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Urban Air Mobility Operational Concept (OpsCon) Passenger-Carrying Operations

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Preface

This Operational Concepts (OpsCon) provides a foundational understanding of multiple aspects of passenger-carrying Urban Air Mobility (UAM) for members of the aviation and transportation communities who are unfamiliar with the vision for UAM as an integrated part of the urban transportation system. It summarizes the history of UAM, sets forth the rationale and benefits of the concept, describes the current system, and portrays three time-phased states to introduce a framework for considering the UAM ecosystem as a means to sequence development and progress to serve envisioned UAM markets.

NASA has produced two OpsCons and a Concept of Operation (ConOps) addressing NASA's concepts for UAM. The two OpsCons are intended to serve as foundational tools to introduce new community members to the concepts and to document the work and thinking of NASA's UAM Coordination Assessment Team (UCAT) developed in 2018 and 2019. In 2018 it was decided to produce the two OpsCons – one for passenger-carrying operations and one for small Unmanned Aircraft Systems (sUAS) – to explore similarities and differences between them. Since that time, the community thinking and terminology have evolved and are addressed in the Manned UAM ConOps, a vision document more focused on describing UAM in the intermediate state. These documents will be either superseded or updated as experience is gained and thinking continues to evolve, but they will still provide valuable information documenting the initial concepts of UAM.

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Executive Summary

Urban Air Mobility (UAM) is the name chosen for the concept of using the airspace over urban areas to satisfy the public imperative for fast and efficient transportation within growing metropolitan areas. This Operational Concept (OpsCon) describes a community vision of the projected evolution of urban air service with vehicles capable of carrying one or more passengers.

UAM holds the promise of greater mobility and improved quality of life by reducing congestion and delay, enabling flexible response to changing transportation needs, increasing safety for travelers and the public, enhancing economic vitality, and creating new market opportunities and new jobs. Although UAM is a new and transformational concept, it builds on a history of imaginative concepts long in the public eye, such as flying cars, that can now be realized with the convergence of emerging technologies.

A NASA team has identified the challenges and gaps that must be addressed to enable the UAM vision. To categorize these challenges and their dependencies, the team developed a framework comprising five pillars: (1) Vehicle Development & Production, (2) Individual Vehicle Management & Operations, (3) Airspace System Design & Implementation, (4) Airspace & Fleet Operations Management, and (5) Community Integration.

This OpsCon envisions vertical takeoff and landing (VTOL) aircraft, or, potentially, short takeoff and landing (STOL) aircraft, operating from sites called UAM ports, capable of loading and unloading passengers and servicing multiple aircraft, and UAM pads, capable of loading and unloading a single aircraft quickly and efficiently. Enhanced air traffic management (ATM) concepts and collision avoidance systems assure safe and efficient operation within the airspace.

To help in planning and monitoring progress, the team established three future states: initial, intermediate, and mature. In the initial state, new UAM vehicle designs are introduced and certified, with operations relying initially on existing heliports and selected urban landing sites, as well as leveraging procedures currently used by helicopters. Regulations and certifications will be based on adaptation of existing rules, and new business cases will be tested and validated by these early operations. FAA support will be critical to realization of this initial state.

The intermediate state focuses on increasing vehicle payloads to support larger air vehicles; expanding the ground infrastructure and landing sites; and introducing integrated communication, navigation, surveillance, and information (CNSI) systems and ATM capabilities to support greater traffic volumes. Autonomy advances will focus on developing and certifying semi-autonomous vehicles and ATM functions to reduce direct human involvement while increasing safety and system capacity.

The mature state is characterized by technological and operational maturity across all pillars. It features ubiquitous UAM operations enabled by a fully integrated UAM system with autonomous vehicle, ATM, and information management systems; large networks of UAM ports and UAM pads; and high-precision, weather-tolerant CNSI and infrastructure supporting both semi- and fully autonomous operations.

This OpsCon describes Human Piloted Air Medical Transport, Intra-Metro Air Shuttle, and Ubiquitous Air Taxi missions to illustrate the initial, intermediate, and mature states, respectively, and to identify barriers associated with the pillars of the UAM Framework. These missions demonstrate how advances in the five pillars can open up new dimensions for safe, rapid, economical, and flexible urban travel.

1 Introduction

The movement of people, goods, and information is critical to the nation's safety, security, and prosperity. Urban Air Mobility (UAM) is the name chosen for the concept of using the airspace over metropolitan areas to address this imperative as the need continues to grow for speed and efficiency within those areas. This document describes the Operational Concept (OpsCon) for UAM operations intended to carry aircrews and/or passengers.

1.1 Purpose and Scope

This OpsCon is intended as a foundation to engage members new to the community and to help build consensus on a future community vision for UAM operations that is informed by Federal Aviation Administration (FAA) experience, NASA and industry research, and the public's desires. This foundation, along with the UAM Concept of Operations (ConOps) for passenger carrying UAM, will help to identify regulatory, technical, and public acceptance challenges, and to steer the research and development efforts of NASA, industry, and other stakeholders.

This OpsCon provides a high-level vision of manned UAM operations and a description of operational environments as they are envisioned to evolve and mature. The term manned UAM encompasses vehicles certified to carry people, which may include a pilot, passenger(s), or a pilot with passengers. The format of this OpsCon derives from guidance documents developed by the Institute of Electrical and Electronics Engineers (IEEE), Reference 1, and the American Institute of Aeronautics and Astronautics (AIAA), Reference 2, adapted as needed. A separate OpsCon document describes related unmanned UAM missions. This OpsCon is agnostic with regard to system architectures, designs, and functional allocations. Research results, technology maturity, government and industry design decisions, and market forces will drive such design and implementation decisions.

The remainder of Section 1 describes the benefits that are being sought by developing UAM, the historical foundation for the technologies and public perceptions of UAM concepts, and a UAM system framework that serves as the basis for the descriptions in this OpsCon. Section 2 describes current urban air operations. Section 3 provides an overview of envisioned UAM operations and the system supporting these operations, as well as examples of mission scenarios. Section 4 identifies UAM concept stakeholders and their expected contributions. Appendix A identifies references that have significant bearing on this document, Appendix B defines key terms used in this document, and Appendix C provides a list of acronyms that appear in this document.

1.2 UAM Benefits

UAM leverages the convergence of advances in air vehicle technologies, air traffic management, electric and hybrid propulsion systems, electric energy management, information and communication technologies, data analysis, and autonomy to create time-saving alternatives to ground transportation that will enable faster, safe, and more efficient movement in metropolitan areas. Applying these technologies to air transportation within urban areas has the potential to improve personal mobility and quality of life by reducing the time and cost of urban transportation, enabling flexible response to changing transportation needs, increasing safety for travelers and the public, enhancing economic vitality, and creating new market opportunities and new jobs.

The ability of UAM passenger transportation to bypass ground congestion can result in faster and more efficient transportation for single trips, personal commuting, and public transportation compared to time-consuming and labor-intensive ground modes, particularly considering the value of travelers' trip time. Cost reductions for UAM are expected to come from vehicle production efficiency, introduction of autonomy, and economies of scale, as well as new business models and reduced operating costs, and electric and hybrid propulsion will reduce energy costs as well as noise and pollution.

Although UAM will require air traffic management and an infrastructure of landing sites, the nature of aerial capabilities and technologies allows greater flexibility in locating facilities, managing traffic, selecting alternative routes, and incremental implementation. While there will likely be some reluctance to creation of new UAM ports, their desirability could be weighed against new roads or rail lines. UAM can adjust to serve the growth or shift of urban populations without the need for heavy capital investment in fixed infrastructure and the large amount of real estate, disruption of neighborhoods, and long development times that typify road or rail projects. By minimizing the need for new ground transportation infrastructure, UAM has the potential to enable greater options for land use, and collocation of UAM infrastructure with existing public transportation nodes could amplify these benefits. Additionally, the availability of flexible routes and schedules offers greater flexibility in matching service to varying needs during the operating day, as exemplified by changing travel patterns during commuting hours, mid-day, and evening, as well as allowing more flexible responses to evolving population patterns. Increasing efficiencies may reduce the cost of UAM to be within reach of the average consumer, and UAM may increase mobility for persons who are not able to drive or who lack access to public ground transportation. The flexibility of UAM will enable interoperability with other modes and, ultimately, inclusion of UAM as an essential element of an integrated transportation, distribution, and communication network, providing more choices to match individual desires and respond to changing needs.

To provide safe transportation, UAM will build on many millions of hours of operation gained with unmanned systems, as well as the technology, standards, culture, and over a century of experience that have rendered air travel the safest mode of transportation. New technologies will be introduced incrementally as they demonstrate the required levels of safety. Compared to surface modes, UAM operation in three-dimensional managed airspace can provide greater control and freedom of maneuver to avoid collisions, and advanced autonomy and machine learning can avert human errors, the largest cause of accidents for all modes of transportation.[1,2] Furthermore, automation and autonomy have the

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[1] National Highway Traffic Safety Administration, "Traffic Safety Facts: A Brief Statistical Summary," U.S. Department of Transportation, 2015, https://crashstats.nhtsa.dot.gov/Api/Public/ViewPublication/812115, retrieved April 22, 2020.

[2] Scott A. Shappell and Douglas A. Wiegmann, "Human Error and General Aviation Accidents: A Comprehensive, Fine-Grained Analysis Using HFACS," 2004, https://www.faa.gov/about/initiatives/maintenance_hf/library/documents/media/human factors_maintenance/human_error_and_general_aviation_accidents.a_comprehensive.fine-grained_analysis_using_hfacs.pdf, retrieved April 22, 2020.

potential to not only improve safety, but also to enable humans to focus on decision making and to make high-value contributions in creating and operating complex systems.

UAM can also improve public safety. Manned UAM services have the potential to reduce accidents associated with increasing surface traffic congestion, and new UAM vehicles could provide a bird's-eye view that affords improved surveillance and situational awareness, thereby reducing risk, increasing safety, and reducing cost to cover a given area. UAM enables near-instantaneous response, even during peak traffic hours, enabling faster response for law enforcement, search and rescue, medical transport, and disaster relief. Enhanced traffic monitoring and situational awareness can provide more timely alerts about accidents, flooding, and iced or snow-covered roads, allowing travelers to be better informed of safer routes to their destinations.

UAM can enhance economic vitality in urban areas by providing rapid, reliable transportation supporting economic activity in those areas. Despite the growth of electronic communication, many business functions continue to locate in urban areas to facilitate personal contact and employment mobility. Personal contact is often key to improved coordination to manage complex operations, enabling timely delivery of critical information and resolution of multiple viewpoints to support better-informed decision making. Aerial mobility can also offer a new mobile source for personal inspections, surveys, and observations, particularly those involving multiple sites, again enabling better-informed decisions.

UAM technology advances, combined with new aeronautical communication, navigation, and surveillance (CNS) systems and the use of underutilized low-altitude airspace, will create new markets and new approaches to serve them. Thus, UAM will enable a new high-technology industry, create new jobs, and foster a culture of entrepreneurship in pioneering new options for rapid transportation.

In sum, UAM can enable travelers in metropolitan areas to spend less time in transit and more time for productive and personal activities by opening new dimensions for rapid, flexible, safe, and economical urban travel that will enhance economic vitality and create market opportunities and new jobs.

1.3 Background

1.3.1 Vehicles

As exhibited in the ancient Greek myth of Icarus, personal mobility through flight has long been a dream of mankind. Concepts for personal flight have evolved over time from personal wings to flying carpets to various types of flying carriages powered by unknown energy sources. It wasn't until Alberto Santos-Dumont's personal dirigible *Brasil* in 1889 that humans had the potential to realize the vision of steerable, self-powered personal vertical takeoff and landing (VTOL) aircraft.[3]

The concept of one-person flying platforms for combat grew out of research in the early 1950s by NASA's predecessor, the National Advisory Committee on Aeronautics. Flight tests of prototypes delivered by three companies – de Lackner, Bensen, and Hiller – beginning in 1955 involved pilots

[3] "Alberto Santos-Dumont, Brazil," *Highlights in Aviation*, http://www.smithsonianeducation.org/scitech/impacto/graphic/aviation/alberto.html, retrieved April 22, 2020.

standing atop platforms powered by ducted rotors. In 1956 the U.S. Army Transportation Research Command began an investigation into flying jeeps, also based on ducted rotor technology, leading in 1957 to contracts for prototypes to Chrysler, Curtiss-Wright, and Piasecki. The Curtiss Wright and Piasecki designs successfully flew in 1958.[4] Figure 1 illustrates some of these early concepts. None of these efforts led to full-scale development and production, but military agencies and contractors around the world have since invested significant resources on various designs leading to current rotorcraft designs and vertical/short takeoff and landing (V/STOL) fighter aircraft such as the Harrier. The civil aviation community has also continued innovative efforts to improve the efficiency of air transportation and foster new air vehicle concepts.

Figure 1: Early Prototype Personal Air Vehicles

At the same time, futurists and science fiction writers have postulated various concepts for urban air transportation. Although numerous concepts and depictions of flying cars emerged early in the 20th century, *The Jetsons (1962)* cartoon brought the concept of personal flying cars into mainstream America. Science fiction movies have advanced the visualization of flying cars, from early examples such as *The Absent-minded Professor (1961)* and *Chitty, Chitty, Bang, Bang (1968)* to more recent examples such as *Blade Runner(1982), Back to the Future (1985), Total Recall (1990), The Fifth Element (1997), and*

[4] Greg Goebel, "The Flying Platforms & Jeeps," *Airvectors*, February 1, 2017, http://www.airvectors.net/avplatfm.html, retrieved April 22, 2020.

Harry Potter and the Chamber of Secrets (2002). Figure 2 illustrates some of these imaginative concepts for human-driven flying cars.

Figure 2: Science Fiction Aerial Vehicles

Self-driving cars and taxis, illustrated in Figure 3, have appeared in other science fiction movies, such as *Total Recall (1990), Demolition Man (1993), The Minority Report (2002),* and *I, Robot (2004)*.

Figure 3: Self-Driven Cars in Films

Technology development has been accelerating at an exponential rate and is gradually catching up with science fiction. Aircraft designs and enhancements have evolved over time with experience and technological progress, and continued maturation of FAA certification requirements and processes have helped to reduce aviation accidents and incidents. Innovations in computing power, information networking, and sensor technology have provided tools for the development of safer and more fuel-efficient automobiles; the same technologies, combined with composite materials, modern manufacturing techniques, and advances in electric power storage, motors, and controllers, are enabling similar developments in new aircraft. Today, a number of companies world-wide, such as Airbus, Kitty Hawk, Lilium, and Ehang, are developing and testing electric-powered flying vehicles introducing increasing levels of autonomy. Figure **4** illustrates some concepts for these types of vehicles.

Figure 4: Electric VTOL Air Vehicle Concepts

1.3.2 Air Traffic Management

The evolution of Air Traffic Management (ATM) has progressed in a similar fashion. Today's U.S. air traffic management system has evolved over time as air traffic has grown in volume, speed, and capabilities. Each stage has been enabled by new technologies in air traffic information, automation, and CNS systems. Two-way voice communication radios were introduced in the 1930s at the new Cleveland airport control tower. At the same time, aircraft navigation systems went from bonfires to light beacon towers to 38 radio beacons installed by the U.S. Commerce Department to guide aircraft in poor visibility.

In the early 1930s, the Commerce Department called for the establishment of Air Route Traffic Control Centers (ARTCCs) to track the progress of flights based on telephone communications with the airline companies and time and speed calculations. Aircraft separation was managed through a combination of procedural separation (route assignments and scheduling), air traffic control (ATC) traffic advisories, and right-of-way and see-and-avoid rules. In 1938 Congress established the Civil Aeronautics Authority, which was eventually given control of airport control towers, ARTCCs, and associated supporting CNS infrastructure. [5]

World War II gave rise to revolutionary technologies, such as radio detection and ranging (RADAR), which was embraced for civilian use following the collision of a United Airlines DC-7 and a TWA Constellation over the Grand Canyon in 1956, killing all 128 people aboard both aircraft. Congress

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[5] National Air Traffic Control Association, "A History of Air Traffic Control," https://www.natca.org/images/NATCA_PDFs/Publications/ATCHistory.pdf,. retrieved April 22, 2020.

subsequently appropriated $250 million to modernize the airway system, including added radar advances, and the Federal Aviation Act of 1958 created the FAA to manage and regulate all operations in the nation's airspace. Radar technology evolved from passive radar to cooperative radar in the 1960s and 1970s, which led to installation of transponders to allow air traffic controllers to positively identify each aircraft and determine its location and altitude. Cooperative surveillance technologies have continued to evolve, to the point that Automatic Dependent Surveillance – Broadcast (ADS-B) became mandated equipage in 2020. Similarly, Traffic Alert and Collision Avoidance Systems (TCAS), or Airborne Collision Avoidance Systems (ACAS) internationally, became mandated equipage for most transport-class aircraft and form an integral part of today's capability for separation assurance.

As traffic volume grew to satisfy demand, traffic flow management (TFM) was needed to meter and distribute traffic to efficiently utilize airspace, coordinate terminal and en route radar control facilities, and prevent overloading airports and the ATM system. In 1970, the FAA created the Central Flow Control Facility to collect and correlate system-wide air traffic and weather data, detect potential trouble spots, and suggest solutions. That year, the FAA established the Air Traffic Control System Command Center (ATCSCC) to integrate and manage all strategic traffic management initiatives.[6]

Today, ATM is supported through a combination of strategic, tactical, and supporting safety systems and services to manage the flow and separation of traffic while enabling efficient and equitable utilization of key resources such as runways and airspace. Navigation and communication systems have continued to improve, primarily in the form of Global Navigation Satellite Systems (GNSS), allowing aircraft to safely operate in closer proximity, and digital air-ground communications systems that uplink weather and constraint information. ATM capabilities have also benefited from data processing and networking, and new levels of automation in traffic management will become possible with the addition of enhanced automation, digital communication, navigation, and surveillance technologies.

Like futuristic vehicles, future ATM systems have appeared in science fiction films, such as *The Fifth Element* (1997), *The Minority Report* (2002), and several *Star Wars* movies (1977 to 2015). These films also depict concepts for structuring high-volume urban air traffic, illustrated in Figure 5, but they do more to excite the imagination than providing true insights into how such systems would be designed and managed.

[6] Federal Aviation Administration, "A Brief History of the FAA," www.faa.gov./about/history/brief_history/, retrieved April 22, 2020.

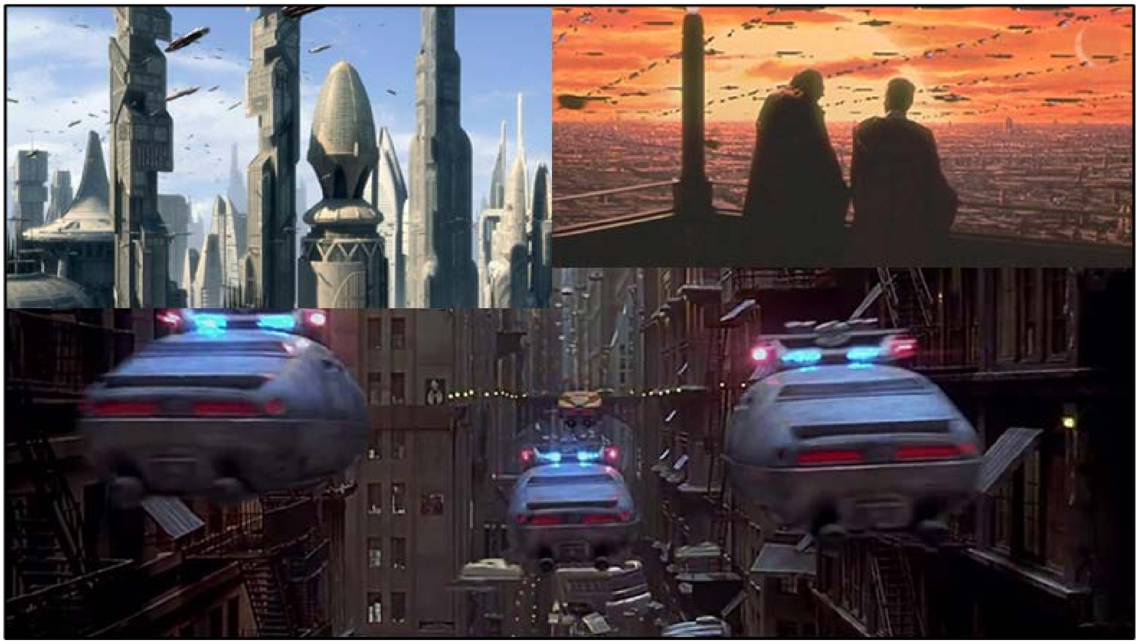

Figure 5: Futuristic UAM Air Traffic Concepts

Today, the FAA's NextGen program is implementing modern technologies that enhance current performance and robustness, as well as providing a foundation on which to build new automation capabilities. NASA has continued to work with the FAA to develop new ATM applications that work within existing system limitations to improve constraint mitigations, congestion management, and traffic throughput, as well as reducing uncertainty and enhancing overall trajectory efficiency. Current studies by NASA and the FAA to define the next generation of concepts to manage sUAS, known as UAS Traffic Management (UTM), will also provide insights into more automated and user-driven methods for managing and separating traffic. ATM researchers and users are working to enable a system that is not impeded by past design choices, where applications are better integrated, operational capabilities can be tested and implemented more rapidly, and ATM services are dynamically scalable to demand. This future system would ideally allow user-desired routes, speeds, and altitudes in operations from the surface to the edge of space, while ensuring the safety of thousands more vehicles than today's system.

1.3.3 Urban Mobility

Models for on-demand mobility have also evolved, from horse-drawn carriages to today's electronic ride-hailing operations, largely as a result of new technologies, growing demand, and new business models.

The first documented public hackney coach service for hire took place in London in 1605, later supplanted by the more maneuverable and economical cab patented in 1834 by Joseph Hansom. Electric battery-powered taxis became available in London at the end of the 19th century, and the world's first gasoline-powered cab with a taximeter to calculate the distance traveled began operation in Germany in 1897. Arranging for transportation in any of these vehicles was either pre-arranged, waiting at fixed locations, or randomly hailed.

The industry grew rapidly in the early 20th century; the next major innovation occurred in the late 1940s, when two-way radios first appeared in taxicabs.[7] Computer assisted dispatching, introduced in the 1980s, combined with smartphone technology introduced in the 1990s, gave rise to today's innovative concepts such as Uber (founded in 2009) and Lyft (launched in 2012).

This historical evolution has not only produced innovative technologies and new operational and business models for on-demand transportation, it has also changed public expectations for improved personal mobility along with increased urbanization. The continuing spread of urban areas, growing traffic congestion, costly parking, crowded public transportation, increasing desire for on-demand transportation, and convergence with new technologies can be expected to continue to encourage innovative new concepts for air vehicles, air traffic management, and urban air operations.

1.4 UAM System Framework

A number of vehicle, airspace, and social challenges must be addressed to realize the UAM vision of safe, convenient, affordable, and accessible air transportation for passenger and cargo within metropolitan areas. This vision implies a large number of vehicles operating simultaneously over metropolitan areas in closer proximity to the general public than current aviation. Achieving this vision will require capabilities that do not currently exist for the UAM vehicles, the airspace they will need to access, the operational infrastructure needed to enable a new mode of transportation, and the requisite rules, regulations, and procedures needed to ensure that people and property can be safely, efficiently, and resiliently moved throughout metropolitan areas.

NASA's Aeronautics Research Mission Directorate (ARMD) established the UCAT to help create a common lexicon and framework to address these challenges. The team identified the challenges across the UAM community that must be addressed to enable the UAM vision; these challenges are identified as barriers in this document, where the term barrier includes issues with clear solution pathways, as well as those with no known solution path.

The UCAT also created a UAM System Framework, depicted in Figure 6, to support dialogue within the UAM community and coordinate efforts to enable UAM markets. As shown in the figure, the framework comprises five pillars, corresponding to the designations of the five lift fans of the pentacopter at the center of the figure. These pillars represent a high-level view of the different facets of the UAM space that ARMD has found useful for discussing various aspects of the UAM system.

The framework is used throughout this document to structure the discussion of the current system, the envisioned future, and UAM stakeholders. The barriers are described as they apply to three passenger-carrying reference missions. The reference missions – Human Piloted Air Medical Transport, Intra-Metro Air Shuttle, and Ubiquitous Air Taxi – were chosen to illustrate a broad set of barriers for missions directly related to the UAM vision for transportation within a metropolitan area. Different missions, such as interurban transport, could result in different descriptions of the barriers.

[7] Wikipedia, https://en.wikipedia.org/wiki/Taxicab, retrieved April 20, 2020.

