 [24].

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 UAM Operator **should** have two-way communication by voice to the PIC. (44 UML-2.CS) The Vertiport Manager **shall** have two-way communication by voice to the PIC, using a pre-defined frequency during pre-flight, taxi, approach, and landing phases of flight. (202 UML-2.CS) Proximate PICs/RPICs **should** be able to communicate by voice between them. (124 UML-2.CS)	The UAM Operator **shall** have two-way communication by voice to the PIC. (154 UML-3.CS)	When operating with a remote PIC, the UAM Operator, 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)

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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**
Telemetry Services	The UAM Operator **should** collect data to support the safety and performance assessment of their ability to receive telemetry from the UAM aircraft. (45 UML-2.CS) The Vertiport Operator **should** collect data to support the safety and performance assessment of their ability to receive telemetry from the UAM aircraft. (46 UML-2.CS)	The UAM Operator **shall** have the ability to receive telemetry information from the UAM aircraft. (82 UML-3.CS) The UAM Operator **shall** share telemetry information with the PSU Network in accordance with the CBRs. (304 UML-3.CS) The UAM Operator **shall** have the ability to receive telemetry information from the PSU Network in accordance with the CBRs. (303 UML-3.CS) The PSU **shall** share telemetry information with ATC on demand. (307 UML-3.CS) The Vertiport Operator **should** have the ability to receive telemetry information directly from the UAM aircraft. (105 UML-3.CS)	**TBR**: The UAM Operator is expected to need telemetry from the vehicle and share with the PSU Network, especially within proximity of the vertiport. (161 UML-4.CS)
Command Services	The UAM Operator **should** collect data on command services that **will** require future certification or qualification for operational use. (64 UML-2.CS)	The UAM Operator and the Fleet Manager **shall** be able to communicate flight path updates to the PIC for flights under active command. (106 UML-3.CS)	The Vertiport Manager **shall** have the capability to receive approach information pertaining to UAM aircraft 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)

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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 communication services that may be qualified or certified to support contingency operations. (57 UML-2.CS)	**TBR** (140 UML-3.CS)	When the link is not degraded, the UAM Operator and the remote PIC **should** have access to enhanced telemetry and sensor data for real-time diagnostics and command (128 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 onboard PIC **should** have the ability to communicate with the UAM Operator, Vertiport Operator, or ATC as needed to resolve contingency and emergency operations. (336 UML-4.CS)
Vehicle-to-Vehicle Services	The UAM Operator **should** collect data on Vehicle-to-Vehicle services that **will** require future safety-critical certification. (47 UML-2.CS)	The UAM aircraft **should** provide a means for Vehicle-to-Vehicle exchange of cooperative information to aid in strategic conflict management. (107 UML3.CS)	The UAM aircraft **shall** provide a means for Vehicle-to-Vehicle exchange of safety-critical 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)

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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**
Pre-/Post-Flight Wireless Services	The UAM Operator **should** be able to receive performance information from the PIC when the UAM aircraft is on the ground. (48 UML-2.CS)	The UAM Operator **should** be able to upload flight plan information to the UAM aircraft when it is on the ground. (109 UML-3.CS) The UAM Operator **should** be able to download flight plan information for the UAM aircraft when it is on the ground. (305 UML-3.CS) The PIC **should** be able to report the readiness of the UAM aircraft. (108 UML-3.CS)	The remote PIC **should** have the means to obtain pre-flight briefings. (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 seamless position determination capability and time synchronization.

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 to and 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)	**TBR** (141 UML-3.NS)	The UAM aircraft **should** employ ground-based PNT services for urban vertiports. (131 UML-4.NS) The UAM aircraft **should** employ ground-based landing assist services for urban vertiports. (130 UML-4.NS)
Satellite-based Positioning Services	The UAM aircraft **shall** use at least one satellite-based PNT service (e.g. GPS). (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 daily, 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 [25], 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, 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, PSUs, Vertiport Managers, the FAA, and other UAM Community stakeholders **should** collect data to inform the cybersecurity risk management processes. (241 UML-2.SA)	UAM Operators, PSUs, Vertiport Operators, the FAA, and other UAM Community stakeholders **should** 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, PSUs, 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, PSUs, Vertiport Managers, 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)	**TBR** (246 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**
Protect	Authentication techniques **should** be utilized for system access to UAM Operators, PSUs, Vertiport Managers, and other industry stakeholders' resources. (227 UML-2.SA) Data transmission between UAM Operators, PSUs, Vertiport Managers, the FAA, and other UAM Community stakeholders **should** be encrypted. (228 UML-2.SA) The distribution of UAM Operator vehicle command services data **should** be encrypted. (229 UML-2.SA) The distribution of UAM Operator vehicle surveillance information **should** be encrypted. (278 UML-2.SA)	Multi-factor authentication techniques **should** be utilized for system access to UAM Operators, PSUs, Vertiport Managers, and other industry stakeholders' resources. (233 UML-3.SA) UAM Operators, PSUs, Vertiport Managers, 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, PSUs, Vertiport Managers, and other industry stakeholders' resources **should** 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, PSUs, Vertiport Managers, the FAA, and other UAM Community stakeholders. (244 UML-4.SA) UAM Operators, PSUs, Vertiport Managers, 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)
Detect	Cybersecurity detection processes and procedures **should** be maintained and tested to provide awareness of anomalous events within UAM Operators, PSUs, Vertiport Managers, the FAA, and other UAM Community stakeholders' resources. (230 UML-2.SA)	UAM Operators, PSUs, Vertiport Managers, and other industry stakeholders' information system and assets **should** 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, PSUs, Vertiport Managers, 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, PSUs, Vertiport Managers, 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)
Recover	**TBR** (243 UML-2.SA)	UAM Operators, PSUs, Vertiport Managers, 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, PSUs, Vertiport Managers, 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 [9]. 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 [9, §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 [9]. 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 Systems : 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 [9]. Collision avoidance for sUAS that rely on Remote PICs, with the use of on-board sensors and potentially automated decision-making, presents a particularly difficult problem space.