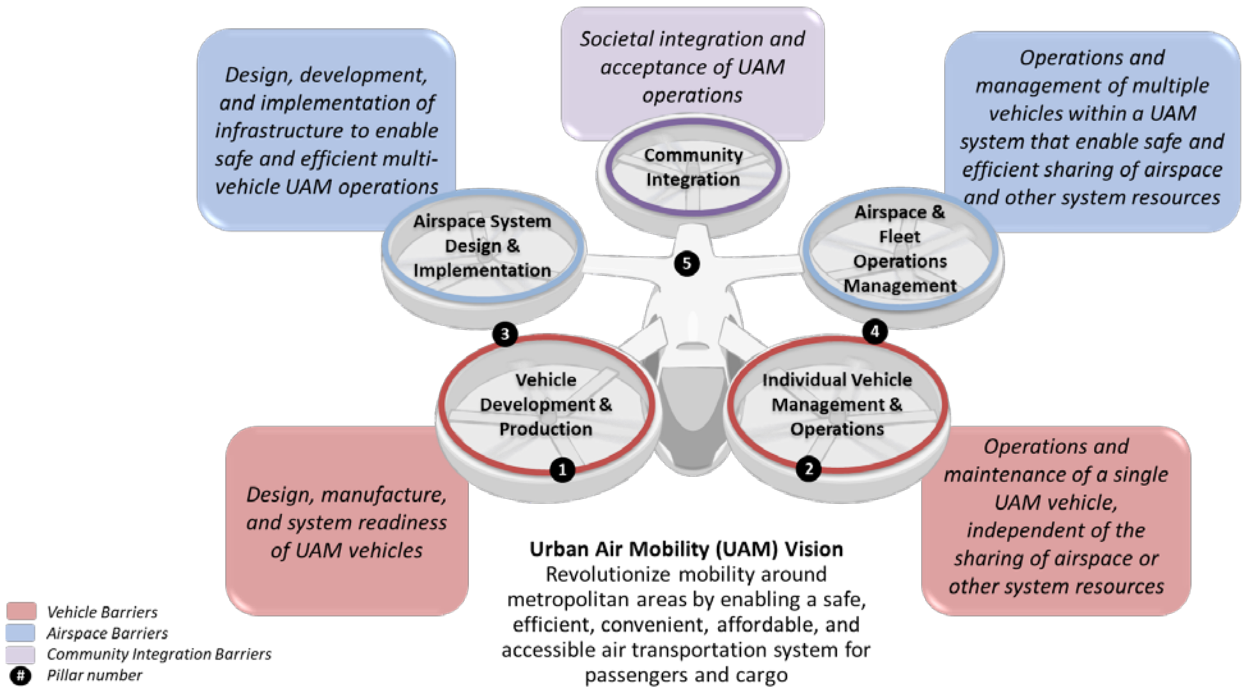

Figure 6. UAM System Framework

1.4.1 UAM System Framework Pillars

The five pillars include two that pertain to the vehicle, two that pertain to the airspace, and one that pertains to the community at large. For the vehicle and airspace pillars, the pillars on the left side of Figure 6 pertain to the design and production of the vehicles or airspace, and the pillars on the right side focus on operations. The five pillars are described as follows.

- *Pillar 1, Vehicle Development & Production*: Design, certify, and produce airworthy, mission-capable, integrated vehicles that operate safely in all weather conditions required by the mission, with adequate passenger comfort and sufficiently low levels of noise.
- *Pillar 2, Individual Vehicle Management & Operations*: Safely operate UAM vehicles in and around metropolitan areas while maintaining compliance with all required operational rules and procedures.
- *Pillar3, Airspace System Design & Implementation*: Design, regulate, and manage the airspace and supporting ground facilities to enable safe, efficient, and reliable UAM flights in and around metropolitan areas.
- *Pillar 4, Airspace & Fleet Operations Management*: Provide airspace operations management services as well as fleet operations management services that ensure safe, efficient, scalable, and resilient UAM operations in and around metropolitan areas
- *Pillar 5, Community Integration*: Achieve public acceptance of UAM vehicle operations in and around metropolitan areas by addressing UAM-related social concerns such as safety, security, affordability, noise, privacy, and legality.

1.4.2 UAM Barriers

Associated with each of the pillars are barriers that need to be overcome to enable each pillar. Figure 7 identifies these barriers in the text boxes next to the ovals representing the pillars. The large concentric ovals represent seven crosscutting barriers that relate to multiple pillars.

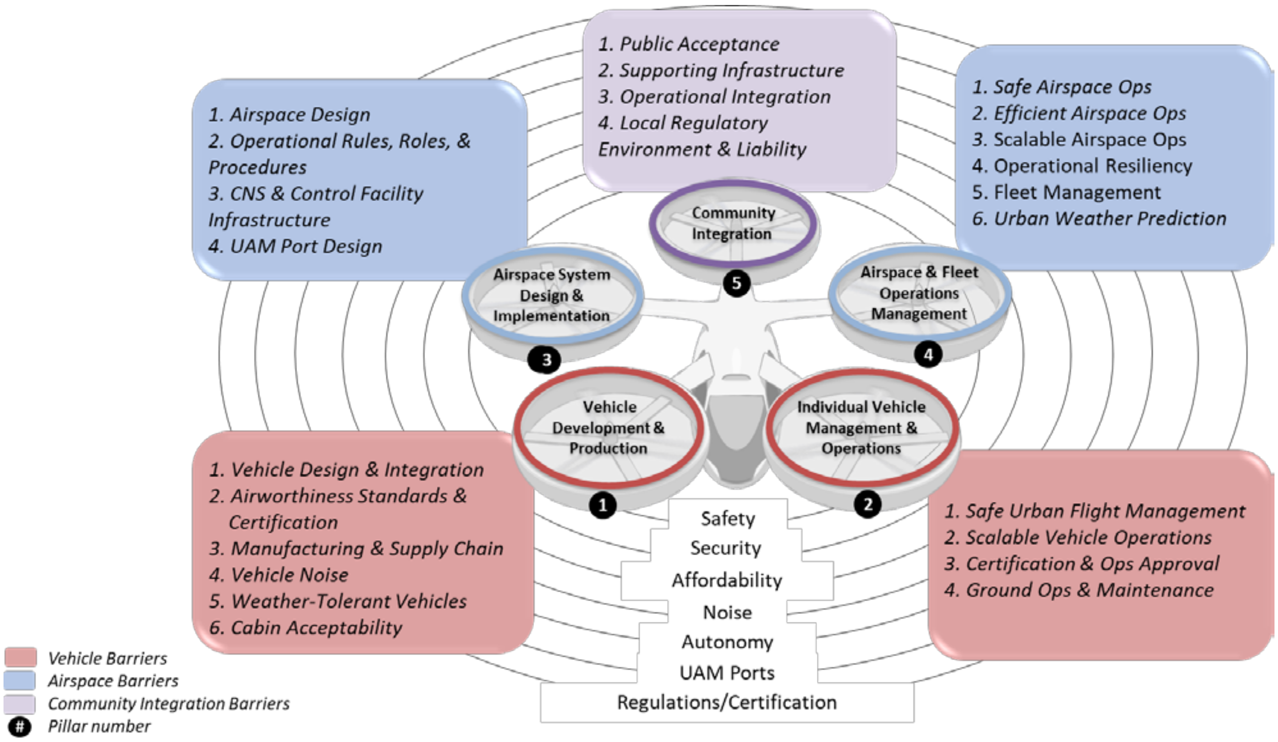

Figure 7: UAM Barriers

To avoid specifying solutions or implementation decisions, the barriers are described in a general manner. Although some of these barriers have a generally accepted solution pathway, others have no consensus path forward. Some paths may resemble approaches previously applied to existing aircraft types, while others will require unique and novel solutions.

Table 1, below, describes the barriers associated with each of the five pillars.

Table 1: UAM System Framework Pillars and Barriers

PILLAR 1: Vehicle Development & Production	
Vehicle Design & Integration	Challenges in developing "mission-capable," integrated aircraft that are compatible with UAM ports and meet all required attributes simultaneously to be safe; operationally and economically competitive with competing transportation modes; environmentally responsible; and secure from digital attack.
Airworthiness Standards & Certification	Challenges with the initial and continuing certification of novel and/or rapidly evolving aircraft in a cost- and time-effective manner, including developing certification requirements and means of compliance for vehicles and propulsion systems, as well as ensuring harmonized international regulations and standards.
Vehicle Noise	Challenges in developing aircraft with acceptable noise characteristics, such as loudness and annoyance, during all phases of flight, including taxi, takeoff /departure, approach and landing, and cruise.
Weather-Tolerant Vehicles	Challenges in developing aircraft that are capable of safely flying into and maintaining control in nearly all weather conditions, including icing, lightning, high winds, low visibility, high density altitudes, and extreme temperatures.
Cabin Acceptability	Challenges in developing aircraft that provide an acceptable level of passenger comfort and payload protection, including consideration of ride quality, cabin noise, interior climate control, and vibrations.
Manufacturing and Supply Chain	Challenges in developing safe, certifiable, high-volume, affordable, secure, and rapid manufacturing capabilities, as well as a robust and scalable supply chain ecosystem.
PILLAR 2: Individual Vehicle Management & Operations	
Safe Urban Flight Management	Challenges with capabilities for safe, efficient, and accommodating flight planning and execution in metropolitan areas, including navigation performance sufficient for urban environments in extremely low-visibility conditions, assuring controlled flight for safe contingency management (including cyber attacks), and compliance with regulations and other constraints, such as noise limits.
Increasingly Automated Vehicle Operations	Challenges in developing highly automated capabilities and associated operational procedures to enable cost-effective scalability by increasing the ratio of vehicle operations to human operators and support staff.
Certification & Operations Approval	Challenges in developing a framework and corresponding methods of compliance for the holistic certification of advanced automation, humans, and operations of a UAM aircraft, as well as regulations and approval processes for commercial urban operations.
Ground Operations & Maintenance	Challenges with guidance and requirements to ensure safe and efficient maintenance and routine vehicle handling between flights, including considerations for UAM port design and operations.
PILLAR 3: Airspace System Design & Implementation	
Airspace Design	Challenges developing and implementing a practical, feasible, flexible, scalable, implementable, and equitable airspace design for UAM operations that includes considerations for interoperability of diverse missions and vehicle types (including piloted, autonomous, VTOL, STOL, and sUAS), placement of UAM ports to minimize community concerns such as noise and privacy, and cumulative fleet emissions (including noise and CO_2) over local communities.
Operational Rules, Roles, & Procedures	Challenges in developing operating rules, roles, procedures, and airspace management concepts of operation that enable safe and efficient operations and are compatible with urban environments, scalable operations, interoperability, and weather-tolerant operations.
CNSI & Control Facility Infrastructure	Challenges in developing and implementing in an economically viable manner sufficient, resilient, and secure communication, navigation, surveillance, and information (CNSI) infrastructure and control facility infrastructure, including spectrally-efficient communication links, navigation services including but not limited to Global Positioning System (GPS), high-resolution weather surveillance near the ground, ability to account for non-cooperative vehicles; and functionality in urban canyons.
UAM Port Design	Challenges with understanding of developing guidelines for optimal UAM port design and procedures to support the anticipated number of operations, including safe handling of contingency situations, minimizing noise impacts, and development of design guidelines and standards.

PILLAR 4: Airspace & Fleet Operations Management	
Safe Airspace Operations	Challenges in developing and implementing an airspace operations management system and corresponding regulations that enable safe, secure, sustained, close-proximity, multi-vehicle operations in constrained urban environments and that allow for interoperability of diverse missions and vehicle types, including in off-nominal situations.
Efficient Airspace Operations	Challenges in developing and implementing an airspace operations management system that provides user-preferred routing while allowing equitable, predictable, and on-demand airspace access for diverse missions and vehicle types, including legacy as well as emerging operations.
Scalable Airspace Operations	Challenges in developing and implementing a scalable airspace operations management system to enable higher volumes of air traffic than exist today.
Resilient Airspace Operations	Challenges in developing and implementing an airspace operations management system that allows for graceful degradation of UAM operations in reaction to unintended disruptions to UAM services such as loss of GPS, flight services, CNSI, and/or weather information; UAM port issues; and cyber security attacks.
Fleet Management	Challenges with scalable, safe, secure, affordable and efficient fleet operations management services that ensure safe navigation and efficiently handle vehicle operations throughout an operator's UAM network while managing contingencies, meeting mission demand, and minimizing the impact of vehicle fleet emissions (including noise and CO_2.) on the community.
Urban Weather Prediction	Challenges with weather forecasting with the spatial and temporal resolution needed to support safe UAM operations while maximizing vehicle and fleet productivity within their operating capabilities, areas of operation, and actual weather. These operations may require high-resolution weather prediction over short time frames for hyper-local conditions all the way to the ground.
PILLAR 5: Community Integration	
Public Acceptance	Challenges in achieving public acceptance of the UAM concept due to concerns over issues such as safety, non-user risk exposure, security, affordability, effects of increasing automation, noise, and privacy, as well as a lack of consensus on the public value proposition of UAM.
Supporting Infrastructure	Challenges in developing and implementing the supporting infrastructure required for integrating UAM operations into metropolitan areas, including UAM ports, energy infrastructure, and test ranges.
Operational Integration	Challenges in implementing multimodal transportation integration that addresses operations-related community impacts, including security of passengers and cargo, protection from malicious use of vehicles and denial of service attacks, and graceful degradation of the transportation ecosystem in reaction to disruption of UAM services.
Local Regulatory Environment & Liability	Challenges in enacting appropriate laws and regulations governing UAM operations (such as zoning, privacy, and noise regulations), striving for consistency across operating locations (such as states and municipalities); and developing a framework for the determination of liability associated with the development and operation of increasingly automated and autonomous systems.

In addition to the barriers that relate solely to a single pillar, seven crosscutting barriers each pertain to most, if not all, of the five pillars. The crosscutting barriers are discussed throughout this document. Since UAM is enabled by a system of interdependent systems, progress or obstacles in one barrier may reduce or heighten challenges associated with other barriers. For example, progress made in designing vehicles that produce less noise when operating within specific parameters needs to be coupled with the development of airspace design and procedures that enable these vehicles to operate within those parameters, and the resulting noise levels must be acceptable to the communities where they are flying. Consequently, the research to address challenges impacted by these crosscutting barriers should be a collaborative effort across subjects and disciplines, and it should include requirements development, trade-offs, and paths to implementation.

Table 2, below, describes the crosscutting barriers.

Table 2: Crosscutting Barriers

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

1.5 Urban Air Mobility Maturity Levels (UMLs)

To represent the progression to achieving scalable UAM, the UCAT defined six stages of UAM Maturity Level (UML) to portray a sequential projection of operations. The levels progress in both density and complexity, where density refers to the numbers of aircraft in a volume of airspace and complexity includes considerations such as procedures and operating conditions. The levels are depicted below in Figure 8 and described in the text that follows.

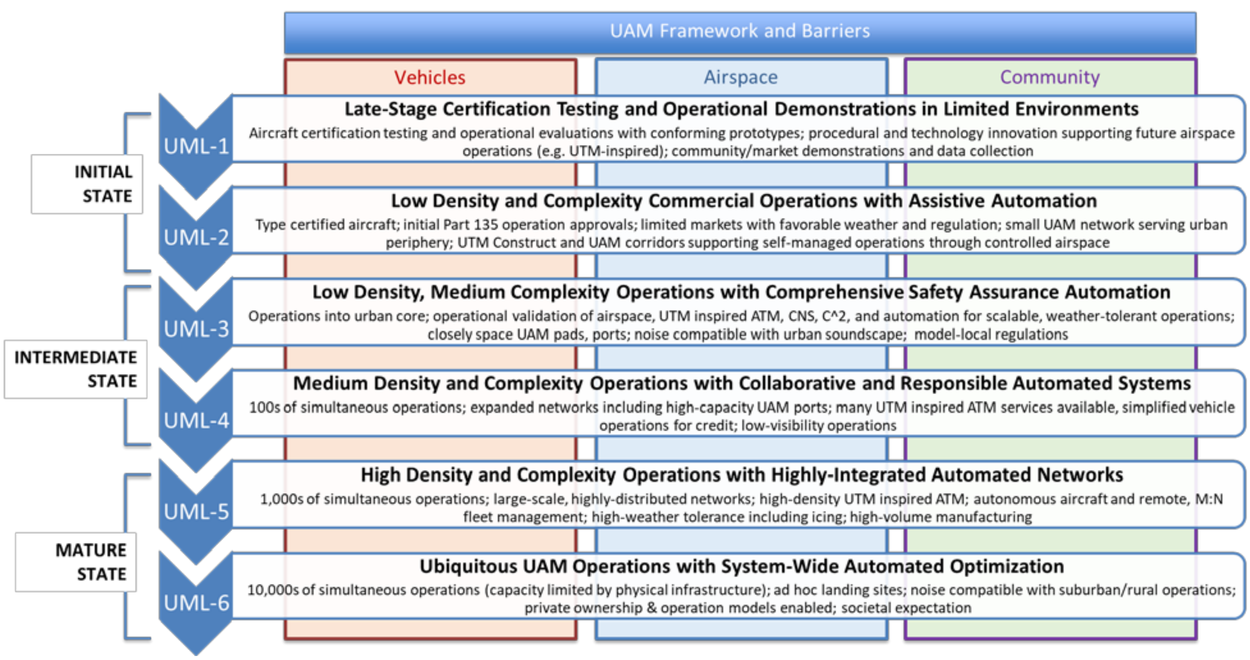

Figure 8: UAM Maturity Levels

Each maturity level depends on achievement of sufficient advances with respect to the vehicle, airspace, and community integration barriers discussed in Section 1.4.2. If progress in any of these three categories falls behind, the ability to achieve a particular UML will likely be impacted.

1.5.1 Initial State

UML-1 and UML-2, defined as the initial state, lay the groundwork for achieving UAM. UML-1 involves late-stage certification testing and operational demonstrations in limited environments, such as dedicated UAM test sites. At this level, conforming prototypes are used for aircraft certification testing and operational evaluations. Modifications to existing procedures and/or novel paradigms, including procedural and technology innovations derived from UTM, are used in operational demonstrations supporting future airspace operations. Community or market demonstrations and data collection are also conducted as part of UML-1. UML-2 involves low-density and low-complexity commercial operations using type-certified aircraft with assistive automation. Initially, requirements will be established for operational approval under Federal Aviation Regulations (FAR) Part 135, and operations will be conducted largely in suburban areas and urban peripheries in limited markets with favorable weather and regulation. For UML-2, it is envisioned that a UTM construct and UAM corridors are used to support self-managed operations through controlled airspace.

1.5.2 Intermediate State

UML-3 and UML-4, defined as the intermediate state, involve gradually expanding operations into more dense and complex environments. UML-3 involves low-density medium-complexity operations with comprehensive safety assurance automation. At this level, operations within the urban core will provide validation of airspace operations management techniques and automation for scalable, weather-tolerant operations. In UML-3, UAM pads and ports are closely spaced, requiring airspace procedures and an airspace operations management system able to handle aircraft taking off and landing close to one another. UAM operations will also have to be compatible with zoning and local regulations such as residential zoning requirements, noise restrictions, and fire codes. UML-4 expands on UML-3 by including medium-density and medium-complexity operations with collaborative and responsible automated systems sharing intent information and autonomously adjusting to avoid likely conflicts. UML-4 involves hundreds of simultaneous operations using expanded CNSI and operational infrastructure, including high-capacity UAM ports. A large number of available airspace operations management services, combined with supporting CSNI systems, will enable operations to be conducted in low-visibility environments. Operations demonstrating the necessary level of safety will enable service in dense urban areas, where demand is expected to be very high.

1.5.3 Mature State

UML-5 and UML-6, defined as the mature state, are the final two levels, culminating in a ubiquitous UAM system. UML-5 involves high-density and high-complexity operations in highly integrated automated networks. At this level, there are thousands of simultaneous operations, with large-scale, highly distributed CNSI and landing site networks. High-density airspace operations management systems are in place and all vehicles possess a high degree of weather tolerance, allowing operations to continue in a wider variety of adverse weather conditions. Autonomous fleet management techniques and procedures will be essential to handle the large numbers of UAM vehicles in operation at any time, and high-volume manufacturing will be necessary to meet this demand. UML-6 involves ubiquitous UAM operations with system-wide automated optimization. At this level, there are tens of thousands of simultaneous operations, but capacity may be limited by available physical infrastructure in certain metropolitan areas. Operations will expand geographically to connect rural, suburban, and urban areas. Operational procedures and an airspace operations management system will handle expedient landing sites, while ensuring compliance with suburban or rural noise restrictions requiring that vehicle noise blend into the background. Private ownership and operation models will become practical, helping to achieve widespread availability of UAM operations.

2 Overview of the Current System

Urban and suburban transportation today rely on various means of surface transportation to meet mobility needs. As urban populations continue to grow and urbanization expands to increasingly larger land areas, today's transportation system is experiencing growing congestion, inefficiency, air pollution, and loss of time for travelers. For example, the extra travel time penalty due to congestion in U.S. Metropolitan Statistical Areas increased from 24% in 2007 to 33% in 2018.[8] Metropolitan and regional jurisdictions rely on expansion of existing surface modes and encouragement of public transportation to meet increasing demand and counter growing congestion and delay, but public transportation accounts for more than 10% of trips to work in only 5 of the 20 U.S. cities with more than one million inhabitants.[9] Air transportation within urban areas is currently limited to costly private or chartered helicopter services, which are constrained to operate from relatively few locations due to ground and airspace requirements and local concerns over noise and safety.

2.1 Motivation for Change

Public dissatisfaction with congestion and delay, as well as continuing growth of urbanized areas in both density and urban sprawl, point to a need for change to maintain mobility within, to, and from metropolitan areas. Surface transportation solutions for relieving congestion and delay require valuable land as well as intensive capital investment, and they may well be environmentally unsustainable. Alternatives are needed to either change demand or add capacity more rapidly, at lower cost, and with less invasive infrastructure.[10] New technologies enabling more efficient use of airspace, as well as more energy-efficient aircraft configurations, may enable aviation to address these issues. Additionally, these technologies may lead to new aviation markets that can bring increased economic vitality as well as greater convenience for metropolitan residents and businesses.

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[8] U.S. Federal Highway Administration, "2018 Urban Congestion Trends," February 2019. https://ops.fhwa.dot.gov/publications/fhwahop19026/index.htm, retrieved April 22, 2020.

[9] Based on 2016 travel data for urbanized areas; the five cities are New York City (33% public transport), San Francisco (20%), Washington, DC (16%), Boston (14%), and Chicago (13%), https://en.wikipedia.org/wiki/Modal_share, retrieved April 22, 2020.

[10] Parker D. Vascik and John Hansman, "Systems-Level Analysis of On Demand Mobility for Aviation," MIT International Center for Air Transportation Report ICAT-2017-02, 2017.

2.2 Aspects of Change

Every day, millions of hours are wasted on the road. For example, the average San Francisco resident spent 230 hours commuting between work and home in 2017, which equates to half a million hours of productivity lost every day. In Los Angeles, residents spend seven whole working weeks each year commuting,[11] not counting the additional lost time due to allowance for unpredictability of delay.

The trends from 1982 on show that congestion is a persistently growing nationwide problem, and urban roadway congestion is expected to continue to worsen in the absence of new approaches. Nationally, in 2017 travel delays due to traffic congestion kept travelers in their cars for 8.8 billion extra hours, imposing a cost penalty of $166 billion, or $1,080 per commuter.[12]

Thus, meeting the mobility needs of future urban populations will require new enhancements or alternatives in order to:

(1) Change demand or add capacity
(2) Avoid congestion
(3) Improve access to urban mobility resources
(4) Reduce cost and enhance urban transportation speed and efficiency
(5) Reduce adverse environmental impacts

2.2.1 Demand and Capacity

Growth in size and population of urban areas increases the demand for transportation services and infrastructure. New road and railway construction already lags demand, and as population grows and infrastructure becomes denser, it is more difficult and expensive to add capacity. An analysis of historical data indicates that increased provision of roads or public transit is unlikely to relieve congestion; in a vicious circle, expanded transportation infrastructure invites more growth to areas with expanded service and changes in commuter behavior that result in renewed congestion.[13] Moreover, even major road construction projects that encounter relatively few obstacles take five to eight years from planning to opening for travel.[14]

2.2.2 Congestion

Bridges and tunnels add significant cost to road and rail projects, but they are necessary to surmount physical obstacles and maintain access and throughput on secondary roads. However, bridges and tunnels also represent chokepoints that impose significant delays at peak hours or when blocked or constrained by accidents or incidents. Highway interchanges, entry and exit points, accidents, drivers searching for parking spots or double parking, and malfunctioning traffic lights also create chokepoints

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[11] Lockheed Martin, "A-Vision for the Future of Urban Air Mobility," 2019, https://www.lockheedmartin.com/en-us/news/features/2019-features/a-vision-for-the-future-of-urban-air-mobility.html, retrieved April 22, 2020.
[12] Texas A&M Transportation Institute, "2019 Urban Mobility Report," 2019, https://static.tti.tamu.edu/tti.tamu.edu/documents/mobility-report-2019.pdf, retrieved April 22, 2020.
[13] Gilles Duranton and Matthew A. Turner, "The Fundamental Law of Road Congestion: Evidence from US Cities," *American Economic Review*, 101 (6): 2616-52, 2011.
[14] Minnesota Department of Transportation, "Road Construction- Steps Involved," 2019, https://www.dot.state.mn.us/roadconstruction/ittakestime/timeline.html, retrieved July 10, 2019.

that impede the flow of road traffic during peak travel periods. Circumnavigating congestion by use of secondary roads can also increase congestion, impose added delay, and exacerbate the cost and environmental impact of travel.

Demand peaking is another source of congestion. Although a growing number of people work from home or have flexible hours, transportation infrastructure capacity is still insufficient to meet demand during peak travel times. In Los Angeles in 2014, peak-hours delay accounted for almost a third of the average commuting trip, or nine eight-hour working days of lost time per year for each commuter.

2.2.3 Access to Urban Mobility Resources

Access to public transit is often limited in many areas of the suburbs and nonexistent as one moves even farther from the urban core. Subways and rail systems are expensive and challenging to add in metropolitan areas, costing as much as $900 million per mile for subways and more than $100 million per mile for light rail.[15] Construction of new or expanded surface transportation infrastructure is a lengthy process. Timelines depend on complexity of the project, funding, environmental concerns, land acquisition, planning and contracting processes, unexpected issues, and contractor performance. The 16-mile Purple Line light rail project in the Maryland suburbs of Washington, DC, scheduled for completion in 2022, was first proposed in 1994 as a Metrorail line, changed to a light rail concept in 2001, and opened for construction bids in 2014.[16] Additionally, public transit systems typically generate only enough revenue to cover operating expenses in areas with very high demand, and they must otherwise be publicly subsidized. Therefore, bringing rail lines to areas of lower demand is difficult to justify.

Bus lines can relieve peak-hour congestion by replacing automobile trips, but only to the extent allowed by road capacity. Both road and rail lines require investments to achieve peak-hour capacity that is used for only short periods each day. In addition, access to rail lines and commuter buses requires commuting to and parking at stations, where demand for parking often exceeds capacity during rush hours. Consequently, commuters arrive earlier and stay later, thereby expanding peak commuting hours. Rail breakdowns or missing scheduled commuter bus or rail services can leave commuters with limited options to get home. The alternative of "kiss and ride" concepts, in which a vehicle drops the traveler off at the station then returns home or travels to another destination, can double the amount of traffic and automobile mileage to access the public transit mode unless the drop-off or pick-up trip is combined with another trip for the driver.

2.2.4 Cost, Noise, and Urban Transportation Speed and Efficiency

Constrained by roads or rail lines, surface transportation is inherently inefficient. Highways, urban street grid patterns, and one-way streets add travel distance and time, particularly if the direct path between departure and destination points is diagonal to the grid pattern. Rail lines, which are totally reliant on

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[15] Alon Levy, "Why It's So Expensive to Build Urban Rail in the U.S.," CityLab, 2018, https://www.citylab.com/transportation/2018/01/why-its-so-expensive-to-build-urban-rail-in-the-us/551408/, retrieved April 22, 2020.

[16] "Timeline: Purple Line project," *Washington Post*, undated, https://www.washingtonpost.com/apps/g/page/local/timeline-purple-line-project/1698/, retrieved April 22, 2020.

expensive fixed infrastructure, are even more inflexible. The requirement for fixed infrastructure for both road and rail services means that they are inefficient during times of low demand, when potential capacity exceeds demand, as well as during peak hours, when congestion leads to lower-than-optimal speeds. Fixed infrastructure also constrains flexibility to accommodate changes in demand due to changing population and travel patterns. In addition, the surface transportation infrastructure necessarily channels and concentrates traffic, often creating areas of high vehicle noise.

Current non-surface alternatives are largely air taxi helicopter services, which are prohibitively expensive for most users for anything but very urgent or special circumstances. Additionally, due largely to safety and noise concerns, there are a limited number of landing sites in most metropolitan areas, limiting demand and revenue potential.

2.2.5 Environmental Impacts

Environmental impacts are a major aspect of the urban transportation picture. The use of fossil fuels in ground vehicles is currently a major source of poor air quality and greenhouse gas emissions in and around cities. Cars and trucks account for nearly one-fifth of all U.S. emissions. About 20% of that contribution comes from the extraction, production, and delivery of fuel, while the remainder comes out of a car’s tailpipe.[17] Nationwide, in 2017 congestion accounted for an annual average consumption of 21 gallons of fuel per commuter.[18]

Electric vehicles will likely help to reduce those impacts, but they will not solve road congestion problems or parking challenges, and they will still require significant amounts of energy, which must be generated from environmentally sustainable sources to achieve significant reductions of greenhouse gas emissions. Moreover, expanding or creating new roads or rail lines requires large amounts of energy for earth movement, the production and transportation of building materials, and the movement of construction vehicles and workers during construction. Other impacts of new or expanded infrastructure include increased noise levels, odors, and air and water pollution, as well as reduction of recreational space and disruption of neighborhoods.

2.3 Current Air Transportation System

UAM proposes to exploit the ability of aviation to provide efficient, environmentally sustainable, and flexible transportation. This OpsCon addresses vehicle operations by VTOL aircraft or, potentially, by short takeoff and landing (STOL) aircraft, in an urban setting. Focusing on the challenging urban environment also addresses most barriers and obstacles related to similar operations in other, less demanding settings. To help compare the envisioned passenger carrying UAM system to today’s capabilities for aviation operations in metropolitan areas, the following description of the current air system is organized according to the UAM System Framework.

[17] Union of Concerned Scientists, “Car Emissions and Global Warming,” July 18, 2014, https://www.ucsusa.org/clean-vehicles/car-emissions-and-global-warming, retrieved April 22, 2020.
[18] Texas A&M Transportation Institute, “2019 Urban Mobility Report.”

2.3.1 Vehicle Development & Production

2.3.1.1 Vehicle Design and Integration

Aircraft have gone through a myriad of designs in the last 100 years, and human-piloted airplanes and helicopters in use today have evolved to be safe and reliable in most weather conditions. Various innovative concepts for rotorcraft and V/STOL aircraft have been developed and tested by the military and NASA, and the general aviation experimental and homebuilt aircraft market has provided a platform for entrepreneurs to develop and test new concepts. Although some novel concepts, such as canard wings and coaxial counter-rotating propellers or rotors, have been adopted in a few limited-production aircraft, type-certified production airplane and rotorcraft designs have settled largely on today's standard configurations, and V/STOL aircraft such as tiltrotor and vectored thrust designs have yet to be certified for operations other than experimental.[19]

Most improvements have come in the form of aerodynamic design, propulsion systems, materials, control systems, avionics, cabin comfort, and safety. All-electric or hybrid-electric propulsion is key to enabling proposed design concepts for UAM vehicles. The fundamental challenge is the continuing development and integration of these technologies into functioning and producible aircraft to meet the performance and economic needs of the UAM market.

Helicopters are the only form of VTOL aircraft currently in use in urban environments. Other types of VTOL aircraft, such as tiltrotor and vectored thrust designs, are in use by the military, but none have proven cost-effective, quiet, and safe enough to be certified or integrated into civil use. Although STOL aircraft have been used in urban settings, the paucity of available real estate for runways make STOL landing sites less practical than VTOL for widespread air transportation within urban areas. The models of helicopters in use today have proven relatively safe and reliable in fair weather. New technologies such as Global Positioning System (GPS) navigation, moving maps, weather and traffic information, four-axis autopilots, and automatic engine controllers have enabled closer integration of air traffic management with flight management and operational procedures. However, there remain challenges in cost, noise, emissions, and weather-tolerant capabilities that limit the integration of VTOL concepts into the national transportation system.

Aircraft designs generally represent a tradeoff in the "good vs. fast vs. cheap" trade space. Since no product can achieve all three qualities to the highest standard, setting realistic product requirements is essential to optimizing the design and manufacturing processes. Additionally, today's design tools do not lend themselves to highly accurate, timely results that can be applied directly to manufacturing and test to accelerate development of new designs. Current tools are generally either low-fidelity with fast-time, coarse outputs, or high fidelity with slow, complex outputs, imposing a need for human interpretation and translation for use in design and manufacturing processes, although new technologies, such as additive manufacturing and integration of production consideration into design tools, show promise for transforming the current state.

[19] The Leonardo (formerly AgustaWestland) AW-609 civil tiltrotor is currently under development, but as of March 2020 it had not yet achieved certification.

2.3.1.2 *Airworthiness Standards & Certification*

Airworthiness standards and certification constitute an essential part of assuring safety and enabling commercial operation. Current processes and procedures will require adaptation to address unique aspects of UAM. The challenges for this barrier will be to identify and address the adaptations required to assure safe and affordable service within a time frame that will meet the needs of the UAM market.

Aircraft certification and manufacturing procedures are regulated by the FAA, as dictated by various parts of the FARs set forth in the Code of Federal Regulations, Title 14, Chapter 1, Subchapter C. Certification and manufacturing procedures for manned aircraft are regulated by Part 21. Certification standards for powered aircraft based on weight, maximum number of passengers, and type design expected for UAM missions are covered under Parts 23, 25, 27 and 29. Engines and propellers are certified under Parts 33 and 35, respectively. Continued airworthiness is regulated by Parts 26 and 43, and approval of after-market or modified aircraft components is regulated by Part 21. The testing, approval, and certification of aircraft and system components is approached from a deterministic, analytical standpoint, in which each part of a system and the contribution that it makes to the assemblage is tested and evaluated for acceptability against performance requirements. This approach allows components to be qualified independently of their application in particular systems, but it increases the challenges associated with certifying highly integrated or nondeterministic systems.

Once an applicant has tested and proved that an aircraft meets all the appropriate certification requirements, the FAA issues a type certificate to the applicant. The process for testing, validating, and certifying aircraft usually takes multiple years for transport class aircraft, and more complex or innovative designs may take longer than conventional designs and small non-transport aircraft. Part 21.17(c) allows applicants for transport category type certificates five years to complete the certification process and three years for non-transport aircraft. This does not include the time it takes to develop the aircraft or the technology it uses to the level of maturity needed to prepare for the formal test and certification process. The Boeing 787 program, for example, began in 2003 and achieved FAA type certification in 2011, eight years later.

Any major changes to an aircraft must submit to similar testing to receive a Supplemental Type Certificate from an FAA aircraft certification office under Part 21. The testing can take several months to years, depending on the magnitude of the modification. Minor changes or modifications to individual aircraft may be approved by an appropriate certified and qualified mechanic through a Field Approval under Part 43.

Continued airworthiness consists of scheduled inspection and maintenance intervals for critical systems such as engines, propellers, and airframe components. When defects or design flaws are discovered, manufacturers and the FAA will alert registered owners through service bulletins or airworthiness directives (ADs). Commercial operators must comply with manufacturers' mandatory service bulletins and ADs.

Aircraft certification regulations were developed for fixed and rotary wing aircraft designs. Although Part 21.17(b) allows for nontraditional aircraft such as powered-lift vehicles, certification regulations are tailored for conventional fixed-wing aircraft or rotorcraft designs and require nontraditional designs to draw from applicable sections, augmented with special requirements. Essentially, each new vehicle concept requires a special one-off certification program that consumes additional time, adds complexity, and requires negotiations with FAA. For example, the Leonardo AW609 civil tiltrotor, originally developed by Bell Helicopters, has spent almost two decades in the test and certification process. Much of this delay has been due to challenges associated with its novel design and the lack of associated certification standards. International harmonization of certificates and standards can present additional challenges when there are no comparable national standards or when additional testing and validation are required.

The introduction of electric or hybrid propulsion will introduce similar issues, as will advanced fly-by-wire capabilities incorporating increased control authority and complexity. Initial designs will likely rely on tailoring of existing standards and regulations. In anticipation of these needs, the industry has begun work to develop standards and enable formulation of certification requirements and procedures.

2.3.1.3 Vehicle Noise

Community noise is a significant factor that limits helicopter operations in urban areas today, and current regulations focus primarily on noise during takeoffs and landings, when aircraft operate close to people on the ground. Aircraft noise levels are regulated according to Part 36, and allowable rotorcraft noise during takeoff and landing is quite high, well in excess of 85dB, a level at which hearing damage can occur without protection.[20] Consequently, concerns still exist regarding aircraft noise levels, and some communities, such as New York and Los Angeles, impose local curfews and limits on numbers of operations. Since UAM flights will cruise at much lower altitudes than conventional air service, noise throughout the flight profile may become more of an issue.

NASA’s Revolutionary Vertical Lift Technology project is investigating factors, such as frequency, amplitude, and duration, that create the nuisance posed to human listeners by rotorcraft, and the aviation community continues to seek technologies, operational mitigations, and new electric VTOL (eVTOL) designs that promise to significantly reduce vehicle noise and annoyance to communities.

2.3.1.4 Weather-Tolerant Vehicles

UAM will require robust air vehicles capable of operating in urban environments, including microclimates. With the exception of zero-visibility landing and takeoff capabilities, adverse-weather capabilities are readily available for many small general aviation airplanes in the form of precision landing systems, anti-ice and de-icing systems, weather detection systems, and autopilot systems. The same cannot be said for helicopters: only high-end transport helicopters offer full icing protection systems, weather sensors, and four-axis autopilot systems. Fixed-wing airplanes are generally less sensitive than helicopters to strong winds and turbulence, and hence more stable as instrument flight rules (IFR) platforms.

[20] National Institute on Deafness and Other Communication Disorders, “Noise-Induced Hearing Loss,” National Institutes of Health, https://www.nidcd.nih.gov/health/noise-induced-hearing-loss, retrieved April 22, 2020.

Although commercial transport aircraft can be equipped and approved for near-zero-visibility landing, airports must be equipped with the proper equipment to enable these landings. Heliports and helipads, generally lacking sufficient radio navigation and ground lighting infrastructure, must rely on Global Navigation Satellite System (GNSS) approaches that require commercial helicopter operators to have at least ¼-mile visibility and a cloud ceiling of at least 200 ft above ground level (AGL), often with more restrictive requirements, depending on the published approach minimums. The absence of approach lighting systems often imposes even higher minimums.

Additionally, UAM aircraft operating in urban areas may encounter the threat of localized turbulence due to concentrations of large structures in the landing and takeoff environment. UAM aircraft will have to maintain a safe flight path in the face of this turbulence. Furthermore, as noted in a recent NASA-sponsored study, turbulence can be unpleasant and frightening for passengers.[21] The detection and prediction of microweather near urban structures is likely to require significant research, testing, and demonstration to enable full implementation of the UAM concept.

2.3.1.5 Cabin Acceptability

Today's helicopters and small airplanes are often offered with comfortable, plush cabins, albeit sometimes small and confined. Interior noise levels have typically ranged from 90 to 100 dB in terms of speech interference level,[22] with crewmembers and passengers advised to use hearing protection that still permits communication, such as headphones with intercom systems. Newer model helicopters are being equipped with improved noise-absorbing interiors and active vibration suppression, and electric propulsion holds the promise of eliminating engines and transmissions as major sources of noise and vibration. Wireless connectivity to communication and information networks is normally unavailable or limited when the aircraft is in flight – a condition which can be unacceptable to passengers in today's connected world. Additionally, there are currently no standards or requirements regarding access to UAM for people with disabilities; such access will be required for urban transportation operations to comply with the Americans with Disabilities Act.

2.3.1.6 Manufacturing & Supply Chain

Aircraft manufacturing and assembly processes have historically been human centric and labor intensive, primarily because of complex structures, exacting tolerances, and demanding material requirements. Consequently, consumer costs have been high and production rates relatively low. Since the 1990s, both general aviation and transport aircraft manufacturers have increasingly employed composite materials and more advanced manufacturing techniques. This trend has enabled design and production of innovative, lightweight, and aerodynamically efficient airframe designs, and it is transforming the supply chain as well as the manufacturers' processes. The industry also continues to more closely integrate production considerations into its design processes. Although these advances have led to reductions in manual labor needed in the manufacturing and assembly processes, skilled

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[21] Thomas Edwards and George Price, "eVTOL Passenger Acceptance," NASA report CR—2020–220460, January 2020.

[22] Kirby J. Harrison, "The Quiet Cabin: No Simple Solution," *Aviation International News*, December 2, 2013, https://www.ainonline.com/aviation-news/aviation-international-news/2013-12-02/quiet-cabin-no-simple-solution, retrieved April 22, 2020.

labor continues to play a significant role in the production process, leading to high costs and limited production rates, with consequent limitation of demand. Materials, processes, and the supply chain will continue to evolve as the demand for UAM leads to higher production rates and new performance requirements.

2.3.2 Individual Vehicle Management & Operations

2.3.2.1 Safe Urban Flight Management

Helicopters performing missions such as law enforcement, news reporting, and corporate transportation currently account for most aircraft operations within metropolitan areas. Other helicopter activity in metropolitan areas includes medical evacuation and transport, utility inspection, search and rescue, and training in urban areas. These operations are governed by the federal regulations covering aircraft, airmen, operations, and airspace access. Part 135 governs scheduled and non-scheduled (on-demand) commercial operations in airplanes and rotorcraft that are comparable to those envisioned for UAM operations.[23] Part 91 covers other manned commercial operations with small aircraft of less than 12,500 lb gross weight on missions such as traffic reporting, local sightseeing, and corporate transportation. For safe urban operations, the current system will have to provide suitable navigation and traffic management capabilities to assure safe flight within the urban landscape, as well as contingency management in the event of system or vehicle anomalies.

2.3.2.2 Increasingly Automated Vehicle Operations

Current vehicle operations reflect a continuing trend of increasing automation to replace, augment, or shift the role of humans. At one time, a typical flight crew comprised a pilot, copilot, navigator, flight engineer, and radio operator. Over time, the responsibilities have shifted and operations have become more efficient. Now, rather than an onboard navigator replotting a course around emerging weather, the flight crew coordinates with air traffic controllers and dispatchers in airline flight operations centers (FOCs) and airline operations center (AOCs) to plot the new course, deconflict it with other traffic, plan for adjusted arrival times, and adjust gate assignments at the arrival airport. In addition to changing the roles of humans, with consequent changes in training and certification requirements, these changes have come with new concepts, systems, and industries for ATM, navigation, flight planning and management, controls and displays, and communications. Today these changes are being accelerated by systems such as digital communications, electronic cockpit displays, electronic flight bags, and ADS-B, as well as the introduction of unmanned aircraft systems (UAS).

2.3.2.3 Certification & Operational Approval

Aviation is one of the most regulated industries in the world, and certification of workers, aircraft equipment, operations, and landing sites, as well as the supporting procedures, processes, and record keeping, all significantly affect cost, complexity, and resulting business models. The introduction of new

[23] Per FAA Order 8900.1 (Reference 3), Volume 2, Chapter 2, Section 2, with one exception, non-turbojet-powered airplanes with nine or fewer passenger seats and a maximum payload of 7,500 pounds or less, as well as any rotorcraft, are covered by Part 135. The exception is that intrastate, nonscheduled commercial operations may employ airplanes with up to 29 passenger seats and a maximum payload of 7,500 pounds.

vehicle configurations and capabilities, electric or hybrid propulsion, and extensive operations in an urban setting may well require new or revised standards and regulations.

Commercial operators transporting passengers on demand must obtain an FAA operating certificate under Part 135, and operators conducting scheduled operations must obtain an FAA operating certificate under Part 121, as well as compliance with operating specifications (OpsSpecs) that identify FAA-approved policies and procedures for managing all aspects of the operation, including training, flight operations and maintenance.

Depending on the type of operation and aircraft to be flown, to operate an aircraft in commercial service, pilots must obtain either a commercial or air transport pilot (ATP) certificate, with appropriate ratings, under Part 61. An instrument rating may be required for commercial pilots, while instrument competency is required to obtain an ATP. In addition, a type rating is required for each large transport aircraft type. Pilots must also meet recent experience requirements to ensure that they remain current and proficient in the types of aircraft and operations they conduct.

Mechanics must obtain an Airframe and Powerplant (A&P) certificate under Part 65 to work on or supervise maintenance and approve aircraft for return to service after maintenance. A&P mechanics with FAA Inspection Authorization (IA) may conduct and approve annual and progressive inspections airframes and engines in accordance with Parts 43.13 and 43.15. Dispatchers must be certified under Part 65 and meet experience and training requirements appropriate to the type of Part 135 air taxi, commuter, or Part 121 operations being conducted.

2.3.2.4 Ground Operations & Maintenance

Ground operations consist of personnel and equipment scheduling, passenger ticketing, security screening, flight planning, loading and unloading passengers and baggage, and aircraft support, including moving aircraft, fueling, cleaning, and preflight inspection. Like flight operations, ground operations must be carried out in accordance with the operator’s operational specifications and applicable regulations and guidance materials. Due to the magnitude and complexity of those requirements, ground operations must be well coordinated and recorded to ensure safety.

Aircraft maintenance, including overhaul, inspection, replacement, repair, and modifications, is an essential part of maintaining airworthiness of an aircraft. Scheduled maintenance comprises periodic inspections and component replacements based on operating time, cycles, or usage. For the aircraft’s airworthiness certificate to remain valid, repairs, preventative maintenance, and alterations must be performed in accordance with federal regulations. Over time, there has been a trend to reducing or eliminating scheduled maintenance through extended component service lives and application of accepted diagnostic and predictive techniques. Unscheduled maintenance must be carried out when aircraft experience malfunctioning equipment. The need to perform unscheduled maintenance may be identified by the flight crew, but today it is increasingly detected by diagnostic and health monitoring systems onboard the aircraft or systems on the ground that analyze data collected by sensors on the aircraft and transmitted to the ground by Aircraft Communications Addressing and Reporting System

(ACARS) digital datalink. As described in Section 2.3.1.2, maintenance requirements may also arise from service bulletins and ADs.

New vehicle configurations and capabilities, electric or hybrid propulsion, and extensive operations in an urban setting may well require new or revised processes. Introducing electric propulsion, for example, will require significant new or revised standards, infrastructure, procedures, and employee qualifications to address the need for recharging or swapping batteries between flights, as well as the capabilities and safety measures involved in dealing with potentially massive amounts of electricity.

2.3.3 Airspace System Design & Implementation

2.3.3.1 Airspace Design

U.S. national airspace is defined using A through G alphabetic classifications, with associated criteria, dimensions, and operational requirements. The locations, dimensions, and reporting points for these airspace areas are designated in Part 71. Procedures for handling airspace matters are defined in FAA Order JO 7400.2L. A change to airspace requirements or dimensions must go through the rulemaking process covered in Part 11, which generally requires justification for the change, publishing the proposed change(s) in the Federal Register, and a public comment period. Controlled airspace, requirements for associated equipage, and operating requirements support safe movement and separation of visual flight rules (VFR) flights and IFR operations. Pilots and aircraft that do not meet the minimum requirements for an airspace class are not authorized to enter it. Additionally, certain weather and atmospheric conditions must be met to operate VFR, enabling separation of VFR flights from IFR operations when weather conditions are safe for see-and-avoid separation.

Figure 9, below, illustrates the various classes of airspace. Airspace in the vicinity of metropolitan areas consists primarily of Classes B, C, D, and E controlled airspace, as well as Class G uncontrolled airspace. Airspace boundaries are defined geographically and in terms of altitude above mean seal level (MSL) or, where clearance above terrain is a factor, in height AGL.

Class A airspace extends from 18,000 ft MSL to 60,000 ft MSL, where generally only high-performance, pressurized, turbojet and turboprop aircraft operate. The potential closure rates between these high-performance aircraft make see-and-avoid separation unsafe, therefore all operations are required to be conducted under IFR and receiving air traffic separation services. Equipment and operating requirements are structured to support separation of such aircraft. Class A airspace does not have a direct bearing on UAM operations since it is above the altitudes at which UAM vehicles are expected to operate, but it does provide another example of how airspace requirements are used to ensure minimum aircraft and ATM capabilities support a certain level of performance.

	Class A	Class B	Class C	Class D	Class E	Class G
Entry Requirements	ATC clearance	ATC clearance	Prior two-way communications	Prior two-way communications	Prior two-way communications*	None
Minimum Pilot Qualifications	Instrument Rating	Private or Student certification—local restrictions apply.	Student certificate	Student certificate	Student certificate	Student certificate
Two-Way Radio Communications	Yes	Yes	Yes	Yes	Yes, under IFR flight plan*	None
Special VFR Allowed	No	Yes	Yes	Yes	Yes	N/A
VFR Visibility Minimum	N/A	3 statute miles	3 statute miles	3 statute miles	3 statute miles**	1 statute mile†
VFR Minimum Distance from Clouds	N/A	Clear of clouds	500' below, 1,000' above, 2,000' horizontal	500' below, 1,000' above, 2,000' horizontal	500' below,** 1,000' above, 2,000' horizontal	Clear of clouds†
VFR Aircraft Separation	N/A	All	IFR aircraft	Runway operations	None	None
Traffic Advisories	Yes	Yes	Yes	Workload permitting	Workload permitting	Workload permitting
Airport Application	N/A	• Radar • Instrument approaches • Weather • Control tower • High density	• Radar • Instrument approaches • Weather • Control tower	• Instrument approaches • Weather • Control tower	• Instrument approaches • Weather	• Control tower

*Exception: temporary tower or control tower present
**True only below 10,000 feet
†True only during day at or below 1,200 feet AGL (see 14 CFR part 91)

AGL—above ground level
FL—flight level
MSL—mean sea level

Figure 9: Airspace Classification and Operating Requirements

Class B airspace is established around the busiest airports and designed to contain IFR operations and associated published procedures serving those airports. To qualify for Class B airspace, the primary airport must have least five million passengers enplaned annually and a total airport operations count of 300,000, of which at least 240,000 are air carriers and air taxi. Class B airspace is individually tailored for local operations, but usually consists of a surface layer topped by two or more progressively larger diameter layers. Most of these areas resemble a modified upside-down wedding cake extending upward to 7,000 ft to 10,000 ft MSL. The only exception is Dallas/Ft. Worth, which extends up to 12,500 ft MSL.

To qualify for Class C airspace, the primary airport must have at least 75,000 annual instrument operations, 100,000 combined annual instrument operations at the primary and secondary airports, or at least 250,000 enplaned passengers annually at the primary airport. Class C airspace is individually tailored for local operations, but usually extends up to an elevation of 4,000 ft MSL above the primary airport, with a 5 NM radius core surface area and a 10 NM radius shelf area that extends no lower than 1,200 ft above the airport. Most major metropolitan areas have major airports within the area or in close proximity, and thus lie within and under Class B or C airspace.

Class D airspace exists at airports having an air traffic control tower, with lateral boundaries tailored to encompass local airport operations, usually within a radius of about 5 statute miles from the airport, with extensions to encompass IFR approach procedures, and it extends from the surface to 2,500 ft AGL. Airspace extensions are normally Class E airspace.

Class E airspace is controlled airspace that is not Class A, B, C, or D, and it begins at 700 ft or 1,200 ft AGL. Most metropolitan areas in which UAM operations are likely to occur will have overlying Class E airspace at 700 ft AGL and above. Class G airspace begins at the surface, and, with rare exceptions, extends up to 700 ft or 1,200 ft AGL, depending on the overlying Class E airspace.

In addition, various types of Special Use Airspace (SUA) exist in the U.S. This category includes prohibited or restricted airspace, Military Operations Areas (MOAs), and airspace with Temporary Flight Restrictions (TFRs). Special flight rules may also be defined for certain airspace areas under Part 93, some of which apply to metropolitan areas such as Washington, DC, and Los Angeles.

Although some UAM services will necessarily be introduced within this existing construct, achieving the vision of large-scale air service in metropolitan areas will require an airspace design that will enable federated traffic management incorporating third-party service providers.

2.3.3.2 Operational Rules, Roles, & Procedures

Operations within U.S. airspace are regulated by Part 91. Currently, all controlled airspace in the U.S. imposes minimum VFR visibility and cloud clearance requirements to separate IFR and VFR operations and enable see-and-avoid traffic separation. In general, VFR requires that pilots have 3 statute miles visibility and remain at least 500 ft below, 1,000 ft above, and 2,000 ft laterally from clouds when operating below 10,000 ft MSL. However, Class B airspace rules permit pilots to operate so long as they remain clear of clouds. When operating VFR above 10,000 ft MSL, pilots must have 5 statute miles visibility and remain at least 1,000 ft below and above and 1 statue mile laterally from clouds.

An ATC clearance is required to operate in Class B airspace, and all aircraft that are cleared receive separation services within the airspace. Requirements to operate within Class B airspace include the following:

- At least a pilot certificate or special training and logbook endorsement
- Approved navigation equipment

- Two-way radio to communicate with ATC
- A transponder with altitude reporting
- ADS-B Out equipment (as of January 1, 2020)

Additionally, all aircraft in Mode C veil airspace (i.e., within 30 NM of the center of a Class B area below 10,000 ft MSL) must be equipped with an altitude reporting transponder unless they obtain a waiver.