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 [9]. 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	UML-2: Initial	UML-3: Transition and Growth	UML-4: New Predetermined Separator
	UAM Maturity Level		
Strategic Conflict Management Services	ATC and the UAM Operator **will** strategically manage conflicts for UAM operations using existing flight rules, procedures, and technologies. (204 UML-2.SS) The UAM Operator **should** collect data to support the certification or qualification of Demand Capacity Balancing services. (286 UML-2.SS) The UAM Operator **should** collect data to support the certification or qualification of Traffic Synchronization services. (281 UML-2.SS) The UAM Operator **should** collect data to support the certification or qualification of trajectory generation services used for strategic conflict management. (282 UML-2.SS)	The UAM Operator **shall** use Demand Capacity Balancing services to share airspace resources with other UAM Operators, in accordance with the CBRs. (205 UML-3.SS) The PSU **shall** allocate the capacity of the shared airspace resources to the UAM Operator in accordance with established CBRs (311 UML-3.SS) The UAM Operator **should** use Traffic Synchronization services to establish and maintain a safe and efficient flow of UAM aircraft cooperatively with other UAM Operators, in accordance with the CBRs. (83 UML-3.SS) The UAM Operator and the PSU **shall** share flight intent over the PSU Network to enable the development of the shared strategic plan, in accordance with the CBRs. (312 UML-3.SS) The UAM Operator and the PSU **shall** use shared intent as inputs to strategic plan services. (313 UML-3.SS) The PSU **should** identify when the UAM aircraft is sufficiently out of conformance with the cooperative strategic plan. (69 UML-3.SS) The UAM Operator **will** leverage the properties of the airspace constructs, en-route, approach, and departure procedures as part of the strategic plan. (208 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 on-board PIC **shall** ensure that their aircraft remains Well-Clear by "see and avoid" under VFR. (22 UML-2.SS) ATC **will** provide separation services under existing IFR and VFR, as appropriate and as requested by the UAM Operator. (209 UML-3.SS) The PIC **should** use onboard situation awareness tools, such as Cockpit Display of Traffic Information (CDTI) to support the visual separation task. (216 UML-3.SS) The UAM Operator **should** employ services that provide assistive guidance to the PIC that supports their see and avoid responsibilities. (51 UML-2.SS) The UAM Operator **should** collect data to support the certification or qualification to keep the aircraft well clear of other hazards. (284 UML-2.SS) The UAM Operator **should** collect data to support the certification or qualification to help the aircraft regain well clear when it has been lost. (280 UML-2.SS)	The UAM Operator **should** employ approved comprehensive safety-assurance services that keep the UAM aircraft well clear of other hazards. (112 UML-3.SS) The PIC **should** respond to approved guidance intended to keep the UAM aircraft well clear of other hazards. (352 UML-3.SS) The UAM Operator **should** employ approved comprehensive safety-assurance services that guide the UAM aircraft to regain well clear when it has been lost. (308 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 UAM Operator **shall** monitor the conformance of the UAM operations under their control to the active flight intent. (212 UML-3.SS) The UAM Operator **shall** make other UAM Operators aware when any operation under their control has deviated from the active flight intent. (354 UML-3.SS)	The UAM Operator **should** employ approved collaborative and responsible services that keep the UAM aircraft well clear of other hazards. (134 UML-4.SS) The UAM Operator **should** employ approved collaborative and responsible services that guide the UAM aircraft to regain well clear when it has been lost. (340 UML-4.SS) The UAM Operator **should** use approved flight intent as input to their separation provision intervention capability. (221 UML-4.SS) The UAM Operator **should** employ approved collaborative and responsible services that help the aircraft conform with the strategic schedule. (214 UML-4.SS) The UAM Operator **should** use collaborative and responsible services that help the aircraft achieve 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** collect data to support the certification or qualification of trajectory generation services used for separation assurance. (283 UML-2.SS) The UAM Operator **should** collect data on services that may be certified or qualified to help the aircraft conform with the strategic schedule. (279 UML-2.SS) The UAM Operator **should** collect data on services that are expected to be certified or qualified to help the aircraft achieve appropriate spacing from other aircraft (285 UML-2.SS)	The PIC **shall** ensure that the UAM aircraft is adhering to the expected flight path. (213 UML-3.SS) The UAM Operator **should** employ approved comprehensive safety-assurance services that help the aircraft conform with the strategic schedule. (113 UML-3.SS) The UAM Operator **should** use comprehensive safety-assurance services that help the aircraft achieve appropriate spacing from other aircraft. (314 UML-3.SS)	
Collision Avoidance Systems	The PIC **shall** not operate the aircraft so close to another aircraft as to create a collision hazard by "see and avoid" under VFR. (210 UML-2.SS)	The PIC **should** use onboard comprehensive safety-assurance services to avoid a collision hazard, once the separation mode has been compromised. (142 UML-3.SS)	The PIC **should** use onboard collaborative and responsible services to avoid a collision hazard once the separation mode has been compromised. (88 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**
Roles & Responsibilities	ATC or PIC **will** be the predetermined separator for all UAM aircraft operating under VFR or IFR. (23 UML-2.SS)	The UAM Operators **will** be accountable for the cooperative development of a strategic plan for traffic management, in accordance with the CBRs. (217 UML-3.SS) The PIC and Fleet Manager **will** be responsible for executing the cooperative strategic plan, in accordance with the CBRs. (310 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 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 needed to support 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 sensors and automation onboard and offboard the aircraft that **will** be certified for use by the PIC. (220 UML-3.SS)	Under VMC, the Remote PIC **should** use sensors and automation onboard and offboard the aircraft to provide a level of performance equal or superior to visual separation for piloted aircraft. (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, hi-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 will be leveraged. As UAM operations expand to areas where existing radar coverage may not be sufficient, it is expected that a public/private effort will establish and maintain the infrastructure to fill in the gap.