Pilots are required to establish and maintain two-way radio communications with ATC prior to operating in Class C airspace, and all aircraft that do so receive separation services within the airspace. Requirements to operate within Class C airspace include:

- Two-way radio to communicate with ATC
- A transponder with altitude reporting, unless a waiver is obtained from ATC
- ADS-B Out equipment (as of January 1, 2020)

Transponder and ADS-B requirements also apply to operations in controlled airspace under and above Class C airspace.

Class D airspace requires pilots to establish and maintain two-way radio communications with ATC prior to entering and operating within Class D airspace unless prior approval is obtained from the tower.

The only requirements for operating in Class E airspace are the previously mentioned visibility and cloud clearance requirements. Consequently, Class E extensions associated with Class D areas allow pilots to operate in those extensions without the need to communicate with the tower when within the required visibility and cloud clearances.

In class G airspace, airplane pilots must have 1 statute mile visibility and remain clear of clouds when operating VFR during the day; at night they must have 3 statute miles visibility and remain at least 500 ft below, 1,000 ft above, and 2,000 ft laterally from clouds. Rotorcraft pilots must have at least ½ statute mile visibility and remain clear of clouds during the day or when operating within ½ statute mile of an airport at night. Otherwise, nighttime rotorcraft operations require 1 statute mile visibility.

Airspace constraints also play a role in access to urban areas, considering that most large urban areas have or are near one or more major airports with Class B, C, D, or E airspace requirements and ATM operational restrictions. VFR flights meeting airspace access requirements may contact local air traffic controllers to gain access to that airspace when controller workload and traffic allow. Formal helicopter routes have been established in some metropolitan areas, improving access and traffic management while reducing controller involvement and workload. Although some UAM services will necessarily be introduced using or adapting existing procedures, large-scale UAM operations in metropolitan areas will require new capabilities and procedures for weather-tolerant operations serving a network of UAM ports and pads.

2.3.3.3 CNSI & Control Facility Infrastructure

CNSI infrastructure and services built up over the last 60 years play a critical role in today's aviation system and airspace access. The major changes required to the CNSI infrastructure to enable manned

UAM operations will be the capabilities required for operation to, from, and between UAM ports and pads with the reliability, precision, and accuracy needed for safe operation in the urban environment, including landings and takeoffs in confined urban areas under adverse weather conditions.

The elements of CNSI may be defined as follows:

- Communication is the capability to exchange information among aircraft, pilots, and air traffic controllers.
- Navigation is the capability of aircraft to follow a prescribed trajectory within prescribed accuracy limits.
- Surveillance is the capability of air traffic controllers to monitor the positions of aircraft relative to each other and relative to obstacles or restricted airspaces and the capability of pilots or aircraft to detect obstacles.
- Information is the capability to collect, process, and transmit data collected by the aircraft and its onboard systems to and from the aircraft for a variety of other reasons, including safety-related information, vehicle status, mission results, and passenger communications and entertainment.

Air-ground and ground-ground communications are currently supported by a communications network known as the FAA Telecommunications Infrastructure, used to maintain communications among ATM facilities as well as between aircraft and air traffic control facilities. Communication radio equipment and antennas are located at ATC sites as well as remote sites, known as remote communications outlets (RCOs), many of the which are collocated with radio navigation sites, to provide the coverage necessary to support IFR operations and Flight Services throughout the NAS.[24] All remote sites include robust shelters for electronics, automatic backup generators, and security fencing and monitoring.

Today GNSS, in the form of GPS in the U.S., is the primary form of radio navigation for Area Navigation (RNAV) and Required Navigation Performance (RNP) navigation for both general aviation and air transport operators. Other forms of GNSS include Galileo in the European Union, Russia's Global Navigation Satellite System (GLONASS), the Chinese BeiDou satellite navigation system, and other systems under development. Traditional radio navigation systems include Very High Frequency Omni-Directional Range (VOR) radio beacons, Distance Measuring Equipment (DME), Non-Directional Beacons (NDB), and Instrument Landing Systems (ILS) and associated marker beacons.

The National Airspace System (NAS) includes approximately 1,000 VOR and VOR/DME stations, over 1,300 NDBs, and more than 1,200 ILSs.[25] The airlines currently use ILS and DME for legacy aircraft and as a backup to GNSS and Inertial Navigation Systems (INS). VORs are used primarily by general aviation as a backup to GNSS, and thus are being drawn down to a minimum operational network of between 300 and 600 VORs. NDBs are also being drawn down, but many will remain operational in Alaska at airports without other approach procedures and in association with ILS outer markers. Since these are ground-

[24] The FAA is currently eliminating redundant or underutilized RCOs, with a target of reducing the number of RCOs in the NAS to 292, from over 1,200 RCOs in 2017, https://www.faa.gov/news/safety_briefing/2017/media/MarApr2017.pdf, retrieved April 22, 2020.

[25] 2019 Federal Radionavigation Plan, U.S. Departments of Defense, Homeland Security, and Transportation, 2019.

based, line-of-sight radio navigation systems, they are of limited use at low altitudes in urban areas, where tall obstructions block or reflect signals.

Air traffic surveillance systems consist of primary (skin paint) radar, Secondary Surveillance Radar, and ADS-B systems. NextGen relies heavily on ADS-B, and in January 2020 an ADS-B Out aircraft equipage mandate went into effect for all aircraft operating above 10,000 ft MSL and within Class A, B, and C airspace. The radar network is being networked and will be downsized slightly, but it will continue to serve as a backup to ADS-B. There are radar sites at every ARTCC and Terminal Radar Approach Control (TRACON), as well as approximately 800 ADS-B ground stations throughout the NAS. Like traditional radio navigation stations, these are ground-based, line-of-sight systems whose performance can be hampered in urban areas. Radar can be particularly problematic, since it reflects off buildings and confuses surveillance automation.

Information, the fourth element of CNSI, consists of infrastructure and services not included in the other three elements. This information includes aircraft- and passenger-generated information, such as vehicle health monitoring data as described in Section 2.3.2.4 and data for safety management systems, as well as vehicle-collected weather observations and information collected as a part of a mission, such as survey results after a natural disaster or from a pipeline inspection. In addition, connectivity with internet services is becoming increasingly important to maintaining passenger satisfaction.

2.3.3.4 UAM Port Design

There are currently no public UAM ports in the NAS, but private UAS-specific landing pads have been created by UAS and test site operators for their own use. Standards for UAM port design do not yet exist, so existing sites vary significantly in their design and surrounding environment. Depending on their size, large UAS may require more stringent operating site standards than small UAS that use sites resembling heliports or small airports.

Generally, only large airports serving scheduled commercial passenger air service are certified by the FAA under Part 139. These certification requirements are limited to safety, including crash, fire, and rescue mitigations. Heliports and smaller airports are not certified, but they may use Part 139 requirements as a reference. Airport design standards and recommended practices covered by Part 150 Advisory Circulars (ACs), which include guidance for noise compatibility planning. Heliport design standards are covered in AC 150/5390-2C. These standards follow, and are augmented by, International Civil Aviation Organization (ICAO) Standards Annex 14, Vol. II. These standards are voluntary unless seeking Part 139 certification. New standards and guidance will be required for UAM ports and pads to ensure safety and standardization.

Airport design and construction standards are covered by AC 150/5370-10H, which addresses runways, taxiways, ramps, turf areas, drainage, fencing, and lighting. These guidelines are intended for airports that support aircraft with gross weights in excess of 30,000 pounds, but they may serve as points of reference in combination with other guidance, such as civil engineering best practices and state and local construction standards, when designing and constructing small airports. Heliport design standards are covered in AC 150/5390-2C. These standards follow and are augmented by ICAO Standards Annex

14, Vol. II. Airports and heliports offering scheduled passenger service are required by Part 150 to conduct noise compatibility planning and update the plan and noise contour maps when airport operations change noise profiles around an airport. The noise plan and contour maps are used for land-use planning, zoning, and building codes, as well as noise mitigations.

FAA airport certification is covered by Part 139 and applies to airports that serve scheduled passenger-carrying operations by aircraft with more than 9 passenger seats or by unscheduled passenger-carrying operations with aircraft having more than 30 passenger seats. Part 139 includes safety requirements for airport operations and maintenance, markings and signage, fire and rescue resources, protection of safety areas and critical infrastructure, insurance, and coordination with control towers. Although operational in nature, some requirements may influence airport design and upgrades. Heliports and small airports normally do not fall into Part 139 applicability criteria, and are, therefore, not certified by the FAA. Like construction standards, these requirements generally serve as a reference point, and are adapted to reflect aircraft served, local building codes, insurance requirements, and other local and operational considerations.

2.3.4 Airspace & Fleet Operations Management

2.3.4.1 Safe Airspace Operations

UAM air traffic management must enable safe, sustained, resilient, close-proximity, multi-vehicle operations in constrained urban environments, including off-nominal situations and interoperability within the NAS. The core function of air traffic management is the safe separation of aircraft, which begins with trajectory planning. Traffic flow management tools are used by the ATCSCC in collaboration with ARTCCs to strategically assess and predict available capacity and to meter demand accordingly.

Tactical metering and separation services at ARTCCs and TRACONs, supported by automation to manage the flow of traffic into capacity-constrained airspace and airports, maintain the safe separation of flights throughout their trajectories. Takeoffs, landings, and surface operations at towered airports are managed by Airport Traffic Control Towers (ATCTs). At non-towered airports, pilots use standardized traffic pattern procedures and air-to-air voice communications to coordinate sequencing and separation. IFR and VFR flights that are not landing at or departing from an airport within Class B, C, or D airspace are normally routed around or above that airspace. Helicopters operating in urban areas outside (including below) Class B, C, or D airspace typically operate under VFR and are not in communication with any ATM facility. Urban helicopter operations within Class B, C, and D airspace are coordinated with the local ATM facility and often follow special procedures. With the exception of aircraft certified without electrical systems, all aircraft operating within 30 NM of most major airports within Class B airspace; above, below, or within Class C airspace; and above 10,000 ft MSL must be equipped with transponders to permit them to be seen by radar surveillance TCAS. TCAS, which is required equipment on fixed-wing commercial aircraft, provides a safety net in case of a breakdown in strategic and tactical separation services and procedures. Rotorcraft are not currently required to be equipped with TCAS. To improve surveillance information, ADS-B is now mandated as described in Section 2.3.3.2 to support enhanced avoidance of conflict and collision.

ATM is supported through a combination of strategic, tactical, and supporting safety systems and services to manage the flow and separation of traffic and the equitable utilization of key resources such as runways. These services are provided via a nationwide system of ATM facilities than include 21 ARTCCs, 4 Combined Control Facilities, 154 TRACONs, 264 FAA ATCTs, and 254 contract ATCTs.[26]

The FAA is currently implementing NextGen, an effort deploying advanced technologies to transform the efficiency and capacity of the NAS. These technologies include:

- ADS-B satellite technology to more accurately observe and track air traffic.
- Automation computer systems – notably the Standard Terminal Automation Replacement System and En Route Automation Modernization – for efficient use of airspace resources.
- Data Communications to replace certain voice communications with digital datalink.
- Decision support systems to help air traffic controllers direct traffic flow safely and efficiently. The systems comprise the TFM system to better balance airspace demand and capacity, Time Based Flow Management using time instead of distance to improve en route traffic flow, and the Terminal Flight Data Manager to improve terminal and surface traffic flow.
- Performance Based Navigation enabling aircraft to fly shorter and more-efficient routes to their destinations.

Additionally, UAM flights will operate close to the ground, near urban structures, and in airspace currently designated as uncontrolled (Class G). Therefore, new or modified regulations, such as minimum safe altitude requirements in 14 CFR 91.119, and possibly redesignation of airspace will be required to allow envisioned UAM operations. The UTM effort by FAA, NASA, and other federal agencies is currently exploring concepts, requirements, and procedures to enable UAS operations beyond visual line of sight at altitudes under 400 ft AGL.

2.3.4.2 Efficient Airspace Operations

Airspace efficiency has always been secondary to safety for obvious reasons. However, airspace efficiency has become increasingly important to the movement of people and goods as traffic demand has grown exponentially in the last 50 years. Airspace and ATM efficiency has improved with the implementation of more automation and decision support systems. However, operator and ATM trajectory planning is still not integrated in today's system. Consequently, sharing of operator preferences is cumbersome and slow, and operators often do not receive optimum trajectory profiles simply because traffic flow managers and air traffic controllers may not be privy to those preferences. Thus, ATM efficiency is generally based on what is most efficient for ATM operations first and operator-desired flight trajectories second.

Efforts to incorporate user preferences into day-to-day operations have culminated in a collection of Collaborative Decision Making (CDM) applications and procedures, managed by the FAA's ATCSCC in cooperation with industry and operational participants. Although this enhancement has resulted in

[26] Federal Aviation Administration, "Air Traffic by the Numbers," 2019, https://www.faa.gov/air_traffic/by_the_numbers/media/Air_Traffic_by_the_Numbers_2019.pdf, retrieved April 22, 2020.

greater accommodation of user preferences and more efficient trajectories, there is still much room for improvement through integration of CDM with TFM and operator flight management tools.

Public policy can limit efficiency when operations involve mixing aircraft with dissimilar speed profiles. Airspace and air traffic services are considered public resources, and therefore cannot be restricted by discriminatory policies. As long as aircraft and operators meet minimum capability and performance requirements, access to airspace and services is provided on a first-come, first-served basis. Exceptions are made in cases involving safety, security, and emergency services.

2.3.4.3 Scalable Airspace Operations

Although the current-human centric ATM system is safe, its capacity and capability for complex trajectory management is limited by human cognitive limitations and the lack of highly integrated and capable automation systems. The absence of precise four-dimensional (4D) aircraft trajectory management and lack of integration of ATM airspace, traffic management, and aircraft system functions contribute to this limitation. Consequently, the current airspace and ATM systems are not easily scalable. Controllers separate flights by observing their three-dimensional position on two dimensional displays and manually or verbally directing them to change heading or altitude when conflicts arise. Each controller manages a sector of airspace and is limited to a specified number of aircraft within that sector based on complexity of crossing traffic patterns. The only way to increase the capacity of sectors using this airspace management structure is to split them into smaller sectors, thereby increasing the number of controllers managing the same overall areas. This approach increases the number of aircraft that can be managed, but it also results in additional workload due to the need for more hand-offs as aircraft pass from one sector to another. Thus, the evolution of scalable UAM operations will depend largely on increasing automation and autonomy to overcome the limitations of human-centric systems.

2.3.4.4 Resilient Airspace Operations

Today's air traffic management (ATM) system is designed to ensure safe separation between aircraft to prevent collisions, to organize and expedite the flows of traffic, and to provide awareness and support to pilots about other aircraft and potential threats. This system relies on several layers of CNSI technology supporting four essential functions described in Section 2.3.3.3: communication, navigation, surveillance, and information.

If any one of these four critical functions becomes unavailable or impaired in some way, the system is designed to handle most contingencies through built-in system redundancy or through previously developed procedural actions that ATM operators and pilots are trained to follow. In the case of system redundancies, the operational primary system simply switches to the secondary or back-up system until the primary system is repaired or brought back on line. In some cases, this switchover may be seamless, whereas in others there could be a decrease in overall system performance. Unfortunately, not every aspect of the ATM system has built-in redundancy. For those aspects, either the airspace controller or the pilot in command typically implements predefined procedures. Since these procedures are designed with safety as an overriding concern, airspace efficiency and throughput can be severely impacted until the contingency is identified and appropriately mitigated.

Current UTM systems lack the maturity and resilience of the ATM system. Consequently, operational restrictions and operational procedures are in place to avoid the risk of failures in the system. These procedures include prior authorizations, operator monitoring, and contingency plans for each flight. UTM capabilities are expected to evolve to ensure and enhance resilience in step with the growth and evolution of UAS operations supporting UAM.

2.3.4.5 Fleet Management

Parts 135 and 121 require operators with large fleets to incorporate FOCs or AOCs into their operations to help manage flight scheduling, planning, and resources that contribute to operational coordination and safety, including maintenance scheduling. FOCs and AOCs have access to information sharing portals via the internet, as well as a complete picture of the company's schedule and flight operations, and they are therefore in a better position than flight crews to determine how best to prioritize flights and crews. They also coordinate with ATM traffic flow managers via telephone and web-based applications to modify flight plans when constraints arise. FOCs and AOCs communicate with airborne flight crews via commercial digital and voice VHF and satellite communication services. FAA and commercial flight information services are also available to flight crews operating appropriately equipped aircraft. Each of these airborne communication and information services uses frequency spectrum in the very high frequency (VHF), ultra high frequency (UHF), or super high frequency (SHF) bands. As the demand for airborne information and communication capabilities grow, so will the demand for additional frequency spectrum. UAS fleet management will likely add to that demand.

2.3.4.6 Urban Weather Prediction

Aviation weather forecasts are derived using a large network of National Weather Service and FAA weather sensors, combined with weather prediction models and experienced forecasters, and they play a significant role in flight safety and traffic flow planning. However, the current system is structured to provide current and forecast weather for large areas, augmented with terminal area forecasts (TAFs) at major airports. Small airports are equipped with automated equipment that reports current local weather conditions, but wide-area forecasts are used to predict conditions at these airports. TAFs and automated airport weather reports are currently the closest products resembling urban aviation weather reports, but they might not be granular enough to measure and predict microclimates that could affect UAM operations. Safe weather-tolerant UAM operations will require networks of suitable sensors and the development of local and microclimate prediction methods, including the effects of urban structures.

2.3.5 Community Integration

2.3.5.1 Public Acceptance

Society's perception of safety and noise often affects aviation operations even when established quantitative thresholds are met, and significant local, state, and federal resources are devoted to working with the public and the aviation community to address safety and noise concerns. Since UAM will introduce a new element into the urban ecosystem, it is certain to raise many public concerns, if not opposition. Hence, recognizing and addressing these concerns must be a vital part of the efforts involved in implementing and growing UAM.

Safety is the public's primary concern, particularly when accidents involve third parties on the ground who are not part of the operation. Consequently, the goal of aviation community efforts and aviation regulations and requirements is to avoid any damage to third parties when an accident does occur and ultimately to achieve a zero accident rate. Although that goal has yet to be achieved, the air transport community has come close, with 99.99999 percent of commercial flights being accident-free. The general aviation accident rate continues to be significantly higher than for commercial flights, but still achieves a 99.999 percent accident-free rate. However, statistics mean little to those affected by the small number of accidents that do occur, and public response can have significant impacts beyond fostering improvements in aircraft, operator, and ATM standards and procedures, since community pressure can cause runways and airports to be shut down or operations to be heavily restricted.

Noise is another significant community concern in the vicinity of airports. Noise limits have been applied to aircraft certification standards, airport design, and environmental impact studies, with operational limits and curfews imposed for many airports. Sensors are often used to provide quantitative measures and support enforcement of noise restrictions, and sensor design and placement play a key role in addressing perceived noise concerns. However, public pressure may impose additional restrictions based on qualitative perceptions when quantitative measures do not fully address their concerns. Safety concerns may also generate opposition to aviation despite empirical data that indicates risks are very low. Privacy, which has become an issue with UAS and will need to be considered for UAM, is generally not an issue with current manned aircraft operations due to the speeds and altitudes at which they fly.

Affordability is another factor that will affect public acceptance. With the exception of public safety and newsgathering, helicopter transportation – the current form of UAM – is seen largely as a service for the wealthy. As the cost of UAM service comes down, the market will become more inclusive, providing a valued service for a larger and more diverse slice of the public and thereby facilitating acceptance and approval of UAM operations.

2.3.5.2 Supporting Infrastructure

In addition to the CNSI and ATM infrastructure described in Sections 2.3.3 and 2.3.4, today's aviation system includes significant airport, administrative, and supporting commercial infrastructure. Airport runways, taxiways, ramps, terminal buildings, roads, and parking facilities represent significant investments in real estate and construction. These facilities, in turn, require significant on- and off-airport commercial services, such as food, lodging, and ground vehicles. The size of the work force supporting airport and commercial services encourages the construction of nearby residential areas, which also contributes to demand for commercial services. Consequently, urban and suburban development often follows the installation of busy hub airports, as has been the case with Dulles and Denver International airports. Although these types of infrastructure are often not considered part of the aviation system, they play a critical role in supporting air transportation and are significant contributors to local communities. In addition, as UAM operations continue to grow, they are likely to impose new and unique requirements to develop the regulatory environment, enforcement processes, and planning for this transformational concept.

2.3.5.3 Operational Integration

The air transportation system is a core element of the nation's commerce, and it supports national security through movement of troops and supplies when needed. Airports serve as connecting points to integrate air transportation with other modes for people, cargo, and mail. These forms of transportation include light rail, trucking, buses, taxicabs, hotel shuttles, general aviation, and personal automobiles.

Each of these transportation modes must be integrated into the airport ground infrastructure and operations management for the system to function properly and provide access to the air mode. These modes also serve as the backup in the event of a breakdown in an airport's operations or the entire air transportation system, such as that which occurred after the terrorist attacks on September 11, 2001. However, alternate modes are only a short-term mitigation, since an extended shutdown of the air transportation system would jeopardize the country's safety, security, economy, and well-being.

Along with the integration of these transportation modes into the airport ground infrastructure, the airport is also integrated into a locality's utility networks for electrical power, communications connectivity, water, and sewage.

2.3.5.4 Local Regulatory Environment & Liability

Federal Regulation

Aviation safety oversight and regulation of airspace operations are the sole jurisdiction of the FAA. Article VI, Section 2, of the United States Constitution and 49 U.S.C. § 40103(a)(1) give the U.S. government exclusive sovereignty over U.S. airspace. However, states and municipalities can restrict land use through zoning, and in some cases they can significantly influence low-altitude air operations based on safety, noise, and other negative impacts to the community, as long as they do not conflict with federal regulations. However, the limitations on boundaries between federal and local regulation are not always clear-cut. For example, in response to noise, privacy, and safety concerns, a number of state and local governments have implemented laws and ordinances imposing restrictions on UAS operations that exceed those established by Part 107, and legal challenges and case law have not yet had time to determine the validity or scope of such laws and ordinances. The continuing evolution of the regulatory and legal environment will largely set the pace for implementation and growth of UAM.

The FAA imposes Part 139 airport certification requirements on airports that seek to provide commercial air service. These requirements include topics such as airport operations and maintenance, markings and signage, firefighting and rescue resources, protection of safety areas and critical infrastructure, insurance, and coordination with control towers. Part 150 and associated advisory circulars specify requirements for design and construction of airport infrastructure, such as runways, taxiways, and ramp areas, sufficient to support the types of aircraft to be served, and they govern federal grants and passenger facility charges (ticket taxes). With few exceptions, municipalities receiving federal funding are obligated to maintain airports for 20 years. The Transportation Security Administration (TSA) also imposes security requirements on airports proprietors, including security fencing and access controls as well as passenger, baggage, and cargo screening.

The FAA also funds municipal airport projects that are deemed mutually beneficial to both federal and local interests, but the funding imposes certain obligations to operate and maintain the airport in a safe and serviceable condition, not grant exclusive rights, mitigate hazards to airspace, and make proper use of airport revenue.

Legal liability is another subject that will see evolving legal challenges and case law, particularly as increasing automation and autonomy complicate assignment of responsibility. Insurers may also play a role by imposing requirements or restrictions on insurance coverage.

State Regulation

States generally limit their involvement in aviation operations to owning and operating commercial service airports and reliever airports designated by the FAA to relieve congestion at commercial service airports and to provide improved general aviation access for the overall community. In some cases, these airports may be owned and operated by local governments with political and funding support from the state. States are often involved in local issues such as noise and safety concerns and related statewide zoning issues, and they work with the FAA and local municipalities in administering federal grants for airports. Guidelines pertaining to state regulation of heliport design is governed by the FAA as described in FAA Report DOT/FAA/ND-00/2 – State Regulations of Heliport Design. In the U.S. and its territories, the FAA assures that the landing area meets the general requirements for the safe and efficient use of airspace. These requirements include interfacing with current or planned aeronautical or other use of the subject airspace. State, regional, and local governments will be involved with licensing or permitting based on land use regulations and state laws.

Local Influence

In addition to operating public airports, local municipalities often influence aviation operations through land use planning and zoning relative to airports and heliports. Zoning issues normally involve community sensitivity to noise and concerns about safety and accessibility. Zoning affords local governments some control over where and when aviation operations may be conducted. Local governments also coordinate with state and federal governments on noise issues related to arrival and departure routes. Like states, local municipalities that accept federal funding for airports that they manage are obligated to avoid closing those airports.

2.3.6 Crosscutting Barriers

2.3.6.1 Safety

Safe operation is one of the most important barriers to UAM, as well as the foundation of the regulatory system and a major concern across all five pillars of the UAM System Framework and across all disciplines involved in aviation. Safety assurance is currently accomplished through a system of certification standards, performance requirements, operational approvals, infrastructure, and operating regulations and procedures. Although each facet of safety is regulated individually, they are interrelated and complement one another. The FAA and National Transportation Safety Board view safety as a system and monitor that system for gaps or weakness. This system is continually updated to assure continued safe operation as technology evolves and safety issues are identified. Community acceptance depends on safety, and public perception can place significant pressure on the FAA when the agency is viewed as not doing enough in terms of prevention.

2.3.6.2 Security

The goal of security is to ensure safe and continued operation of the system. Threats are not limited to hostile actions from groups or individuals; they may also arise from sources such as the environment, including electromagnetic phenomena such as sunspots, or even system malfunctions or material failure. Current security concerns tend to focus on the unauthorized operation of unmanned aircraft or the threats posed by malevolent passenger activities, but, as with safety, security affects each pillar, since every aspect of aviation operations must be secure from malevolent or unintentional actions and threats.

Security of the NAS includes both cyber and physical aspects. As information sharing networks and ATM automation continue to play a larger role in managing NAS operations and CNSI technologies gradually evolve from analog to digital, cyber security has become increasingly critical to ensure these guidance and information systems are secure from both intentional and unintentional interference and misuse. Since cyber security is generally managed within each system through information technology tools and procedures, many CNSI systems do not include integrated encryption or protocols, and pilot and ATM procedures are relied on to detect problems and coordinate operational mitigations. Cyber security will continue to play a larger role in upgrades and additions to information sharing and automation systems, particularly as increasing automation introduces opportunities for malevolent actions and reduces the opportunity for human involvement to detect potential security lapses.

Airport security falls under the jurisdiction of the TSA, and passenger and baggage screening is conducted by the TSA. The infrastructure for these security features includes personnel and baggage screening devices using materials detection and various see-through technologies, as well as systems of secure doors and alarms to secure airside areas of the airport. The TSA also oversees cargo screening for cargo operations, but the actual screening is normally conducted by off-site third parties with a tight chain of custody to the aircraft. Electronic access control systems and photo identification are used to manage airport and airline staff access to secure areas. This infrastructure requires a large contingent of security personnel to control and manage it, and together they are a critical component of commercial airport operations. General aviation airports use some combination of similar systems on a much smaller scale and may rely more heavily on security and operational personnel to screen air taxi passengers and more basic electronic systems controlling access to airfields for aircraft owners, pilots, and staff. The TSA also supports physical security in flight by deploying armed federal law enforcement officers, known as air marshals, on passenger flights worldwide. Flight crews and security personnel are subject to a background check upon employment by an operator.

ATM, CNSI, and weather reporting facilities are also protected to assure physical and cyber security. Physical security generally consists of fencing, electronic monitoring, and controlled gate access. Cyber security is supported through secure or isolated communication networks with controlled user access.

2.3.6.3 Affordability

Affordability to the ultimate user – the passenger – depends on (1) the cost of providing the service, (2) recouping the investment costs through profits or subsidies, as is often the case with urban public transportation, (3) competition among the service providers, and (4) the willingness of customers to use the service in the belief that it provides benefit commensurate with the cost of the service. The fundamental elements of cost – aircraft equipment and operations, recovery of development and certification costs, infrastructure costs, regulatory compliance, and personnel – apply throughout the industry, and each of the pillars affects one or more of these cost elements.

With respect to UAM, today's costs are reflected in airline ticket prices that are generally much higher for short trips on a per-mile basis, and what helicopter service exists is far more expensive than other modes. In the case of general aviation, regulatory compliance and aircraft prices, which include an allowance for legal liability and litigation, drive costs beyond the reach of most of the middle class, limiting the size of the market and forcing fixed costs to be spread across a limited market, which further reduces affordability.

Regulation is one means of maintaining competition among vendors and service providers. The Department of Justice approves airline mergers and transfers of landing slots at airports to ensure that no one company obtains a monopoly. Additionally, the Federal Trade Commission's Bureau of Consumer Protection works to ensure that consumers are protected from unfair, deceptive, or fraudulent business practices. The availability of alternative travel modes or substitutes for travel, such as telecommunication, also tends to limit ticket prices.

2.3.6.4 Noise

Noise from aircraft, particularly rotorcraft, is one of the primary community integration issues for operations near population centers. These centers have expanded and become denser, leading to zoning and regulatory mitigations such as requirements to phase out noisy turbojet engines, imposition of airport curfews and peak noise limits at airports, and subsidization of noise-proofing of buildings in noise-sensitive areas. Improvements in navigation, enabled by RNAV and RNP, have been leveraged to move arrival and departure routes away from noise-sensitive areas. However, noise continues to be a point of concern in many metropolitan areas, posing obstacles to operational efficiency, flexibility, capacity, and access. Addressing noise issues spans the pillars of solutions, including aircraft design and operational considerations to support community integration such as noise abatement procedures, airspace design to route traffic so as to avoid densely populated areas or noise-sensitive locations such as schools and hospitals, precise navigation and control to route individual flights to minimize total noise footprint on the ground, and restricting or minimizing traffic during particular time periods.

2.3.6.5 Autonomy

Autonomy in current aircraft and ATM systems is limited largely to automated functions or applications within pillars 2, 3, and 4. Aircraft automation in the form of autopilots is standard in transport category aircraft and increasingly common in general aviation aircraft. However, auto-land autopilot systems are generally limited to larger transport category aircraft and can be used only by crews qualified to conduct Category III operations at runways equipped with Category III ILS and associated approach-light systems.

The industry is now offering autopilot coupled TCAS, and rotorcraft producers are demonstrating optionally piloted helicopters. Some commercial aircraft use automation in the flight and engine control systems to override pilot inputs that are interpreted to be unsafe, and automation is increasingly being applied to piloting functions. But such automation has been shown to have limitations and is not foolproof, as evidenced in two recent 737 MAX accidents.

The ATM system includes automation to manage flight and surveillance data; provide conflict, altitude, and terrain alerts; and provide controller cues such as hand-off of a flight from one controller or sector to another. Automation is also used in TFM to help balance demand and capacity. For example, automation predicts sector demand based on flight plans, compares it to sector capacity and other constraints, and identifies sectors that are blocked by hazardous weather or at risk of traffic saturation. Automation is also used to meter demand by identifying which flights should be delayed or rerouted.

2.3.6.6 UAM Ports

Today's aircraft are typically designed for existing infrastructure, and vice versa, and UAM ports, vehicles, and ATM will evolve together as UAM gains acceptance and markets. Vehicle and UAM port designs (pillars 1, 2, 3, and 4) will be affected by the requirements for landing, ground handling, passenger boarding and debarkation, and maintenance. Approach and departure paths, CNSI requirements, and weather observation and sensing (pillars 2, 3, and 4) will also be important elements of UAM port designs. Community acceptance (pillar 5) will be a vital element of UAM port design and siting.

The current NAS includes significant infrastructure that has been developed, approved, and implemented over decades. Public-use airports are mostly owned and operated by municipalities and funded through local, state, and federal taxes; facility rental or lease fees; and various user fees. Federal taxes are levied on fuel, airline tickets, international flights, airline mileage awards, and cargo or mail, all of which go into the Airport and Airway Trust Fund and are then distributed to airports through federal grants.

Airports include airside infrastructure such as runways, taxiways, aprons, gates, and lighting, as well as landside infrastructure such as terminal buildings with security, baggage handling, shops, parking lots, and feeder roads. Airports use significant energy resources such as electric power for approach, runway, and taxiway lighting, as wells as terminal and parking area systems. Aircraft and ground vehicles consume significant fossil fuel resources that require storage, transport, and infrastructure. Airport security requires infrastructure in the form of personal and baggage screening systems, and airports are supported by on-site and surrounding infrastructure such as hotels, food, and shopping to serve consumers and airport staff.

The availability of urban and metropolitan landing sites is subject to state and local government laws and ordinances that govern heliport and helipad operations and construction, as well restrictions enacted to address noise and safety concerns. For example, rotorcraft operations in New York City have been restricted to the perimeters of the city since the late 1970s, after a New York Airways Sikorsky S-61 helicopter suffered a catastrophic failure and rotor strike after landing on the roof of the Pan Am building, killing four people waiting to board and one person on the street, and injuring eight others with fragments of a rotor blade.[27] A special permit must be obtained from the city zoning and planning commission in order to install and operate a heliport or helipad in New York City, and such permits are considered only for waterfront locations to avoid flights over land. Interestingly, between 1974 and 2014, Los Angeles law required developers to include rooftop helipads when building skyscrapers. The law was intended to enable rescue by helicopters, such as the rescue of five people in 1988 from a fire in the First International Bank building in Los Angeles. [28] Other rescue uses of helipads include more than 1,000 people rescued by military helicopters during the 1980 fire at the MGM Grand in Las Vegas.[29] Because of current limitations on metropolitan operations, there has not been an incentive to develop additional ground or rooftop landing sites beyond those needed to serve current operations. The availability and suitability of ground and rooftop real estate also limit viable landing sites in urban areas, as does the cost and competition for use of land in desirable locations.

2.3.6.7 Regulations/Certification

Design and qualification of air vehicles and equipment (pillars 1 and 2), design and operation of the NAS (pillars 3 and 4), and integration into the community (pillar 5) are guided by the FARs and a corresponding set of policies, procedures, and documents intended to assure the safety of the aviation system. This regulatory system poses major barriers to the introduction of new concepts, since these concepts must either conform to the terms of the requirements, which flow largely from experience or analysis of data for the current system, or they must demonstrate equivalent safety. The regulatory barrier is especially high for concepts which have no operational experience or data to serve as the basis for qualification, and which require new regulations or a change to existing regulations.

New concepts are often introduced with severe restrictions, with the intent to relax these restrictions as the concepts build a safety record and supporting data and analyses. Extended Operations[30] (ETOPS), which enabled operations of two-engine airliners over water, is an example of this approach: operation began on routes with 90-minutes over water in 1984 and grew incrementally to 180 minutes in 2007 and to the current limit of 330 minutes, approved for specific operators and routes.

Introduction of commercial UAS into the NAS illustrates evolution through successive regulatory mechanisms. Regulation began in 2013 with the issuance of Certificates of Authorization, issued on a case-by-case basis for specific operations sponsored by public entities, leading to Part 107 enabling operation of UAS weighing less than 55 lb and subsequent granting of waivers for operations on a case-

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[27] Robert D. McFadden, "5 Killed As Copter on Pan Am Building Throws Rotor Blade," *New York Times*, May 17, 1977, https://www.nytimes.com/1977/05/17/archives/5-killed-as-copter-on-pan-am-building-throws-rotor-blade-one-victim.html, retrieved March 31, 2020.

[28] "Interstate Bank Building Fire," *Technical Report Series*, United States Fire Administration, https://www.webcitation.org/query?url=http%3A%2F%2Fwww.lafire.com%2Ffamous_fires%2F880504_1stInterstateFire%2FFEMA-TecReport%2FFEMA-report.htm&date=2010-07-13, retrieved March 31, 2020.

[29] "Official findings of fire at the MGM Grand Hotel in Las Vegas, Nevada on November 21, 1980," Clark County Fire Department, undated, http://fire.co.clark.nv.us/(S(gtgop1ers1xz2gkadvhp1w1u))/Files/pdfs/MGM_FIRE.pdf, retrieved March 31, 2020.

[30] Originally called Extended Range Operation with Two-Engine Airplanes.

by-case basis. The FAA is also extending regulation of recreational drone operation through AC 91-57B and continues work to develop the basis for future regulation of UAS operations in the NAS.

While the introduction of UAM is expected to follow a similar process, with more stringent safety requirements commensurate with the greater magnitude of potential risks, UAM should benefit from the flexibility afforded by the FAA's recently adopted approach of performance-based regulation specifying "what" rather than "how.".

3 Overview of Future UAM Operations

The convergence of new technologies and business models will accelerate the development and implementation of UAM concepts. Technology advances in batteries, fuel cells, navigation, data links, sensors, computing power, network communications, data services, and autonomy will give rise to cost-effective, quiet, and capable air vehicles. These technologies will enable transformational advances in airspace and traffic management as well as aircraft, revolutionizing mobility in urban areas by enabling safe, efficient, convenient, affordable, and accessible public services and air transportation throughout and between metropolitan areas.

3.1 The UAM Vision

3.1.1 UAM Vision Attributes

The ultimate goal of UAM is to provide urban areas with levels of services and benefits not possible with today's urban transportation at prices competitive with surface modes. Free of ground constraints, the future system could enable rapid transit of people, goods, and information. Passengers will be able to hail and access convenient and timely local air transportation to get where they need to go. Packages will be rushed to their customers affordably and reliably. Public and private information gathering services will operate more efficiently by minimizing the time and resources needed for collection and by locating observation means when and where needed.

Figure 10 illustrates conceptual air vehicles performing three reference missions in the vision for the mature state.

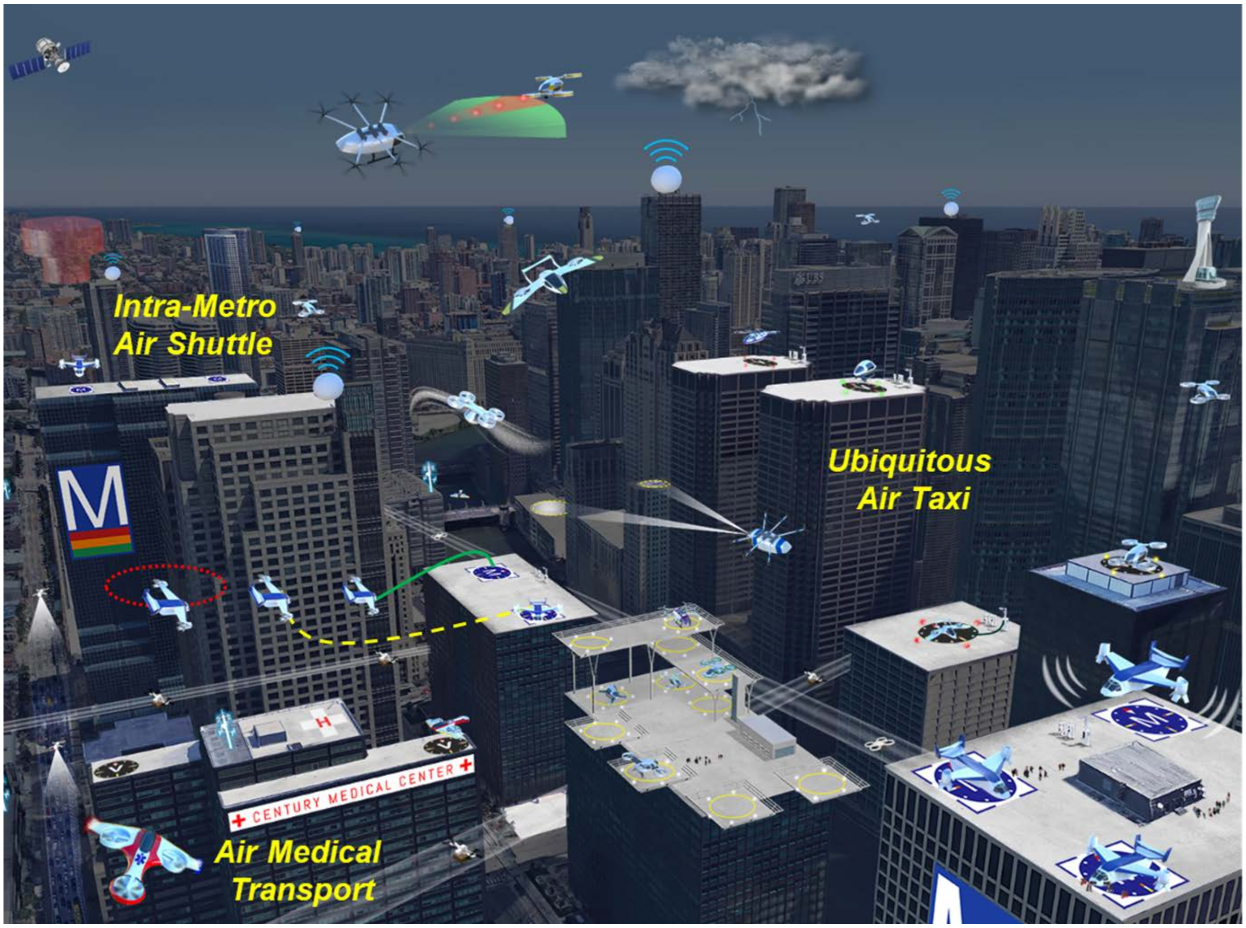

Figure 10: Passenger-Carrying UAM in the Urban Environment

Benefits of this vision include the following:

Lives are saved as medical services are provided with greater speed through rapid, on-demand delivery of medical supplies and weather-tolerant medevac services. Enhanced sensor technology and advanced autonomy enable low-visibility operations at expedient landing sites, shorter response times, and increased access to trauma care for time-critical cases.

Productivity and quality of life are improved as people in need of rapid transit, or who simply want to reduce travel time, are able to move quickly throughout urban areas or commute into, out of, and around cities and surrounding metropolitan areas.

Product costs are reduced as cargo is rapidly transported, in many cases autonomously, to where it is needed, with fewer transfers and traffic-related delays.

Transportation becomes easier and more cost effective. A variety of UAM port and UAM pad designs enable operations at diverse locations, including the tops of buildings, atop parking garages, at airports, near ground transportation access points, at shopping centers, and near neighborhoods or homes. This flexibility enables UAM ports and stand-alone UAM pads to be distributed throughout cities and surrounding metropolitan areas for convenient access to UAM services and connectivity to other modes of transportation, such as regional and long-distance air service and various forms of ground transportation.

Freedom of movement and mobility are increased as UAM increases transportation options and transcends limitations of surface modes. On-demand customers electronically summon fully autonomous, multi-passenger air vehicles to specified locations for pick-up and transport of passengers or cargo from one place to another. Regularly scheduled intra-metro air transports, carrying multiple passengers, operate similarly to buses or light rail and subway systems, shuttling riders between designated stops throughout cities and to and from key commuter service points in the outskirts. The difference is that the air mode, by virtue of not requiring fixed rail or road routes, has inherent flexibility to adjust for daily changes in travel patterns and longer-term population shifts with lower barriers or required investments.

Trip planning is simplified by ride hailing and reservation software applications and network communications available on electronic devices such as smartphones. These applications identify the nearest UAM port or stand-alone UAM pad, provide the distance and estimated time for customers to travel there by foot or ground transportation, and allow them to schedule an air taxi for transport from the nearest UAM port or UAM pad to the one nearest to their desired destination in a fraction of the time possible with ground transportation.

3.1.2 UAM Evolution

Although UAM represents a revolution in urban transportation, it will evolve over time, and with the scope of challenges it will face, the timeline for its maturation is uncertain in terms of specific years. For this reason, the following high-level description of UAM evolution is based on three maturity states in a progression of capabilities needed to realize the UAM vision.

3.1.2.1 Initial State Overview

Innovative UAM vehicle designs are introduced and certified in the initial state. Vehicle designs are expected to start as human-piloted vehicles with supporting automation technologies, relying on existing heliports in parallel with efforts to design and install new UAM ports and revise local regulations to permit additional urban landing sites. Initial UAM operations will leverage and expand routes and procedures currently used by helicopters, while UAM traffic management capabilities will be in the development stage. Enhanced CNSI systems and UAM system integration will also be under development, and new business cases will be tested and validated by early operations.

Attributes of the initial state include the following:

- Rapid technological advances across all pillars, with emphasis on vehicle and ATM development, testing, and validation
- Adaptation of current airspace structure, ATM services, and procedures, with limited system and community impacts

- Emphasis on safety and related technologies, processes, and regulations
- Tightly controlled applications as technology, regulations, and business cases are developed
- Extremely localized and very low volumes of traffic in early-adopter areas

3.1.2.2 Intermediate State Overview

The intermediate state focuses on advances in both vehicle and ATM automation, increasing vehicle payloads to support larger intra-metro air vehicles, expanding UAM infrastructure and landing sites, and introduction of enhanced and integrated CNSI and ATM capabilities to support greater traffic volumes. Autonomy will focus on developing and certifying semi-autonomous vehicle systems to increase safety and capacity, reduce direct human involvement, and enable interoperability with other transportation and communications modes.[31]

The intermediate state includes the following attributes:

- Continued rapid technological advances across all pillars, with expanded emphasis on streamlined manufacturing and production processes, vehicle and ATM autonomy, and enhanced CNSI infrastructure and capabilities to enable UAM operations in reduced visibility conditions
- Certification of semi-autonomous subsystems for vehicles and ATM, maturation of UAM airspace designs and procedures, and continued advances in community integration
- Expansion of applications and services as both technologies and business cases are proven, markets expand, community acceptance increases, and regulatory and liability standards are codified

3.1.2.3 Mature State Overview

The mature state features ubiquitous UAM operations enabled by a fully integrated UAM system with highly autonomous vehicle, ATM, and information acquisition and management systems; large networks of UAM ports and UAM pads; and high-precision, weather-tolerant CNSI capabilities and infrastructure. In this state, ATM, UAM port, and vehicle autonomy, integrated with advanced CNSI capabilities and infrastructure, support both semi- and fully autonomous operations, including flights through urban canyons. Noise compatibility planning and public acceptance lead to increasing UAM services in suburban and rural areas, as well as the expansion of services and business models throughout entire metropolitan areas.

The mature state is characterized by:

- Technological and operational maturity across all pillars, with ubiquitous UAM operations across most services
- Mature vehicle designs, significant demand, and high-volume production capabilities that enable affordable services
- Extremely safe and reliable UAM systems and services
- Advanced CNSI capabilities supporting weather-tolerant operations in confined urban areas

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[31] For purposes of this document, semi-autonomous is defined as performing automated functions without direct human involvement as part of a larger system with human oversight.

- Integrated ATM, vehicle, and UAM port applications and services, enabling high-volume, scalable, and resilient operations and integration of manned and unmanned vehicles
- Stable and widespread implementation and acceptance of UAM operations enabled by safe, efficient, and readily available services, mature technologies, high levels of community integration, and well-established business cases
- Ubiquitous UAM urban air transport providing both private and commercial flights as significant participants in an integrated multimodal transportation, distribution, and communications network

3.2 Evolution of Reference Missions

To illustrate the evolving capabilities in each phase of evolutionary UAM development, Sections 3.2.1 to 3.2.3 describe specific reference missions for each of the three states listed below and defined in Section 1.5, Urban Air Mobility Maturity Levels.

- Initial State (UML 1 /2): Human Piloted Air Medical Transport
- Intermediate State (UML 3 /4): Intra-Metro Air Shuttle
- Mature State (UML 5 / 6): Ubiquitous Air Taxi

Figure 11 illustrates the evolution of capabilities through the initial, intermediate, and mature states, linked to the three reference missions.

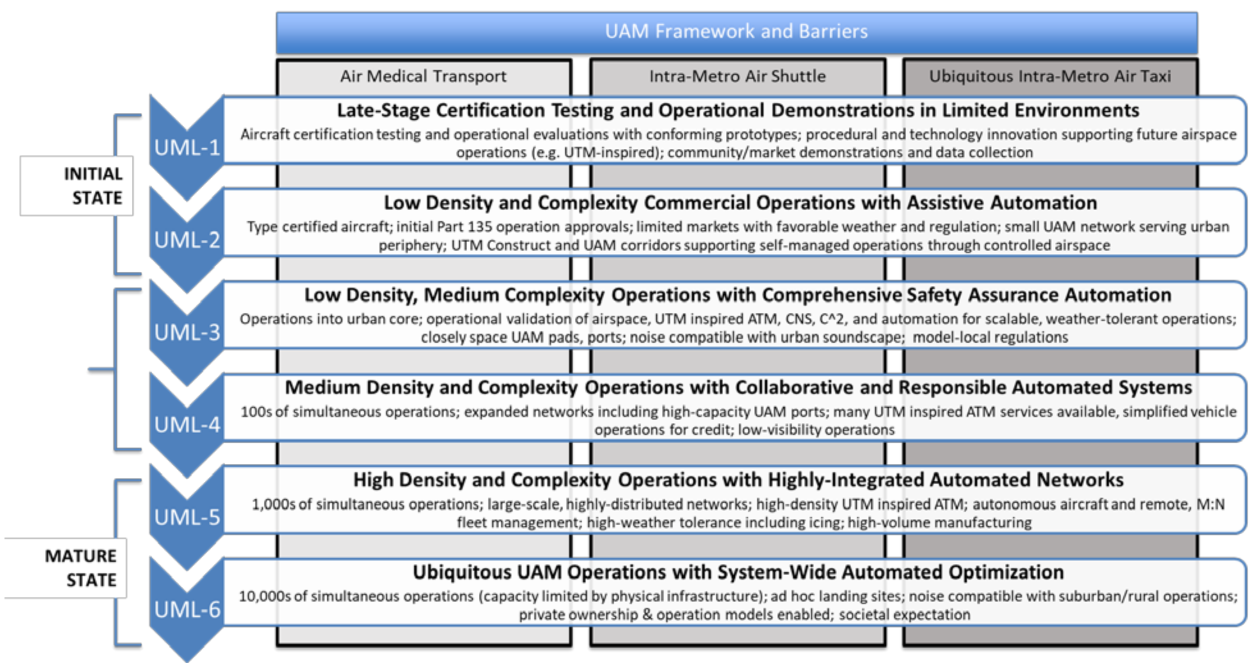

Figure 11: Evolution of UAM Mission Capabilities

Figure 12 depicts mature state vision vehicle concepts for the three missions.

Figure 12: UAM Mature State Vision Vehicle Concepts

3.2.1 Initial State: Human-Piloted Air Medical Transport

Table 3 summarizes the characteristics of the Human Piloted Air Medical Transport initial state mission, an extension of current medevac operations employing near-term UAM capabilities.

Table 3: Human Piloted Air Medical Transport Initial State Mission Summary

Characteristic	Characteristic Details
Vehicle Type	Special purpose VTOL aircraft designed for low noise, derived from existing configurations (helicopter, tiltrotor, etc.) or near-term developments (e.g., quadrotor)
Number of Passengers	3 (2 EMTs + 1 patient) to 9 – 9 would allow multiple patients and/or family members to ride together – 9 is break point in Part 135 regulations for single pilot operations
Takeoff and Landing Locations	Will use both dedicated takeoff and landing areas (e.g., hospital helipad) and expedient locations (e.g., beside an interstate highway) ~10 designated medical center takeoff and landing areas per metropolitan area
Scheduling	Air ambulance flights (unscheduled) Other medical services (e.g., patient transport) may be scheduled in advance
Locations of Flight	Unlikely to include flight into urban canyons (because ground EMS services can reach/treat patients there adequately) High altitude capabilities usually not necessary as aircraft are likely to receive preferential lower-altitude air traffic routing
Trip Distance	Up to ~100-200 NM total Includes round trips from urban area to rural area (e.g., accident on Interstate) and critical patient transfer)
Density of Operations	~10 vehicles per metro area ~2 vehicles flying simultaneously Surges in case of disasters
Diversity of Vehicle Types and Procedures	Minimal diversity ~2 specialized vehicle designs

ATM Paradigm	Current operational concepts Current airspace classification VFR: single pilot, IFR: multipilot
Level of Automation	Piloting functions increasingly aided by automation
Propulsion	Electric or hybrid, limited endurance (urban)

The relatively small numbers of these vehicles and limited numbers of hospital facilities allow routing based on combinations of predefined approaches and departures from medical centers and point routing from corridor endpoints to victim pickup points. The emergency medical aircraft are dispatched and routed to a suitable location for patient pickup based on their starting point, local environmental conditions, and the number of victims. As is currently the practice, these flights are given priority status, and they are afforded priority routing and handling by the ATM system. While in flight, the air vehicles avoid obstacles and hazards and maintain safe separation from other vehicles when required.