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.

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	The 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 UAM Operator 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 FAA **will** approve the use of radiometric tracking and verification of vehicle position reports. (138 UML-4.SU) The UAM Operator and Vertiport Operator **should** receive data collected from on-board collision avoidance instrumentation as a source of non-cooperative surveillance information. (137 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** carry all FAA-mandated equipage to operate in the desired airspace. (25 UML-2.SU) UAM Operators **should** have access to telemetry directly from the vehicle. (55 UML-2.SU) The PIC **should** use vehicle-to-vehicle surveillance for advisory purposes. (54 UML-2.SU) When applicable, ATC **will** use Standard Terminal Automation Replacement System (STARS) to identify UAM aircraft assigned a discrete beacon code, to maintain identity of targets, and to perform handoffs of these targets between controllers. (225 UML-2.SU) When applicable, ATC **should** use surveillance sources, such as Airport Surface Detection Equipment, Model X (ASDE-X) to detect potential surface conflicts. (222 UML-2.SU) The UAM Operator **should** use displays that provide real-time information of the progress of flights under their supervision. (223 UML-2.SU)	Telemetry information provided by the UAM Operator **should** be a surveillance source for other 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 VTOL aircraft and rotorcraft [8]. 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;

- 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 [8].

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 [26].

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, and Foreign Object Debris (FOD) detection and mitigation (see `https://www.faa.gov/airports/airport_safety/fod/`). 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 [26]. *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 [26].

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 [26].

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)	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. (NEW)	Vertiport Managers **should** be responsible for (**TBR**) elements of Conflict Management. (NEW) Vertiport Managers **should** assess operational risk and make decisions to mitigate risk in accordance with the CBRs. (344 UML-4.VS) The Vertiport Manager **shall** monitor aircraft and ground vehicle conformance to trajectories. (345 UML-4.VS) The Vertiport Manager **shall** execute approved off-nominal procedures when an aircraft or ground vehicle trajectory is out of conformance with the expected trajectory. (NEW)
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** (NEW)
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. The Vertiport Operator **should** have automated FOD detection systems. The Vertiport Manager **should** identify hazards. (NEW)	The Vertiport Manager **shall** identify hazards. (342 UML-4.VS)
Landside Services	**TBR** (290 UML-2.VS)	**TBR** (318 UML-3.VS)	**TBR** (NEW)

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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	**TBR** (NEW)	The Vertiport Manager **should** manage arrival, departure, and parking reservations at the vertiport. (317 UML-3.VS)	The Vertiport Manager **shall** manage vertiport resources. (343 UML-4.VS)
Vertiport Information Management	**TBR** (290 UML-2.VS)	**TBR** (318 UML-3.VS)	**TBR** (NEW)
Vertiport Operations Training	The UAM Operators and Vertiport Operators **should** define the roles and responsibilities of the Vertiport Manager that need to be approved by the FAA. The FAA **will** establish training standards for defined Vertiport Manager roles as necessary.	The UAM Operators and Vertiport Operators **should** establish training programs for Vertiport Managers. Vertiport Managers **should** be trained and approved for service.	**TBR** (NEW)

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 the safe, efficient, and scalable UAM operations. As the low-altitude urban airspace in which UAM operations occur is a highly dynamic environment in which conditions vary rapidly both spatially and temporally, weather conditions are anticipated to be a significant hazard. Thus, adequate weather information at urban-scale scales is necessary to ensure conditions are within regulatory and safety constrains, inform route planning, and facilitate efficient operations. The specific weather information requirements (e.g., resolution, accuracy, precision) for different parameters (e.g., temperature, wind speed and direct, pressure, etc.) is highly dependent on vehicle specifications, vertiport and airspace procedure design, density of operations, and other factors. The weather element consists of the following components:

Decision Support : Raw weather information translated into products to support decision making and planning incorporating UAM-specific constraints. These support tools incorporate vehicle performance, operator preferences, airspace management procedures, current observations and forecasts together to aid in decision making. Observational and forecast uncertainty are utilized to assess risk and the range of potential operational impacts across the UAM ecosystem including operation rate at vertiports, capacity of corridors, and energy management for UAM Operators.