The vehicles are special purpose vehicles, configured to address anticipated transport missions, with the capability to interact or communicate with all mission participants, from emergency medical personnel on the ground to the receiving hospital. During this initial stage, piloting functions will be increasingly aided by automation. Over time, advances in propulsion systems, sensors, and CNSI capabilities will enable electrically powered, human-piloted medevac vehicles to be operated to a wider variety of expedient landing sites in more demanding weather conditions.

Figure 13 portrays mission profiles for the Human Piloted Air Medical Transport mission.

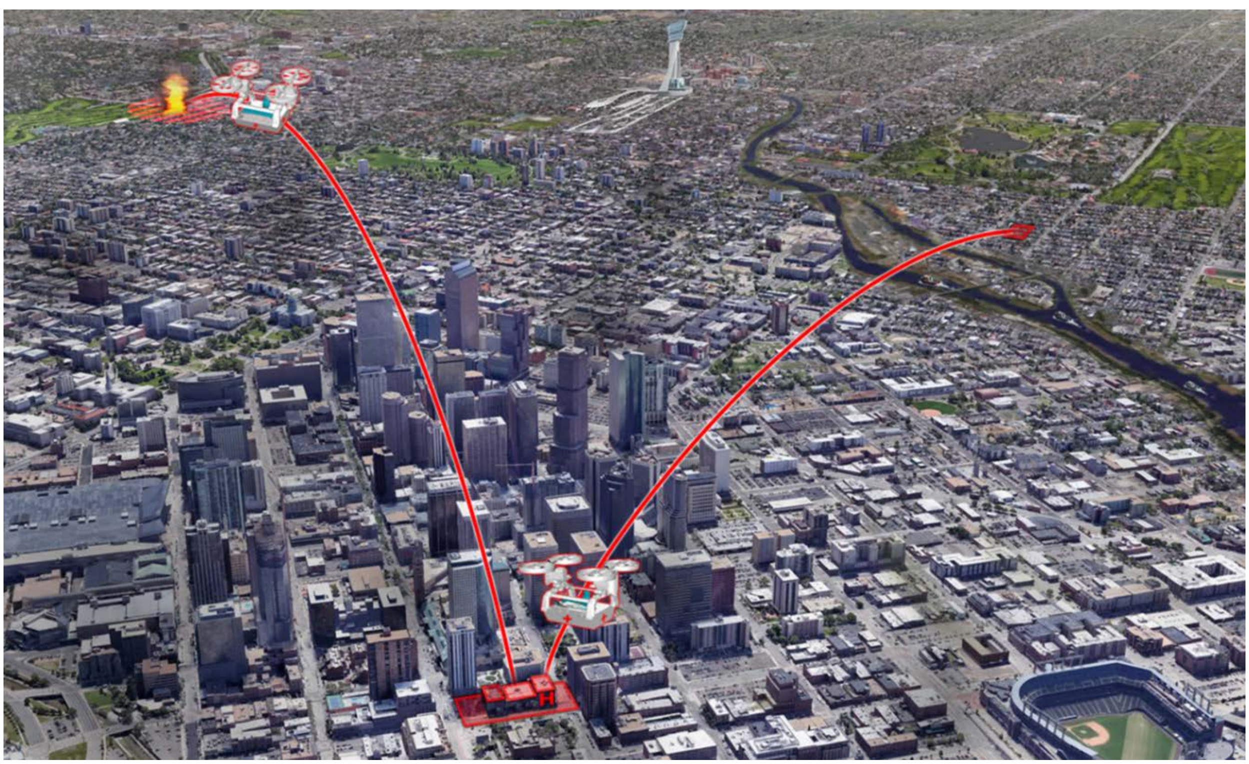

Figure 13: Human Piloted Air Medical Transport Mission Profiles

Vehicles are dispatched by an operator (public or private) with qualified emergency personnel embarked. Multiple varied capabilities may be considered for the mission, based on a number of factors:

- Required travel distance – base to pickup to medical facility
- Number of personnel to be transported – medical personnel, patients, other
- Nature (and severity) of medical emergency – e.g., cardiac, burn, pediatric
- Weather conditions – visibility, turbulence, icing, etc.
- Landing environment – dedicated facility, prepared or unprepared, local obstacles, density altitude, day/night lighting

In the event of a medical emergency requiring evacuation by air, a call for emergency air transport is initiated by on-scene emergency responders. Dispatchers identify the optimal location and vehicle from those available and work with the medevac crew and on-scene personnel to quickly plan and execute the emergency transport from a pickup location at or near the victim's location to the designated medical facility. Routine or emergency transport will still be conducted via ground transportation when that is the most suitable mode. Critical to the Human Piloted Air Medical Transport mission is the selection of the landing area most beneficial to the patient. The greatest asset of air transport is speed; that benefit diminishes greatly if the medical transport air service requires lengthy ground transport of the patient to or from an aviation facility as part of the mission. Thus, VTOL air vehicles with small footprints are particularly useful in urban environments.

During the initial state, pre-approved prepared and unprepared expedient landing sites for UAM medevac operations are often identified upon arrival on-scene. Law enforcement and other first responders assist in ensuring that predefined and expedient landing areas are kept clear of obstructions and hazards. The aircrew identifies the designated pickup landing area, assesses the safety to land, and lands, avoiding hazards and obstructions. Depending on the condition of each victim, medical personnel select an appropriate medical facility and request immediate and appropriate priority routing from ATC. Following takeoff, the aircraft is given priority routing to its destination. The medical personnel on board use onboard services to best address the needs of the patient, and they communicate the patient's situation and vital data to the destination medical facility.

Upon arrival at the medical facility, the pilot locates the assigned landing area, ensures that there are no hazards or obstacles, and lands safely in an orientation optimized for local conditions and patient needs.

After completing delivery, the aircraft and crew (no longer entitled to priority handling if not actively engaged in a mission) return to their base location, where they will prepare for subsequent calls. These turnaround activities include such tasks as cleaning, refueling, resupply, inspections, and maintenance.

3.2.2 Intermediate State: Intra-Metro Air Shuttle

Table 4 summarizes the characteristics of the Intra-Metro Air Shuttle intermediate state mission.

Table 4: Intra-Metro Air Shuttle Intermediate State Mission Summary

Characteristic	Characteristic Details
Vehicle Type	VTOL aircraft designed for low noise, low operating cost, rapid turnaround, and passenger comfort and convenience
Number of Passengers	3 to 9 – 3 passengers as minimum size consistent with current transportation – 9 passengers as breakpoint in Part 135 regulations
Takeoff and Landing Locations	Only designated takeoff and landing areas 10s of takeoff and landing areas per metro area
Service Provider	Private undertaking, local transportation authority, or public-private partnership
Scheduling	Largely scheduled, but also semi-scheduled variations
Locations of Flight	Include ability to fly up to multiple thousand feet AGL (aircraft no longer limited to flight below 400 ft AGL)
Trip Distance	10s of miles
Density of Operations	100s of vehicles per metro area 10s of vehicles flying simultaneously
Diversity of Vehicle Types and Procedures	Moderate ~5 different vehicle types Piloted, semi-autonomous, and remotely piloted operations
ATM Paradigm	Airspace reclassification Qualified supplementary service providers Weather-tolerant operations
Level of Automation	Semi-autonomous or remotely piloted operations
Propulsion	Electric or hybrid, limited endurance (urban)

At the onset of the intermediate state, lack of infrastructure may limit Intra-Metro Air Shuttle operations to routes supported by very high demand. Those routes are likely to be between public ground transportation centers, airports, and commuter stations in high-population centers most impacted by ground transportation delay. Dual-use ground and air transportation hubs will likely be the first UAM ports for Intra-Metro Air Shuttle services, and schedules may be limited to peak travel times while demand builds. In the intermediate time frame, infrastructure will have expanded to serve many high-demand areas. Intra-Metro Air Shuttle service will expand in terms of landing site locations and frequency of service. UAM ports capable of supporting multiple vehicles simultaneously will serve the urban population to the extent that a business case analysis can be made for the combination of costs, demand, routes, and trip density.

As system capabilities develop and air vehicle operational ranges expand, UAM pads supporting sequential single-vehicle operations may also be available to support inter-metro shuttle services in high-demand traffic areas. Some UAM pads may be used only for disembarking passengers if the security infrastructure for embarkation is not available. The locations and spacing of UAM ports and UAM pads will be driven by passenger demand, availability of infrastructure, relationship to current high-density passenger destinations, proximity to other public and mass transportation, and air vehicle capabilities such as capacity and range. Hundreds of UAM air vehicles will handle expected passenger traffic in the larger metropolitan areas, with dozens of air vehicles in flight at any one time.

No matter the air vehicle type or level of autonomy, all vehicle systems will be required to meet the same safety thresholds and interoperate seamlessly with all vehicle types within the evolving ATM network. Semi-autonomous or remotely piloted operations will likely be the initial models, but these will quickly evolve into increasingly automated operations as the technologies mature, passengers' trust increases, and business cases encourage autonomous operations.

Because air shuttle operations rely on predefined routes, the ATM system is able to manage separation through a combination of strategic trajectory planning, procedural separation, and collision avoidance services. Trajectories for Intra-Metro Air Shuttle and other UAM flights are deconflicted by time and space, with non-intra-metro flights avoiding Intra-Metro Air Shuttle routes based on updated schedules. Initial operations use UAM ATM trajectory planning, as well as conflict detection and resolution technologies augmented by sense-and-avoid procedures for separation. Intra-Metro Air Shuttle vehicles are generally given the right of way by virtue of their structured routes and limited maneuverability. In the intermediate timeframe, human and/or automated services enable collision avoidance during reduced visibility conditions. UAM, in conjunction with the ATM system, analyzes and integrates demand for routes with local environmental conditions and adjusts departure times and flight profiles to support on-time arrivals. Prior to aircraft departure, the UAM system automatically communicates both passenger manifest and pertinent flight information to ATM.

Figure 14 portrays mission profiles for the Intra-Metro Air Shuttle mission.

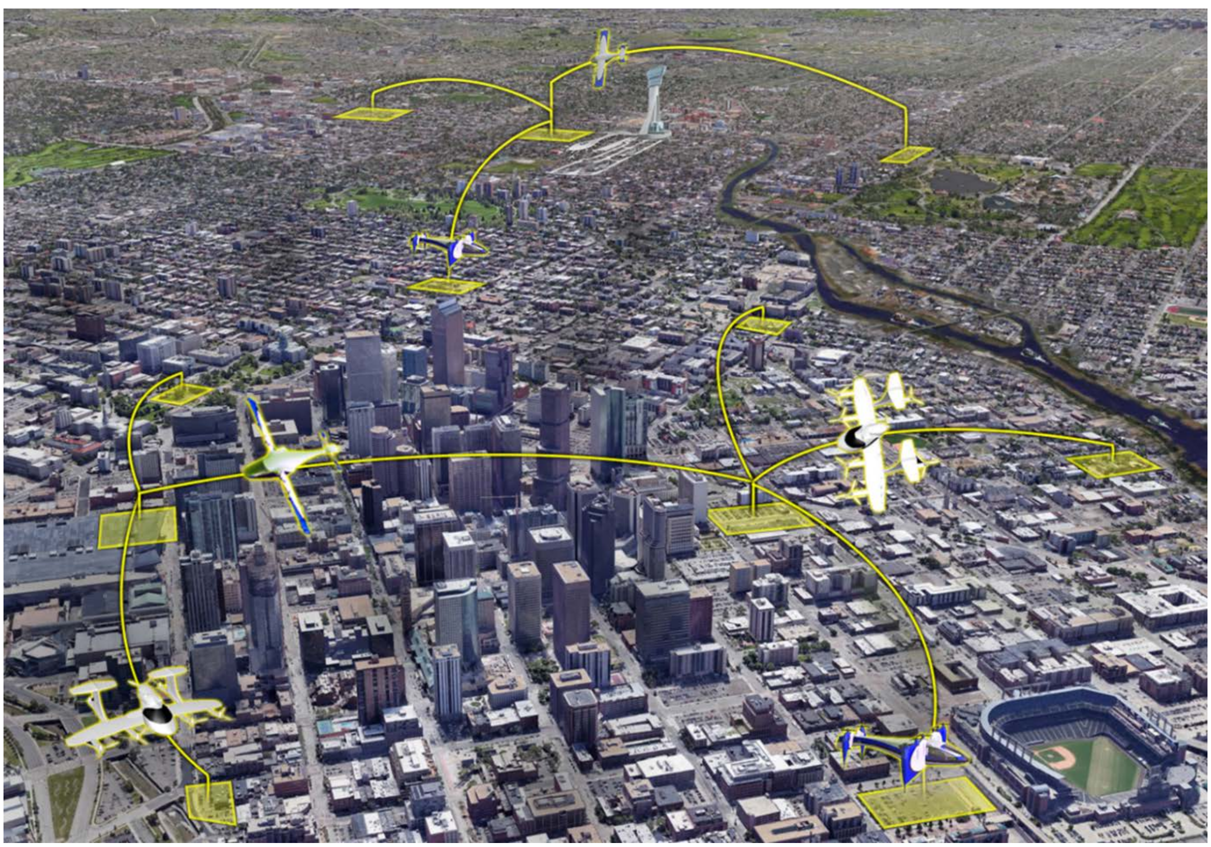

Figure 14: Intra-Metro Air Shuttle Mission Profiles

In an Intra-Metro Air Shuttle scenario, a passenger selects an embarkation point from the list of departure-capable and available UAM-port shuttles, destination UAM-port shuttle, and possible schedules. Flight status and schedules are updated in near-real time, allowing prospective passengers to adjust short-term plans and quickly determine which form of transportation best suits their needs. A moderate diversity of vehicles types is available for route assignment. Air vehicles with limited capacity may be assigned in periods of low demand. Multiple air vehicles with greater capacity may be used in high-demand times or on high-demand routes. Passengers purchase electronic tickets in advance for UAM flights for the particular time and route selected. Ticket purchase is accomplished online or on arrival at the UAM port. Transparent to the passenger, the UAM operations center aggregates demand for particular routes and automatically assigns appropriate numbers and types of air vehicles to support those routes.

At the UAM port, ticketed passengers proceed through automated security screening, at which time weight and balance calculation is automatically performed and, if required, passengers are assigned vehicles and seats to ensure that the air vehicle remains within operational limits during its entire flight.

Screened passengers are informed of their assigned vehicle's location and their assigned seat as they prepare to board the air vehicle. Depending on demand for the route and time, passengers may find themselves traveling alone on a smaller vehicle or with multiple passengers on a larger air vehicle. Baggage is stowed and secured as required prior to takeoff, and onboard systems or ground personnel ensure that both passengers and baggage are adequately secured for flight safety in accordance with FAA requirements. A safety briefing is provided prior to departure and passengers are advised of the imminent takeoff. Vehicle self-checks ensure the air vehicle is configured for taxi (if required). The UAM system ensures that there are no hazards or obstructions prior to engine start.

Once engine start and taxi (if required) are accomplished, the vehicle orients itself for takeoff, and it is then cleared by the ATM system for departure. As the air vehicle departs the UAM port, it continues to avoid hazards and obstacles, including other air vehicles arriving and departing the UAM port. Once airborne, the air vehicle proceeds on its departure route and climbs to an altitude specified for its planned route or as assigned by the ATM system. While en route, the vehicle system avoids temporary obstacles and hazards, and it shares its location, status, and other information of interest such as winds and weather conditions. The system self-monitors operating parameters as it proceeds on its assigned route and communicates information to its operations center as required. Enhanced weather-tolerant operations permit Intra-Metro Air Shuttle service to continue in periods of low visibility.

When en route to the UAM port, the air vehicle's onboard system status determines the proper course of action to effect a safe landing. On approach to UAM ports or UAM pads, the system configures the vehicle for landing, identifies the designated UAM pad, verifies that it is safe to land, and continues to avoid obstacles and hazards. Should the landing area be determined to not be safe, or if conditions prohibit a landing, the operations center, in coordination with UAM ATM, provides revised route and flight instructions. These instructions are integrated into the vehicle's flight planning, and its revised intent and flight plans are shared with ATM and other interested systems. Passengers are informed and assisted as necessary if routing to an alternative landing is required.

Immediately upon landing, the air vehicle begins its preparations for the next flight. This preparation may be identical to the previous cycle, or it may involve activities such as maintenance and servicing.

Should it become necessary due to an in-flight emergency or external catastrophic event, ATM and UAM systems will be capable of coordinated reroutes to alternative landing areas. Tactical separation services will be provided as necessary. Landing areas in emergency situations are taken in the broadest sense, to include runways, landing strips, and unimproved landing areas, UAM ports, UAM pads, and expedient landing sites, which may include offshore platforms, building roofs, roads, ships, and fields, depending on the nature of the emergency.

The Uber Elevate white paper, Reference 4, describes one concept for this type of service.

3.2.3 Mature State: Ubiquitous Air Taxi

Table 5 summarizes the characteristics of the Ubiquitous Air Taxi mature state mission.

Table 5: Ubiquitous Air Taxi Mature State Mission Summary

Characteristic	Characteristic Details
Vehicle Type	Semi-autonomous or fully autonomous VTOL aircraft designed for low noise, low operating cost, and passenger comfort and convenience
Number of Passengers	1 to 4 passengers, with 1-2 passengers on a typical transport mission Allows multiple passengers to fly together
Takeoff and Landing Locations	Mix of designated takeoff and landing areas with expedient landing sites 100s of dedicated takeoff and landing areas per metro area
Scheduling	Generally on-demand, with ability to schedule trips in advance – For example, book trip to the airport the night before to arrive at a set time, or take trip to airport with no advance notice
Locations of Flight	May include flight into urban canyons to reach landing locations Includes ability to fly up to multiple thousand feet AGL (for airspace integration or to overfly an airport)
Trip Distance	Includes ability to connect suburbs and exurbs to main urban center Enables flights across major urban areas
Density of Operations	10,000s of vehicles per metro area 1,000s of vehicles flying simultaneously
Diversity of Vehicle Types and Procedures	Very diverse 10s of different vehicles types Highly autonomous operations
ATM Paradigm	Multiple federated, qualified ATM service providers Substantial number of supplementary data service providers Weather-tolerant operations Airspace resource management for highly dense operations
Level of Automation	Semi-autonomous or fully autonomous
Propulsion	Electric, high-endurance (metro-area)

The mature state represents the realization of the envisioned future system, the result of many years of capability enhancements, infrastructure expansion, and autonomy development. Public trust of UAM safety and autonomy enables ubiquitous use of convenient and cost-effective air taxi services. Operations have evolved from human-flown UAM vehicles operating on limited routes with a few landing sites in the initial state to a wide variety of semi- and fully autonomous vehicles flying efficient weather-tolerant trajectories to hundreds of dedicated landing sites throughout a metro area.

Ubiquitous Air Taxi exemplifies the flexibility and responsiveness of UAM in the mature state. Passengers are able to schedule or hail air taxis for transport between any number of locations, including UAM ports, airports, stand-alone UAM pads, and suitable expedient landing sites. CNSI, ATM, and weather systems capabilities enable reduced separation from obstacles and between vehicles, allowing low-altitude flights into and through urban canyons These capabilities also enable high-volume operations from low altitude to multiple thousands of feet above the ground to allow overflight of airports or UAM ports and to avoid the primary flow of air transport aircraft into local airports.

Figure 15 portrays mission profiles for the Ubiquitous Air Taxi mission.

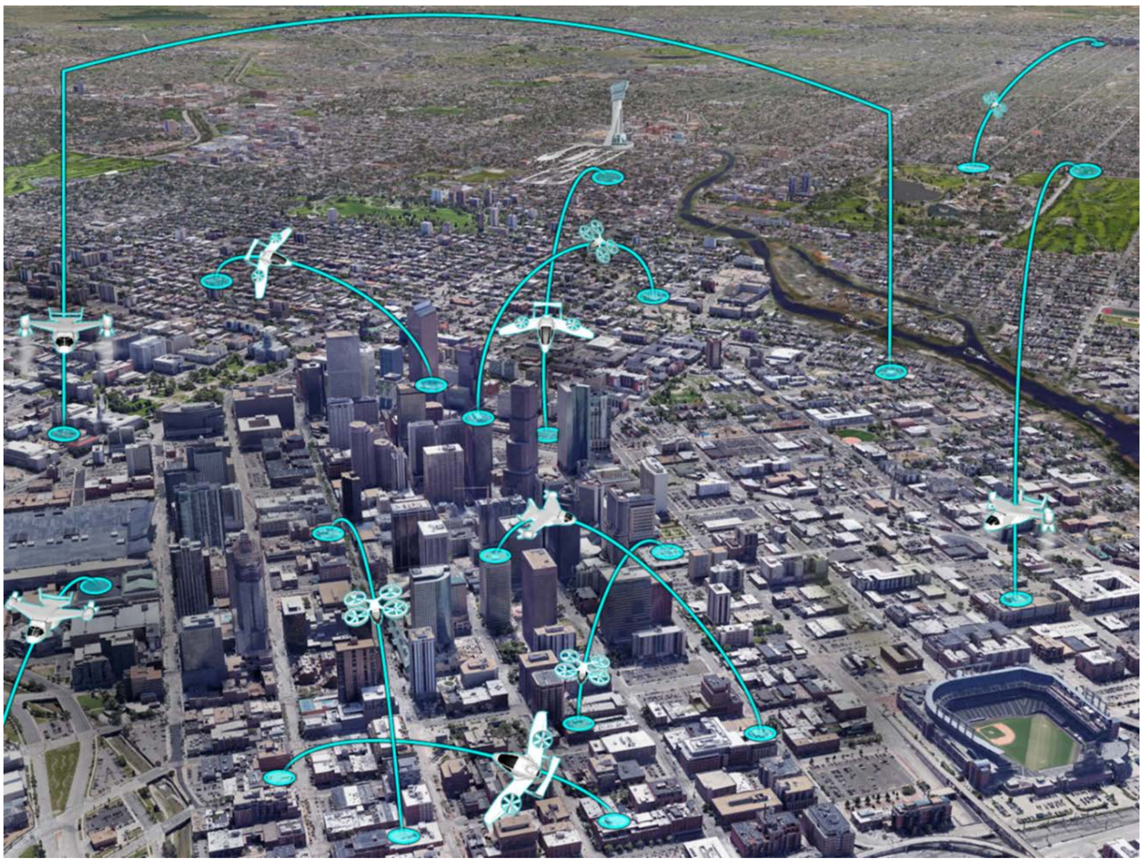

Figure 15: Ubiquitous Air Taxi Mission Profiles

With the ubiquitous nature of UAM in the mature state, air vehicles are prepositioned to account for passenger demand, such as traffic into the city in the morning and outbound from the city in the evening. The typical scenario begins with customers using ride-hailing applications on electronic devices to request transportation. Their request specifies the number of passengers, desired pickup time, departure point, and destination. Alternatively, the UAM pads may be assigned based on the customer's point of departure and destination, along with information on connecting transportation modes and their current status.

The air taxi operator's scheduling system determines what resources are available to support the request, and it automatically responds with available times and locations that most closely fit the customer's needs, considering estimated travel time from their current location to the point of departure and the time needed for passenger processing and boarding. The customer selects the option that best fits their needs. If there is no air taxi vehicle prepositioned or already en route to the departure site, one is dispatched. Dispatch operators monitor the system and interject directions if needed to best manage their resources.

The ride hailing application may allow the operator to monitor the customer's progress and estimated time of arrival at the departure UAM pad and advise the customer of any necessary adjustments. Once at the pickup UAM pad, passengers pass through security screening. This screening is envisioned to enable passengers to walk through a corridor of sensors that screen them and their belongings. When the passengers reach the end of the corridor, they either pass security criteria and are admitted to the gate or waiting area, or they are diverted to additional screening. Passengers are directed to their gate and vehicle or to a designated waiting area until their vehicle is ready to board, and they receive continuous updates on the location and time of arrival of their assigned air vehicle. Once the vehicle is assigned a gate and offloads any passengers, waiting passengers are notified and directed to the vehicle for boarding.

As they approach the air vehicle, passengers are automatically checked against the assigned manifest and allowed to board. The weight of each passenger and baggage items determined during passenger screening is used to calculate weight and balance and assign seating and baggage loading locations for the flight. Once passengers and baggage are loaded, the vehicle is assigned a UAM pad for takeoff by the UAM port management system, and the operator's dispatch system requests a departure time and trajectory to the destination. The ATM system automatically negotiates with the operator's system any modifications needed for deconfliction or to meet capacity limitations. Simultaneously, the ATM system is notified of the vehicle's location and readiness status, and when it's ready to depart. The ATM system negotiates with the FAA for issuance of a clearance and then transmits that clearance for the flight to depart at a specific time, if not immediately. The passenger's assigned air vehicle safely navigates the route to the assigned UAM pad, while avoiding hazards and obstacles and continuously providing status and location updates.

Current and planned flight trajectories and modifications are shared simultaneously with multiple interested parties. All vehicles periodically transmit, at a minimum, their location, status, and pertinent flight or mission characteristics via secure data links to support traffic management conformance monitoring, changes in intent, sequencing, and the like. Onboard systems in fully autonomous air vehicles maintain communication with the ground and monitor the cabin to assure passenger safety. Any changes desired by the passengers or operator are coordinated with the ATM system and the flight is dynamically rerouted based on current and anticipated demand, conflicting traffic, and other constraints.

While en route, the vehicle's status, including fuel status and maintenance condition, is used by the UAM operator's automated operations center to determine what course of action will be taken once passengers are disembarked. Options include taking on additional passengers, returning for service, returning to a maintenance point, or proceeding to a designated shutdown point to await re-tasking.

Arriving at the destination, the vehicle is assigned a UAM pad and sequence number, if required, and lands safely while avoiding hazards and obstacles. Once the vehicle has landed, the passengers are safely disembarked and directed to the terminal exit. Some UAM ports may embark and disembark passengers at a separate parking site, in which case the vehicle will either taxi to the spot or be moved by external means. The vehicle undergoes any preparation for the next flight, including refueling or recharging, servicing, or cleaning.

3.3 UAM System Framework – Evolution within the Pillars

This section describes the envisioned evolution of the UAM system, organized by UAM System Framework pillars and associated barriers. Figure 16, below, repeats Figure 7, providing a visual representation of the framework, with the five pillars designated by the ovals and their associated barriers identified in the boxes and the large circles representing seven crosscutting barriers that apply to multiple pillars.

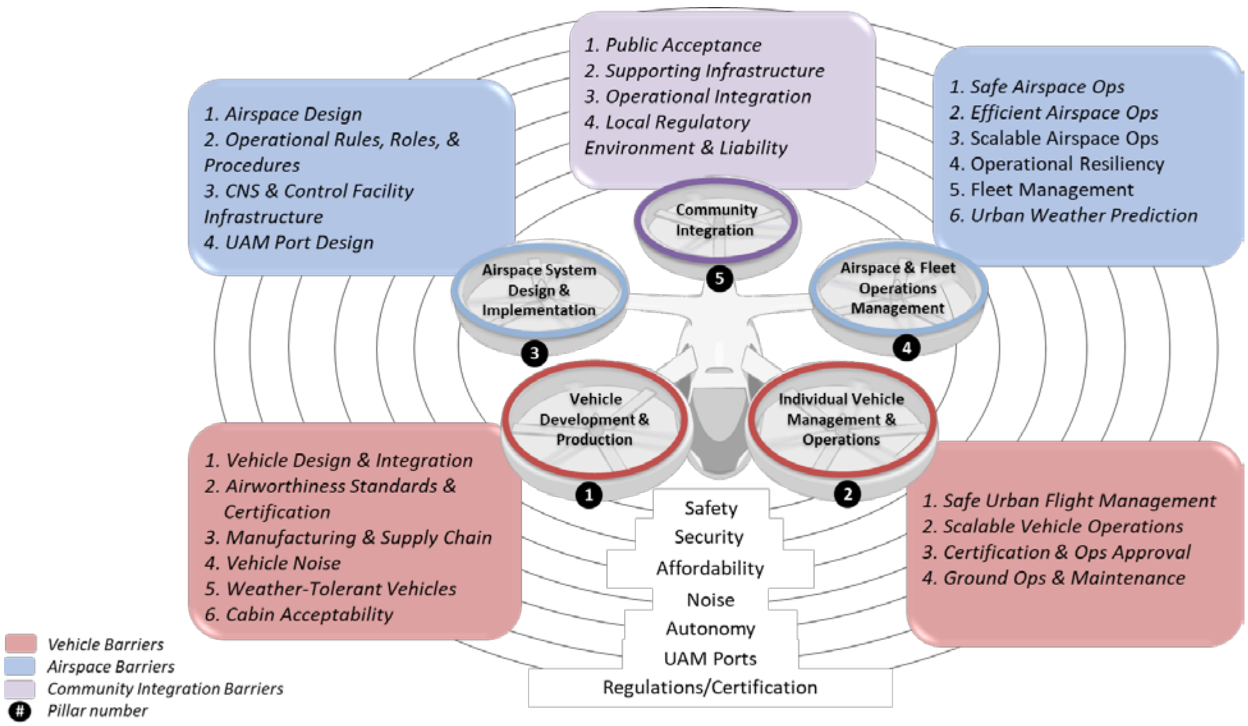

Figure 16: UAM System Framework

3.3.1 Vehicle Development & Production

This section addresses the barriers associated with developing, certifying, and producing mission-capable integrated vehicles that operate safely in adverse weather conditions with adequate passenger comfort and acceptably low noise levels.

3.3.1.1 Vehicle Design & Integration

Although early proof of concept flights in the initial state may use helicopters, it is likely that rapidly advancing electric motor, power storage, and distribution system technology will enable cleaner and quieter propulsion systems, such as suites of small electrically powered tilting rotors. A variety of vehicle designs can be expected to compete for design primacy as UAM evolves. Early efforts will focus on safety and maturing of air vehicle design technologies. Vehicles flown by onboard human pilots will be the initial approach for passenger-carrying vehicles as UAM infrastructure and ATM mature, but some limited functionality may be automated. Designs will be developed using currently existing modeling and simulation tools, with multiple hardware iterations preceding certification, and system integration will rely largely on today's methods. Proprietary architectures are expected, considering the large number of potential competitors and the limited number of existing standards. Battery technology and operating efficiencies will initially limit the range and endurance of UAM air vehicles to operation within the boundaries of metropolitan areas.

As UAM matures and competing design concepts succeed or fail, the intermediate state will be characterized by decreasing variability in systems design, driven by safety, operational and economic competition, and environmental considerations. UAM vehicle automation will progress to a point that, in some applications, air vehicles can be managed by remote operators, and onboard pilots are no longer required. Both onboard and remotely piloted systems will show increasing levels of automation, with some limited, non-flight-critical functionality becoming autonomous.

Semi-autonomous air vehicles will begin to carry out required piloting functions, based on preprogrammed rules and human directives. VTOL and STOL vehicle designs will grow in size to accommodate more passengers in Intra-Metro Air Shuttle operations. Air vehicles with less capable automation may still require onboard flight crews with the ability to fly the air vehicle. Human crewmembers may be onboard larger air vehicles to monitor operations, interject when needed, and assist in passenger management. Automation of design tools and system and subsystem integration methods will take advantage of high-speed and high-capacity computing to optimize designs and reduce development time by more closely integrating design and analysis, including systemwide impacts of design decisions and changes. Common, and in some cases open, architectures will emerge as reduced cost and upgradability of these architectures are realized. Improved battery efficiency, increased system propulsion efficiency, and highly effective energy management will result in increased range and endurance supporting both longer-duration intra-metropolitan operations and limited inter-metropolitan service.

As UAM reaches the mature state, the safest, most cost effective, and operationally efficient designs will have been identified and fully developed. Overall, the range of UAM air vehicle concepts will be limited and basic system and subsystem elements will be considered stable. As with the automobile, routine variations in design of non-flight-critical elements will incorporate more esthetically pleasing elements. Autonomy technology will have matured and semi-autonomous and fully autonomous systems will be the norm, resulting in increased system capacity and significantly reduced operating costs. To support increased competitiveness and cost effectiveness, open system architectures will be standard, and interoperability of many parts will be common. Design tools and system and subsystem integration methods will take advantage of artificial intelligence, machine learning, and big data to incorporate experience from previous designs and include production as an integral part of the design process. Designers will specify concepts, requirements, constraints, objectives, and tradeoffs, rather than making detailed design decisions. In the mature state, stimulated by the demands of electric ground vehicles and electric aircraft, advances in battery technology and electric motor efficiency will provide increased intercity endurance and range, enabling regional UAM operations in large geographic areas.

3.3.1.2 Airworthiness Standards & Certification

Initial airworthiness standards and certification will be primarily system and safety focused based on conventional aircraft standards, with nonstandard certification processes to address the range of novel designs.

As UAM evolves into the Intermediate state, standards will evolve to become more oriented to eVTOL systems and components, and their application will expand from safety to include environmental standards addressing characteristics such as noise and emissions. Standards may also include environmental requirements focused on production, such as minimizing use of hazardous materials. Certification processes will start to become standardized as the variations in basic designs are reduced and the most cost-effective designs are adopted.

In the mature state, eVTOL standards will include not only safety and environment, but they will also expand to economic standards, much as miles-per-gallon standards have evolved with conventional ground vehicles. Standardized certification processes will be the norm as the variability in basic design approaches is reduced to a minimum set of mission-based vehicle types, analogous to ground transportation categories such as cars, vans, motorcycles, and buses.

3.3.1.3 Vehicle Noise

In the initial state vehicle noise will be at the upper limit of both passenger and community acceptance. Design characteristics associated with low noise will be applied only in limited fashion as other design characteristics such as weight, efficiency, and cost are considered higher priority. Noise levels will be sufficiently low to support operations in the limited number of applications expected in this state.

In the intermediate state, low vehicle noise will emerge as a potential differentiator in competing system designs, along with low cost, longer battery life, and other attributes. Lower noise will allow UAM operations in a broader set of urban and rural locations. As a result, noise will increasingly become a design consideration, although likely weighted lower than cost and other mission-related requirements when minimum requirements are met.

In the mature state, as designs mature and markets grow and expand, a limited number of competitors will look more intensely for competitive advantage, and noise increasingly will become a differentiator much more heavily weighted in design tradeoffs. In this state, noise will become sufficiently low to allow operation in all expected locations.

3.3.1.4 Weather-Tolerant Vehicles

Vehicles will be designed for both day and night operations. However, in the relatively early UAM development state, with an initial safety-centric focus and in an effort to keep cost manageable, most UAM operations will be limited to visual meteorological conditions (VMC), with some early evolution into operations in marginal VMC. Due to the small size and weight of UAM vehicles, they will generally be able to operate only in good-to-moderate conditions, initially limited to light winds, light turbulence, moderate temperatures, and light precipitation.

As UAM evolves into the intermediate state, designs will mature, system cost will be reduced, technology will mature, and, as a result, systems will become more robust. In the intermediate state systems will continue to be day and night operable. Operations in moderate winds, moderate turbulence, and moderate precipitation will be enabled by new vehicle capabilities, and operations in instrument meteorological conditions (IMC) will become routine.

In the mature state, system designs will have evolved to a point where operations take place in day, night, VMC, and IMC, and operations in high winds with heavy precipitation become possible. UAM operations may be limited to moderate turbulence to maintain passenger comfort and ensure safe operation and vehicle integrity.

3.3.1.5 Cabin Acceptability

In the initial state, passenger comfort will be a design consideration, but other design constraints, such as weight, as well as production cost issues associated with low-volume production and handmade systems, may result in only moderate comfort. This is likely to be acceptable to passengers for the relatively short-range flights expected in this state. For passenger convenience, vehicles will enable Wi-Fi and individual cell phone use in the initial state. Because of the initial design focus on weight and efficiency, the passenger cabin will likely be subject to moderate noise and vibration. As UAM becomes a means of public transportation, access for people with disabilities will become a requirement for vehicle designs and operations, including boarding and deplaning.

In the intermediate state, UAM cabin acceptability will improve considerably as designs evolve and production costs decline, allowing more cost to be allocated to comfort. Basic Wi-Fi and cell phone connectivity will improve in coverage and bandwidth, and cabin noise and vibration will be significantly reduced as noise and cabin comfort become differentiators for the smaller number of design variations in use at this time. Enhanced crashworthiness will become integrated into vehicle structures as new materials and design methods reduce the associated weight and cost penalty.

In the mature state cabin comfort will evolve to a point where UAM air vehicle comfort is comparable to automobile comfort at a significantly reduced weight penalty. Varying levels of comfort will be available in different UAM designs, based not only on system cost, but also on expected duration of flights, with higher cost systems used for longer duration flights offering higher level of comfort. In-flight high-tech interactive entertainment will be a routine capability of most systems, providing not only a high level of entertainment value, but also ubiquitous connectivity between the platform and the internet of the future. Additionally, design evolution and competition will place a premium on cabin comfort, and as a result very low levels of noise and vibration are expected.

3.3.1.6 Manufacturing & Supply Chain

Based on relatively low system demand, low production volume is expected in the initial state. With high variability in design, low-fidelity modeling, and low production volume, UAM systems will be produced with little or no automation. Some common limited, higher-usage-rate components, such as motors and rotor blades, may be produced in a more automated fashion. Current composite materials will be used primarily for airframes and propellers. High levels of manual labor will result in high cost due to the high percentage of touch labor and high level of skills required to produce the handcrafted systems. Product lifecycles will initially be limited as more is learned about the longevity of material applications and designs.

In the intermediate state, high-fidelity modeling accelerates development cycles and enables safe designs and refinements to be more rapidly brought to market. Expanded use of composite materials and more automated component manufacturing processes will support moderate production rates as demand for vehicles increases and variability in designs decreases. The transition to more automated production processes is expected to reduce cost, improve quality, and increase product longevity. System costs in the mature state will trend down but will still be considered expensive, becoming affordable only when systems are purchased and operated in large numbers.

In the mature state, the demand for UAM services and vehicles is expected to significantly exceed that for other aircraft, and manufacturing automation will enable high production volumes to satisfy that demand. Economies of scale will drive system cost down to a level considered affordable and cost effective in the marketplace as producers leverage automation, supply chain management, and other practices from the high-volume automotive industry to reduce cost, enhance integration of producibility into the design process, adjust production to accommodate changes in demand, and enable flexibility to introduce modifications and new designs.

3.3.1.7 Vehicle Development & Production Summary

Table 6, below, summarizes the projected evolution from initial to mature state of key areas of Vehicle Development & Production.

Table 6: Projected Vehicle Development & Production Evolution

Barriers	Initial State	Intermediate State	Mature State
Integrated Vehicle Design	Large variations in design Piloted Low-fidelity/high-speed modeling and design tools focused on subsystems Electric/hybrid, limited endurance (urban) Limited payload, limited number of flights between refuel/recharge Market-specific designs Proprietary architectures Intracity endurance and range	Decreasing design variations Remotely piloted High-fidelity/low-speed modeling and design tools with increasing system integration capability Electric, limited endurance (urban) Limited payload, limited number of flights between recharge Expanding market demand, reduced variability of designs Increasingly common architectures Intercity endurance and range	Stable but limited design variations Semi- or fully autonomous High-fidelity/high-speed modeling and design tools integrated with production considerations Electric, high-endurance (metro-area) Higher payloads, high number of flights between recharge Multi-market acceptability and designs Open systems architectures Intercity endurance and range
Airworthiness Standards & Certification	Conventional aircraft-based standards, safety focused Nonstandard certification processes as a result of multiple novel designs	eVTOL focused standards, safety and environmentally focused Increasingly standard certification processes based on converging designs	eVTOL standards, safety, environment, economically focused Standard certification processes based on limited number of design variants
Manufacturing	Low-rate production Little or no automated production Traditional application of existing materials Limited product longevity Expensive systems	Moderate-rate production Automated production components Expanded use of strong, lightweight materials Increasing product longevity Lower cost, but still expensive	High-rate production Rapid fully automated production New materials and processes enabling rapid production Extended product longevity Low-cost affordable systems
Vehicle Noise	Noise at upper limits of community acceptability	Increasingly lower noise levels	Low noise levels acceptable for all communities
Weather-tolerant Vehicles	Day/Night VMC and limited IMC Light winds, light turbulence, light precipitation, moderate temperatures	Day/Night VMC/IMC Moderate winds, moderate turbulence, moderate precipitation	Day/Night VMC/IMC High winds, moderate turbulence, heavy precipitation
Cabin Acceptability	Moderate passenger comfort Wi-Fi and individual cell	High passenger comfort 5G connectivity	Very high passenger comfort Interactive high-tech entertainment

	Moderate noise and vibration	Reduced noise and vibration	Very low noise and vibration
Assumptions • Standards development organizations and regulators will establish the necessary policies, procedures, regulations, and standards in a timely manner to provide manufacturers, operators, and the public with a framework for achieving certification.			

3.3.2 Individual Vehicle Management & Operations

This section addresses the barriers associated with assured safe air vehicle operations, including flight management, vehicle operations, operational certification and approvals, and vehicle ground operations and maintenance.

3.3.2.1 Safe Urban Flight Management

Individual vehicle flight safety will be supported by a combination of pilot, vehicle, and operational certification; pilot proficiency; vehicle safety technologies; vehicle automation; ground support and maintenance; and management oversight. As UAM operations mature, automation and new or enhanced technologies will play an increasingly prominent role in safe weather-tolerant operations in urban environments.

In the initial state, passenger-carrying vehicles will likely still be flown by onboard pilots, supported by increasingly automated safety systems such as stability and control systems, system monitors, and ballistic parachutes. Remotely or semi-autonomously piloted vehicle designs will be in development and test stages, supporting the development of new standards and requirements. Flight operations will be predominantly VFR, with limited IFR operations between qualified airports, heliports, and UAM ports under existing performance standards and procedures. Safety will be managed much the same way as it is today, based on risk and hazard analysis, existing safety requirements and certification, and responses to incidents and accidents. Contingency operations will be managed much the same way as they are today through operational restrictions to manage risk, as well as system redundancy and procedures to counter on- and off-board component and system failures. Automation supporting boarding, preflight preparation, and vehicle surface movement is expected to play a larger role in ground operations as UAM ports are deployed.

As new vehicle safety technology and automation are certified and implemented in the intermediate state, predictive risk analysis will be embedded in operational systems to alert operators to potential vulnerabilities in their fleets' operations. Some of these capabilities are embedded in operating system and enable real-time incident and accident avoidance. The resulting improvement in safety permits UAM operations to safely expand to more dense urban areas. High-precision CNSI operational capabilities, combined with enhanced terrain and obstacle sensors, will enable operations in reduced visibility to more UAM ports in more confined areas, as well as increased airspace capacity in IMC. Onboard safety monitoring systems will inform pilots and operators of potential hazards, and air-ground on-time data sharing will allow operators to monitor and manage each flight in near-real time. Contingency management systems and procedures will keep pace with expanded operational capabilities and scope.

In the mature state, advanced technologies, automation, and connectivity of information networks support a wide array of real-time predictive safety enhancements that enable autonomously flown vehicles to safely conduct weather-tolerant operations and operate in suitably wide urban canyons. Advanced technology will include high-precision auto-land, navigation, surveillance, and hazard avoidance systems, supported by associated ground systems such as CNSI networks, weather sensors, lighting systems, UAM ports, and ATM. Contingency management will be provided through a system-of-systems approach augmented with preplanned procedures. Additional ground infrastructure may augment vehicle safety systems to ensure public safety in cases of forced landings in areas such as urban canyons.

3.3.2.2 Increasingly Automated Vehicle Operations

Scalable vehicle operations will be capable of adapting to fluctuations in demand or scope. Early urban air operations involve highly skilled pilots and support personnel employed in human-centric operational paradigms that limit scalability due to high costs and operational resource requirements. It is expected that this will remain the case in the initial state as new UAM vehicles, automation, fleet data management, and ground support infrastructure will be in their early stages and human-centric operations will still be required to ensure safety while new technologies prove to be safe and reliable. Consequently, costs will remain high and scalability will be limited.

As UAM moves into the intermediate state, new automation, sensors, and fleet data management capabilities will enable automation to perform increasingly varied and complex tasks, allowing operators to leverage existing human resources and expertise to manage a larger number of vehicle operations to meet increasing demand for UAM services. Vehicle automation, CNSI, and safety enhancements will enable pilots to fly demanding missions with less effort, including remote piloting of passenger vehicles. Increased revenue opportunities will enable a broader set of UAM services, as well as the potential for remotely piloting vehicles to reposition them to locations with greater demand, thus minimizing non-revenue downtime and increasing scalability. These capabilities will allow for modest reductions in consumer prices for the service.

The mature state is envisioned to consist of highly automated vehicles connected through fully integrated fleet data management and networking systems to enable semi-autonomous vehicle operations. These capabilities, together with automated ground support systems, enable a single qualified individual to simultaneously manage operation of several vehicles. Combined with weather-tolerant operational capabilities and more versatile vehicle designs, the increasing scalability of vehicle operations will reduce consumer prices to levels that will be affordable for a large percentage of the public.

3.3.2.3 Certification & Operational Approval

Certification standards and operational approvals will evolve with new vehicle designs, technologies, and management paradigms. In the initial state, the existing system of certification standards and operational approval processes will be adapted as needed to ensure that policies and procedures are in place for safe UAM vehicle operations with qualified personnel and management oversight for each flight.

In the intermediate state, certification standards will be revised to better support innovative UAM vehicle designs and automation systems for vehicle operation and management. These standards will also enable more rapid certification, allowing faster evolution of operational paradigms and incorporation of safety enhancements as vehicles become more efficient and sophisticated.

In the mature state, new certification standards and operational procedures will support semi-autonomous vehicles, management systems, and weather-tolerant operations, including operations in dense urban environments.

3.3.2.4 Ground Operations & Maintenance

Ground operations and maintenance deal with all aspects of vehicle loading and unloading, handling, and maintenance. The goal is to ensure safe ground operations and maintenance practices that also support safe flight operations, while successfully supporting revenue-producing operations.

In the initial state, ground operations and maintenance will continue to be human-centric, although early applications of automated functions may assume some tasks, such as automatically briefing passengers or determining weight and balance conformance. Scheduled and on-condition inspection and maintenance requirements and procedures will be tailored to vehicle designs and supporting infrastructure, but they are not expected to differ entirely from those used in current operations. Consequently, ground operations and maintenance costs may not change significantly.

Implementing automation to perform more tasks in the intermediate state will enable lower levels of direct human involvement. Surface movement, passenger and luggage loading and unloading, and some vehicle services may be supported by automated capabilities. Vehicle components, assemblies, or subassemblies may be made replaceable by automated machines networked with vehicle diagnostics and maintenance management systems.

In the mature state, automation will be embedded in most facets of ground operations and maintenance, allowing operators to support large fleets with fewer personnel. Support personnel will rely on automated systems for ground handling to perform most preflight and postflight passenger handling and vehicle support functions, acting only when tasks are beyond the capability of automation or as otherwise needed. Maintenance personnel may use automated vehicle diagnostic systems and robotic maintenance tools to identify and remove or replace faulty or suspect components or assemblies, thereby minimizing the time that vehicles are taken out of service. Although the cost of installing automated systems and obtaining approvals will offset some of the savings in labor costs, overall costs to the operator and consumer prices are expected to fall.

Automation will require fewer humans, but they will have to be trained and qualified to perform and manage a higher level of tasks and, for the foreseeable future, step in for contingencies and off-nominal situations. Thus, the shift to automation will require determination of the cost-effective roles of humans, as well as definition of the necessary standards and training to perform those roles with the required level of safety assurance.

3.3.2.5 Individual Vehicle Management & Operations Summary

Table 7 summarizes the projected evolution from initial to mature state of key areas of Individual Vehicle Management & Operations.

Table 7: Projected Individual Vehicle Management & Operations Evolution

Barriers	Initial State	Intermediate State	Mature State
Safe Urban Flight Management	Piloted operations augmented with automated safety systems	Increased vehicle automation enabling operations in more confined urban environments and more adverse weather and visibility	Highly automated vehicles and systems enabling pilotless vehicles and weather-tolerant and urban canyon operations
	Limited IMC operations using existing CNSI systems	Expanded IMC operations using high-precision CNSI capabilities	Ubiquitous IMC operations using high-precision, weather-tolerant CNSI capabilities
	Contingencies managed through procedures and restrictions	Technology enhancements enabling expanded scope of contingency management	Ubiquitous operations supported by complete contingency management enabled by automation, technology, and procedures
	Obstacle and terrain avoidance through existing mechanisms	New onboard sensors and high-performance navigation enabling reduced obstacle and terrain clearance	High performance sensor and navigation technology enabling urban canyon operations
Scalable Vehicle Operations	Specialized services	Broader application of services	Ubiquitous availability of services
	Limited operational integration of fleet data management	Increasingly integrated fleet data management using data integration	Fleet data management fully integrated into operations
	Human-centric operations	Increasing human-automation teaming for vehicle operations, passenger support, and ground handling	High levels of automation and autonomy for vehicle operation, passenger support, and ground handling)
	Very high average cost per flight	Decreasing cost, but still expensive for average consumer	Service affordable for the average consumer
Certification and Operations Approval	Compliance with established FAA policies and procedures for standard certification of flight operations.	Evolving FAA UAM policies and procedures for certification of personnel, flight operations, and supporting automation and autonomy.	UAM-specific FAA policies and procedures for more rapid certification of aircraft, personnel, flight operations, and supporting automation and autonomy.

Ground Operations and Maintenance	Many ground operations personnel Inspections and periodic maintenance based on flight hours or time High operations and maintenance costs	Fewer ground operations personnel Condition-based maintenance, streamlined maintenance requirements Reduced operations and maintenance costs through increasing automation	Very few ground operations personnel Highly automated diagnostics and maintenance Relatively low operations and maintenance costs enabled by high levels of automation
Assumptions • Autonomous air vehicles will operate with a level of safety equal to or higher than that of human-operated systems. • The Pilot In Command (PIC) or Operator In Charge (OIC) of the flight may be located either on board the air vehicle or in a remote location. • Basic operator responsibilities will remain unchanged throughout the evolution of UAM. As is the case today, the operator will be responsible for the safe conduct of flight, including use of qualified personnel and certified equipment.			

3.3.3 Airspace System Design & Implementation

This section addresses the barriers associated with designing, regulating, and managing the airspace and supporting ground facilities to enable safe, efficient, and reliable flights in and adjacent to metropolitan areas.

3.3.3.1 Airspace Design

Airspace design encompasses both the scope and structure of airspace classes and requirements, as well as the structure used to manage traffic within those classes – namely, ATC sectors, traffic flow patterns, and published routes.

The FAA is responsible for designing and implementing an airspace structure to "meet the need for increased capacity and efficiency while maintaining safety and mitigating environmental impacts."[32] Today, this is accomplished through analysis of traffic demand and system capacity to optimize traffic flows within the bounds of acceptable safety, using the regulatory process specified by Part 170 to vet and address public safety and environmental concerns. The process can be slow and cumbersome, result in less than optimal airspace designs that compromise capacity and efficiency, and take years or decades to implement, particularly when data is uncertain or subjective.

Enhancements in data collection and analysis, as well as fast-time simulation tools, have continued to evolve to enable more timely assessment of large sets of complex variables when evaluating traffic flows and associated environmental impacts. These enhancements support more objective, data-driven solutions to complex problems, and they enable metrics-based approaches to evaluating and optimizing practical, feasible, flexible, scalable, implementable, and equitable airspace design solutions that account for community concerns such as noise, privacy, and cumulative fleet emissions (such as CO_2) in surrounding communities. This capability will minimize uncertainties, increase transparency, and reduce parochial influences, all of which will help to expedite the regulatory process.

[32] https://www.faa.gov/nextgen/media/futureofthenas.pdf.