Dissemination : Data networks to distribute pertinent weather information across the UAM system in a timely manner, such as to alert UAM Operators of new hazards when conditions rapidly deteriorate. These networks utilize common data formats for use across the different components of the UAM system. The networks will be resilient, such as to data outages from any source, and secure from potential outside threats.

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. 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 are expected to have uncertainty metrics to support UAM operations including contingency planning.

Numerical Weather Models : Computational models that process current weather observations to produce an analysis of current weather conditions in full three-dimensions 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 effects, and machine learning or artificial intelligence models. These models inform UAM Operators of full four-dimensional weather conditions and serve as tactical and strategic aids.

Policy : A set of common rules and guidelines to be followed regarding the collection, use, and dissemination of weather data across all the UAM ecosystem. These policies include CBRs 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.

Weather Observations : 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 observations enable UAM Operators to understand the current weather for tactical decision making, ensuring conditions are within operating constrains, and determining the flight rules applicable to current meteorological conditions.

Table 10: Weather

	UAM Maturity Level		
Component	**UML-2: Initial**	**UML-3: Transition and Growth**	**UML-4: New Predetermined Separator**
Decision Support	**TBR**: Flight planning tools utilized by UAM Operators in UML-2 will likely use existing decision support and weather translation products. (291 UML-2.WX)	The SDSP or PSU **shall** include weather information and associated uncertainty to assess capacity and availability of shared airspace resources. (322 UML-3.WX) The SDSP or PSU **shall** provide decision support capability to advise users of relevant weather impacts near vertiports. (324 UML-3.WX)	**TBR** (346 UML-4.WX)
Dissemination	The UAM operator **should** obtain meteorological information from a source approved by the FAA. (292 UML-2.WX)	The SDSP or PSU **shall** publish a weather forecast with associated uncertainty to all subscribers. (325 UML-3.WX) The SDSP or PSU **shall** alert UAM Operators of hazardous weather conditions when they are detected. (323 UML-3.WX)	**TBR** (347 UML-4.WX)
Forecasts	**TBR**: Flight planning tools utilized by UAM Operators in UML-2 will likely use existing forecast products. (296 UML-2.WX)	The SDSP or PSU **shall** issue forecasts meeting performance standards for winds, ceiling, and visibility over all shared airspace resources. (319 UML-3.WX)	**TBR** (348 UML-4.WX)
Numerical Weather Models	**TBR**: Flight planning tools utilized by UAM Operators in UML-2 will likely use existing operational weather models. (295 UML-2.WX)	The SDSP **shall** use numerical weather prediction models and computational fluid dynamics meeting performance standards to estimate wind, turbulence, precipitation, ceiling, and visibility. (327 UML-3.WX)	**TBR** (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**
Policy	**TBR**: The UAM operator **will** comply with any requirements under existing FAA policy and regulations. (294 UML-2.WX)	The FAA **should** include weather and microclimate information in establishing and approving airspace constructs to minimize susceptibility to weather hazards. (320 UML-3.WX) The UAM operator **should** take meteorological measurements (i.e., temperature, pressure, wind speed, wind direction) on vehicles and transmit the observations periodically for shared use among other operators, SDSPs, and PSUs. (326 UML-3.WX)	**TBR** (350 UML-4.WX)
Weather Observations	The UAM operator **should** use certified weather observations to support situational awareness and flight planning, ensuring compliance with existing policy and CBRs and to increase safety and efficiency. (293 UML-2.WX)	The SDSP **shall** collect and use weather observations meeting performance standards of wind, turbulence, precipitation, ceiling, and visibility to support situational awareness. (321 UML-3.WX)	**TBR** (351 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 [27] and [28]. 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
ACMS	Aircraft Conformance Monitoring Service
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
ARMD	Aeronautics Research Mission Directorate
ASDE-X	Airport Surface Detection Equipment, Model X
ASTM	American Society for Testing Materials
ATC	Air Traffic Control
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 Business Rules
CC	Critical Commitment
CDTI	Cockpit Display of Traffic Information
CFD	Computational Fluid Dynamic
CFR	Code of Federal Regulation
CNS	Communication, Navigation, and Surveillance
COA	Certificates of Authorization
COP	Common Operating Picture
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
FIDXP	FAA-Industry Data Exchange Protocol
FIMS	Flight Information Management System
FY	Fiscal Year
GA	General Aviation
GBAS	Ground Based Augmentation System
GPS	Global Positioning System
HIS	Hazard Identification Service
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
MRO	Maintenance, Repair, and Overhaul

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
RAS	Risk Assessment Service
RF	Radio Frequency
RMSS	Resource Management and Scheduling Service
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
STARS	Standard Terminal Automation Replacement System
sUAS	Small UAS
SVO	Simple Vehicle Operations
TBR	To Be Resolved
TC1	Technical Challenge 1
TFR	Temporary Flight Restrictions
TLOF	Touchdown and Liftoff
UAM	Urban Air Mobility
UAS	Unmanned Aircraft System
UML	UAM Maturity Level
USS	UAS Service Supplier
UTM	UAS Traffic Management
VAS	Vertiport Automation System
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
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).

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.

Aircraft Conformance Monitoring Service (ACMS): The ACMS monitors airborne and surface trajectory conformance to detect anomalies that could disrupt nominal vertiport operations. Airborne traffic is monitored as part of ACMS.

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.

Assistive Automation: Applies to reliance on lower-level automated functions (e.g., highly augmented flight controls) with limited integration and that human agents retain full-responsibility for operational safety.

Capabilities (Roadmap): Discrete fundamental elements which cover and decompose the entirety of the UAM airspace system.

Collaborative and Responsible Automation: Applies to automation which is assured to perform specified functions such that human monitoring and mitigation of potential failures of those functions is no longer necessary.

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.

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.

Community Business 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.

Comprehensive Safety-Assurance Automation: Provides the capability for safety-critical monitoring and interventions mitigating a wide range of specific hazards within the system (e.g., ground collision avoidance, traffic collision avoidance, etc.), significantly improving the safety of the system, but with human agents still retaining full-responsibility for operational safety.

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

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).

FAA: In the United States, the FAA is the transport agency of the United States government regulating all aspects of civil aviation in the NAS, including but not limited to the regulatory areas of ATM, certification of personnel and aircraft, standards for airports and vertiports to ensure aviation safety and minimize environmental impact. The FAA is the organization accountable for delivering ATM services and is also the regulatory authority.

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.

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, Remotely Supervised Aircraft, Remote Supervisors, 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.

Remote Supervisor: The individual who is accountable for operational control of one or more Remotely Supervised Aircraft.

Remotely Supervised Aircraft: Programmed and fully autonomous UAM aircraft, with the ability to operate under limited human supervision and largely independent of external control. 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.

Resource Management and Scheduling Service (RMSS): RMSS generates vertiport resource availability which are communicated to other UAM system actors, exercises prioritization of the vertiport resources under a set of configurable rules and manages the resources to achieve efficient vertiport surface operation in accordance with the configurable business rules and local, state, and federal rules and regulations.

Risk Assessment Service (RAS): The RAS receives the hazards from HIS and assesses the risk level. If the risk exceeds the designated acceptable level, the RAS will recommend a pre-defined mitigation strategy designed to reduce the risk to an acceptable level.

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 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).

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 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.

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.

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 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.

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.