Continual improvements in ATM and aircraft automation and trajectory management are expected to augment airspace redesign efforts by enabling dynamic adjustments in response to changes in demand, constraints, and available airspace capacity. The UAM community will leverage this progress and develop new innovative approaches to designing and managing airspace to enable the interoperability of diverse missions and vehicle types (e.g., manned, remotely piloted, autonomous, VTOL, STOL, and sUAS).

Initially, airspace classes will remain the same, but UTM-inspired airspace management concepts will support self-managed low-density and low complexity UAM traffic management in designated corridors through controlled airspace in metropolitan areas between UAM ports and other designated UAM landing sites.

Increasing demand, more closely spaced UAM ports, and vehicle automation in the intermediate state will drive the need for changes in airspace design to enable increased flexibility and scalability to accommodate hundreds of simultaneous UAM operations and the associated traffic densities and complexities. The revised airspace designs will incorporate noise compatibility in urban areas to blend in with local soundscapes, support reduced visibility operations, and accommodate new and more weather-tolerant vehicles.

In the mature state, advanced airspace design and management will be implemented to support high-density UAM operations, with up to tens of thousands of simultaneous flights to meet high levels of consumer demand in various types of weather. High-density and near-zero-visibility operations will drive new aircraft performance requirements and airspace access regulations, potentially requiring new airspace operational paradigms and capabilities to support advanced UAM operations during periods of high demand. Airspace designs will support a high density of UAM ports as well as expedient landing sites, considering noise compatibility for suburban and rural areas and accommodating dynamic soundscapes. In the mature state, UAM capacity is limited only by physical infrastructure.

Figure 17, below, illustrates a notional airspace allocation and its relationship to current airspace designations.

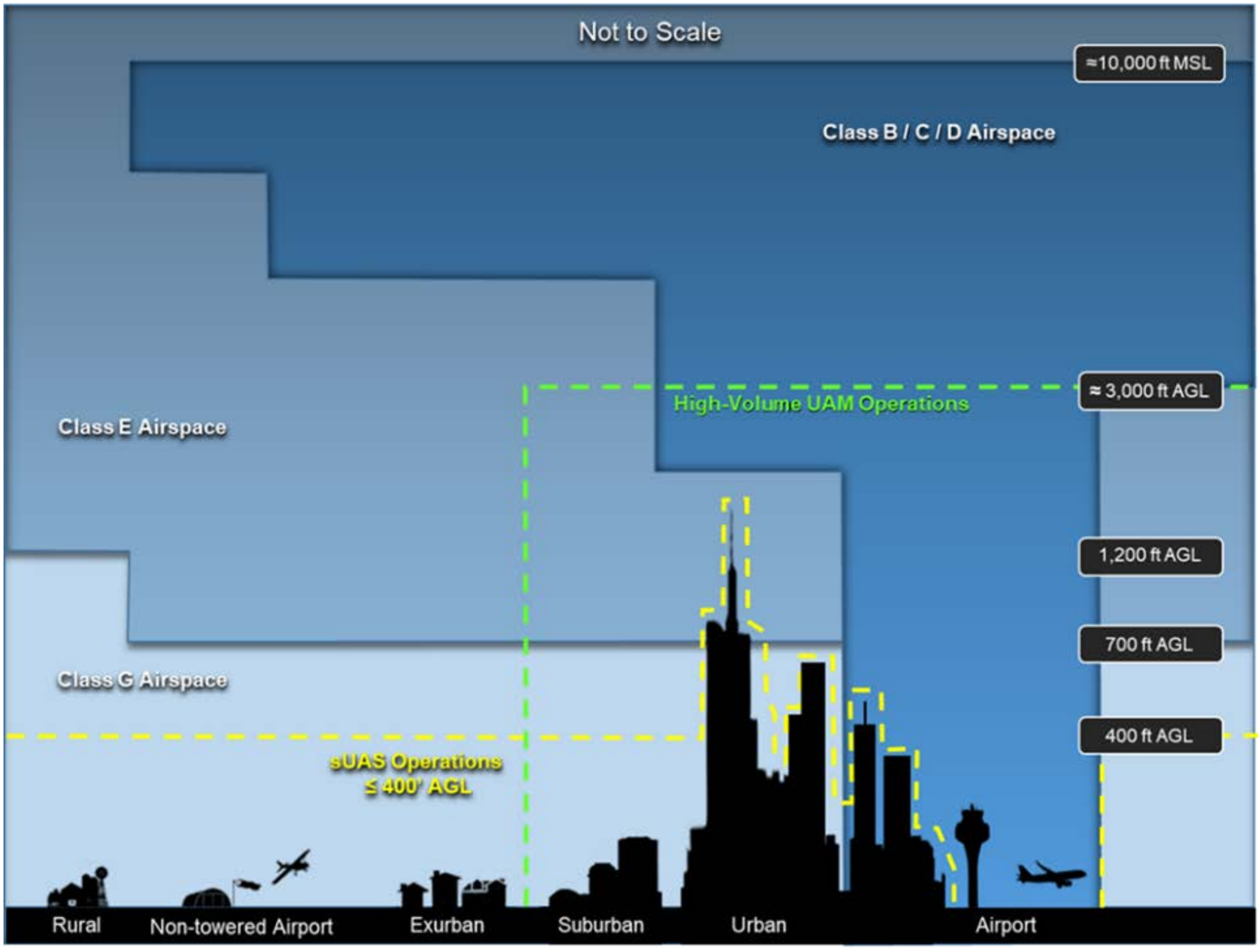

Figure 17: Future Notional UAM Airspace Design

3.3.3.2 Operational Rules, Roles, & Procedures

Operating rules, roles, procedures, and airspace management Concepts of Operation will be developed and evolve to enable safe, efficient, and scalable operations that are compatible with urban environments, enable interoperability across diverse vehicles, and support operations in moderately poor weather operations.

UAM operations will initially be VFR due to procedural requirements and ATM limitations. Procedural and technology innovations derived from UTM will enable self-managed, low-density, low-complexity UAM operations in designated corridors in controlled airspace. Market demonstrations will be conducted to support data collection and introduce service concepts to the public. Part 135 operating approvals will begin and UAM operational rules will enable the introduction of limited air taxi services in the urban periphery. During the early stages of UAM implementation, humans will continue to serve as pilots and controllers in their traditional roles.

In the intermediate stage, increased vehicle and traffic management automation, combined with UTM-inspired procedures, will support the expansion of ATM services to enable UAM operations to move into urban areas, with moderate traffic density and complexity consisting of hundreds of simultaneous UAM flights. The roles of pilots, dispatchers, and ground support personnel will evolve as technology, automation, and associated procedural advances allow the removal of humans from the cockpit in the intermediate state and automation begins to assume larger roles to increase safety and enable higher traffic density and complexity, as well as high-capacity UAM ports. Responsibilities may shift between actors, but they will remain with humans somewhere in the chain of command and control.

In the mature state, new technologies and procedures will be developed to support remotely piloted and auto-piloted vehicles. Advanced ATM, CNSI, and command and control capabilities, networks, and automation will enable high-density, complex, and weather-tolerant UAM operations involving thousands to tens of thousands of simultaneous flights throughout metropolitan areas in both visual and instrument meteorological conditions. Human roles will evolve from direct operational control to one of operational direction, and the relationships among responsible parties and the associated training requirements will evolve accordingly. UAM will have systematically progressed from a stovepiped operational structure (the UAS operator providing all aspects of service and support) to a more complex, yet diverse and efficient, system of interdependent service providers.

3.3.3.3 CNSI & Control Facility Infrastructure

The development and implementation of communication, navigation, surveillance, information, and control facility infrastructure is critical to the successful implementation of flexible and scalable airspace design and management to support ubiquitous UAM operations. This critical infrastructure will be economical; sufficient to support the desired services, coverage, and capabilities; resilient to failures; and secure from intentional and unintentional physical and cyber threats, including non-cooperative vehicles. Radio frequency communication links will also be spectrally efficient. Navigation services such as augmented GPS, multi-constellation GNSS, and other technologies will be developed to enable navigation capabilities with high accuracy, integrity, and continuity at all UAM operational altitudes and locations. Information networks and airspace control facilities and services will be similarly robust and tied into communication networks to provide complete and timely information and control capabilities. These capabilities will enable high-resolution traffic management and full system functionality in urban canyons. As these technologies and services mature, so will the efficiency, flexibility, and scalability of airspace designs and management.

Initially, UAM operations will rely on existing CNSI capabilities, leveraging improved information sharing through a variety of networks to support fleet operation and traffic management. New and more precise and secure navigation, digital communications, and surveillance systems and capabilities will be in development and evaluation to support new airspace design and management concepts. Information sharing will include elements such as safety-related data, trajectory intent, weather, passenger routing changes, and passenger Wi-Fi and cell phone connectivity.

In the intermediate state, more secure high-precision integrated CNSI capabilities that provide the required level of accuracy, integrity, resilience, and continuity of service will be introduced to support low-volume IMC and high-volume VMC operations in urban areas, and infrastructure will be deployed and expanded as needed to accommodate demand for UAM services. System integration, redundancy, and procedural requirements provide the resilience necessary to ensure safety and security. Increasingly automated coordination and CSNI integration across vehicle and ATM systems will improve interoperability and increase the scalability and flexibility of airspace design and management.

In the mature state, high demand for UAM services in urban areas will drive the need for new CNSI minimum performance standards across both manned and unmanned operations, and command facility infrastructure throughout metropolitan areas, including in urban canyons, will support ubiquitous UAM operations. This coverage, combined with advanced CNSI and airspace management capabilities, will enable high-density operations in both VMC and IMC on the order of tens of thousands of simultaneous operations. CNSI will be highly responsive to changes in constraints, available capacity, and vehicle or subsystem failures. High-density operations may also drive new aircraft performance requirements and airspace access criteria, potentially requiring new and dynamic airspace designs and management paradigms.

3.3.3.4 UAM Port Design

Designs and construction guidelines for UAM ports and stand-alone UAM pads will be developed to accommodate the anticipated volume of demand and diverse vehicle configurations in both fair and adverse weather. These guidelines include provisions for safely handle contingencies, such crash, fire, and rescue. The guidelines will leverage current airport and helicopter design standards and safe operating practices and they will be tailored to the types of UAM operations and vehicles. These standards include provisions for CNSI, weather, and command systems, standardized lighting and markings, and integration of surface management systems with ATM traffic management to sequence and meter arrival and departure traffic so as to enable safe and coordinated staging and movement of vehicles and passengers. Noise compatibility standards will also be developed to define the needs for various mitigations based on the types of vehicles served and the environments in which the UAM ports or pads are located.

Initially, UAM operations will leverage existing heliports and airports while new UAM port designs are developed, public policies are revised, and property is acquired or existing facilities are expanded to support construction of landing sites. Surface movement will rely on traditional methods and procedures, in which vehicles are moved under their own power with personnel well clear or powered down and moved by ground vehicles. Auxiliary power units and battery chargers and storage will be adapted to the methods of operation at each heliport. Limited numbers of purpose-built UAM port designs will be built and evaluated operationally to support development of requirements and low-density operations in in fair weather. Security requirements will be established and passengers and baggage, as well as on-site personnel, will be processed as necessary to meet those requirements.

In the intermediate state, UAM port and pad requirements will be completed, and the number of UAM port and UAM pad installations will rapidly increase to meet growing demand for UAM services. Safety and noise compatibility policies and procedures at the federal, state, and local levels will support moderate density of UAM ports and pads. Many UAM ports will be collocated with surface transportation nodes, while UAM pads will tend to serve currently underserved low-density areas. UAM port automation applications tied to ATM and vehicle applications will coordinate surface operations with arrival and departure sequencing, as well as supporting high-volume operations in VMC and low-volume operations in IMC. Passenger processing and staging infrastructure will be integrated with surface movement operations to create a smooth and efficient flow of passengers in and out of vehicles and the UAM port terminal. Information sharing with surface transportation modes will be introduced to connect passenger air and ground movements.

In the mature state, large networks of UAM ports, pads, and expedient landing sites support ubiquitous UAM services. Connectivity with ground transportation services provides convenient, efficient, and readily accessible urban mobility. High-volume IMC operations to UAM ports in near-zero visibility will be enabled though high-precision CNSI capabilities and advanced ATM and UAM port capabilities and automation. UAM port passenger screening and processing technologies and automation will streamline passenger movement through terminals and support maximum UAM port throughput.

3.3.3.5 Airspace System Design & Implementation Summary

Table 8 summarizes the projected evolution from initial to mature state of key elements of Airspace System Design & Implementation.

Table 8: Projected Airspace System Design & Implementation Evolution

<table>
<tr><th>Barriers</th><th>Initial State</th><th>Intermediate State</th><th>Mature State</th></tr>
<tr><td>Airspace Design</td><td>UAM adapts to traditional airspace requirements</td><td>Revised airspace requirements to support UAM operations procedures and interoperability (i.e., dynamic airspace)</td><td>UAM-specific airspace and requirements</td></tr>
<tr><td>Operational Rules, Roles and Procedures</td><td>Human rules, procedures, and roles for airspace access largely unchanged

Special UAS rules and airspace restrictions

Limited traditional IMC operations</td><td>New airspace access rules and procedures for UAS

Reduced UAS restrictions

UAM-specific IMC operations</td><td>Airspace access rules and procedures support all manned aircraft and UAS

UAS fully interoperable with manned operations

Weather-tolerant operations</td></tr>
<tr><td>Communication, Navigation, Surveillance, and Information & Control Facility Integration</td><td>Traditional CNSI capabilities with enhanced information sharing

Traditional IMC operations</td><td>Enhanced CNSI capabilities support low-volume weather-tolerant capabilities

New high-precision approach and departure capabilities</td><td>Fully integrated CNSI and ATM capabilities enable high-volume weather-tolerant operations

New weather-tolerant, high-precision approach and departure capabilities</td></tr>
<tr><td>UAM port Design</td><td>Leverage existing heliports & airports design and safety characteristics</td><td>New UAM port design and safety characteristics</td><td>Purpose-built UAM ports support high-volume, weather-tolerant operations</td></tr>
<tr><td colspan="4">Assumptions
• Extensive automation will be required to support high volume UAM and unmanned vehicle operations in the intermediate to mature state time frames.
• Dynamic airspace configurations will allow UAM to use all available airspace near airports within Class B, C, and D airspace.
• Local and state laws and ordinances will be modified to enable sufficient UAM ports and UAM pads to support UAM operations.</td></tr>
</table>

3.3.4 Airspace & Fleet Operations Management

This section addresses the barriers associated with safe, efficient, and scalable ATM and fleet operations, as well as urban weather prediction to assure safe flight.

3.3.4.1 Safe Airspace Operations

ATM system integration and automation will evolve to eventually enable high-density, weather-tolerant UAM operations with system redundancy and procedural mitigations to support off-nominal operations and sustain operational resilience.

Initially, UAM will leverage existing ATM systems and procedures, with enhanced information sharing to support innovative fleet management and business models. In-time Aviation Safety Management Systems (IASMS) will perform monitoring functions such as collecting, quality checking, fusing, and distributing flight planning safety-related data. Human-piloted UAM vehicles will be interoperable with traditional aviation operations. New and expanded procedures will enable expanded access to low-altitude urban airspace, high-volume VFR operations, and traditional low-volume operations in IMC.

In the intermediate state of UAM implementation, increasingly automated information sharing and traffic management, combined with high-precision CNSI capabilities, will enable closely spaced IMC operations to most UAM ports in confined urban areas. Integrated piloted vehicle and ATM automation will support interoperability of human-piloted and semi-autonomous air vehicles and increase system resilience. Information sharing will allow the IASMS to model safety hazards and mitigations, assess operational data, and mine safety-related data.

In the mature state, fully integrated, automated vehicle, ATM, and UAM port applications will enable high-density, weather-tolerant UAM operations. Humans will manage traffic through strategic planning, tactical adjustments in metering demand to fit capacity, and 4D trajectories, while enhanced conflict and collision detection and avoidance systems resolve unforeseen conflicts. In this state, the IASMS will have matured to mitigate or resolve current or impending hazardous situations.

3.3.4.2 Efficient Airspace Operations

ATM communication, surveillance, information sharing, and trajectory planning enhancements and autonomy will evolve to support user-preferences and increased operational efficiencies, while ensuring timely and equitable access to airspace and landing facilities. The resulting predictability will allow operators to manage their fleets and supporting resources more efficiently, thereby reducing service costs and enhancing affordability.

Initially, flexible and efficient VFR operations will be supported by ATM and UAM operational procedures, with visual separation augmented by electronic traffic avoidance technologies. Operations in IMC will be based on legacy capabilities, standards, and procedures, and will therefore be limited in scope and efficiency. User preferences will be limited by airspace restrictions, operational limitations, and system capacity.

In the intermediate state of UAM implementation, airspace capacity and UAM port throughput for operations in IMC will increase as high-precision CNSI capabilities and infrastructure are introduced and associated ATM and UAM port capabilities improve and become more integrated. These capabilities will enable enhanced operational flexibility, trajectory efficiency, denser operations, and accommodation of user preferences. New vehicles sensors, automation, and safety systems will enable operations in wide urban canyons appropriate for each operation and vehicle, increasing trajectory efficiency and density by allowing short flights to remain at lower altitudes in urban areas.

In the mature state, fully integrated, autonomous functions will enable high-density UAM operations in IMC while supporting user preferences and efficient 4D trajectories. User-preferred trajectories will be restricted only as necessary to ensure safety, security, and equity. The ATM system will be highly responsive, enabling true on-demand access to airspace, UAM ports and landing sites, and ATM services for both legacy and new operations.

3.3.4.3 Scalable Airspace Operations

The volume of traffic that the ATM system can support will increase with greater autonomy and CNSI capabilities. As automation and autonomous functions mature, ATM resources will be managed more efficiently, focused where and when needed and rapidly adaptable to changing constraints and user demand.

Initially, VFR operations will be predominantly self-managed. Limited ATM capabilities and CNSI infrastructure, combined with the small number of UAM ports, will support low-to-moderate VMC airspace capacity and very limited capacity for airspace access and operations in IMC, with scalability achieved primarily through planning and automation systems that will be able to adjust to increases or reductions in demand, such as the needs of rush hours and scheduled special events.

In the intermediate state, scalability of the ATM system will be expanded as ATM, vehicle, and UAM port improvements increase airspace capacity and support operations in IMC on a larger scale. ATM autonomy enhancements will improve traffic flow planning and metering to efficiently match demand to available capacity. Trajectories will be deconflicted and optimized for user preferences within the bounds of necessary constraints, such as noise-sensitive areas that may change throughout the day, and the system will be able to adjust to developing weather events.

In the mature state, ATM, vehicle, and UAM port autonomy and integration will support the entire range of operations, from low-volume manned operations to high-volume, high-density UAS operations able to dynamically adjust to changes in demand in all meteorological conditions. Automated system monitoring, combined with big data storage and analysis, will support machine learning and allow autonomous systems to evolve and rapidly respond to dynamic changes.

3.3.4.4 Resilient Airspace Operations

To handle the high levels of UAM air traffic envisioned in the future, an airspace operations management system must allow for graceful degradation of UAM operations in reaction to unintended disruptions to UAM services. This resilience should be in place regardless of whether the disruption is caused by failure of an element within the system, an unintentional error by users of the system, or a malicious attack. Examples of such disruptions could include the loss of GPS, flight services, CNSI, or weather information; UAM port issues; or cyber attacks.

When one or several subsystems fail, the airspace operations management system works in degraded mode: A graceful degradation occurs when the transition from a nominal mode of operation to a degraded mode of operation is smooth and without a catastrophic event. To achieve this capability will require the introduction of new technologies and highly automated systems to support off-nominal operations and sustain airspace resilience.

Initially, UAM will leverage existing ATM systems and procedures to handle contingencies. Passenger-carrying UAM will still be relatively few, so they are unlikely to pose significant barriers to addressing disruptions. Automation to enable resilient operations will be developed, tested, and refined during this state.

In the intermediate state of UAM implementation, increasingly autonomous information sharing and traffic management, combined with high-precision CNSI capabilities, will increase system resilience, enabling operations to continue during times of degraded system performance.

In the mature state, fully integrated, automated vehicle, ATM, and UAM port applications will enable rapid fault identification, resolution, and return to normal operations. Humans will oversee and direct autonomous capabilities to manage traffic through strategic planning, tactical adjustments in metering demand to fit capacity, and 4D trajectories, while enhanced conflict and collision detection and avoidance resolve unforeseen conflicts.

3.3.4.5 Fleet Management

Autonomous vehicle and dispatch capabilities, combined with increased ATM-vehicle connectivity, will enable operators to shift from centralized to more distributed flight management models and support larger fleets with fewer human resources.

In the initial state, piloted UAM vehicles will leverage information sharing and digital communications to collaborate with dispatchers in a more effective and efficient manner, while fleet management remains human centric and centralized. Together, pilots and dispatchers will maintain continuous oversight and control of each flight.

As vehicle and flight management capabilities become increasingly connected and automated, the management of flights will become increasingly self-organized, allowing dispatchers and remote operators to safely and effectively manage more flights with fewer people.

In the mature state, relatively large numbers of UAM vehicles will be predominantly self-organized, with suites of autonomous applications and information networks enabling a small number of humans to oversee large numbers of flights. Autonomous applications and backup procedures will provide mitigations for failures or unplanned events such as system failures or passenger emergencies.

3.3.4.6 Urban Weather Prediction

Weather reporting and prediction accuracy will increase with sensor coverage, improved accuracy of hyper-local forecast models, and more effective translation to operational limitations.

Weather reporting and prediction in early stages of UAM implementation will be coarse, due to reliance on nearby terminal area forecasts and atmospheric sensors at a scattered network of landing facilities.

Real-time measurements of atmospheric conditions most pertinent to UAM operations, such as visibility, winds, turbulence, and icing, will become available as atmospheric sensor networks expand and become denser. Additionally, microclimate forecast models will be developed based on experience with increasingly accurate forecasts for UAM operations.

In the mature state, dense sensor networks throughout metropolitan areas will enable high-resolution views of weather. With improved local and hyper-local forecasts, operators and ATM will be provided with real-time local weather conditions and microclimate forecasts, including wind gusts in urban canyons, location-specific turbulence and visibility, and other hyper-local conditions.

3.3.4.7 Airspace & Fleet Management Summary

Table 9 summarizes the projected evolution from initial to mature state of key areas of Airspace & Fleet Management.

Table 9: Airspace & Fleet Management Evolution

Focus Area	Initial State	Intermediate State	Mature State
Safe ATM Operations	Separation based on existing FAA policies	New CNSI, ATM, and vehicle technologies to enable reduced separation	Fully integrated ATM and vehicle separation capabilities to enable safe high-density operations
	Restricted UAS operations	Increased interoperability between manned and UAS operations	Safe interoperability among all vehicles system-wide
	Current levels of system resilience	Increased levels of resilience through new technologies and procedures	Highly resilient system enabled by redundancy and integration
Efficient ATM Operations	Current levels of ATM efficiency based on existing FAA policies and procedures	ATM technologies, policies, and procedures to enable more efficient user-preferred trajectories	New ATM paradigms to enable highly efficient, user-preferred trajectories
Scalable ATM Operations	Services provided by ATM service providers	Semi-autonomous ATM functions to free human controllers from mundane tasks	Autonomous technologies to remove much of the needs and effects of surge operations
	Limited UAM system capacity	Increased system capacity through reduced separation and enhance ATM demand management	High-density, user-preferred trajectories and airspace access enabled by ATM and fleet management integration
Fleet Management	Small fleets, centralized management supported by information networking applications	Larger fleets, leveraging automation and information networking to support distributed management	Large fleets, supported by self-organizing applications for distributed fleet management
Urban Weather Predictions	Augmented current aviation forecasts with UAM-specific urban point reports	UAM port weather reports and forecasts augmented with terminal and area forecasts	Urban hyper-local weather reports and microclimate forecasts
	Uplink of weather reports and forecasts to UAM vehicles	Downlink of atmospheric data from UAM vehicles	Hyper-local weather information sharing and integrated forecasts

Assumptions
• The ATM system will support dynamic and user-preferred trajectories. • Enabling preferred operational parameters, such as speed and climb and descent rates, for varied vehicle configurations will require a greater degree of integration with the ATM system. • UAM traffic will interoperate with conventional piloted aircraft (both fixed-wing and rotorcraft) and UAS (including small UAS) during all phases of flight. • Additional limitations in vehicle capabilities and operational limits can be enforced to support high-volume operations. • UAM trip times and associated routings need to be significantly more efficient in competitive operational and user costs than alternative modes of transportation in order to create and justify the market.

3.3.5 Community Integration

This section addresses the barriers associated with achieving public acceptance of UAM, including policy, security, local regulation, a framework for assessing liability, and the supporting infrastructure, including energy sources and UAM ports.

3.3.5.1 Public Acceptance

In the initial state public acceptance of the UAM concept will be limited by concerns over issues such as safety, non-user risk exposure, privacy, noise, and mistrust of increasing autonomy, as well as a lack of public consensus on the value proposition of UAM. Initial acceptance and use will be by innovators and early adopters, while UAM interests will strive to promote acceptance by engaging government authorities, stakeholder groups, and the public.

In the intermediate state, while still relatively costly to use, UAM service will continue to grow as it accumulates a record of safety, reliability, and increased availability, and tangible benefits, such as time savings, become evident. Maturation of system designs and growing perception of the value of UAM service will further reduce public concerns. Stakeholders who will influence the acceptance and implementation of UAM include:

- Early adopters
- Government regulatory organizations (local, state, and federal)
- Major industry participants and technology developers (e.g., operators and producers)
- Financial institutions and investors
- The population of the metropolitan operation area of interest
- Individuals and organizations economically affected by UAM (i.e., those whose income is directly or indirectly related to UAM).

In the mature state, UAM will achieve wide-scale acceptance. Public approval will result from demonstrated system reliability, safety, and cost effectiveness. Wide implementation of autonomy will reduce operating cost, while demonstrated safety and reliability of autonomous systems will enhance the public's positive perception of, and willingness to use, these systems. The public's understanding of the benefits of UAM will promote general approval, as will efforts by designers to address issues such as noise and environmental impacts. Public approval will also grow as a result of new markets, such as service to exurban and rural areas not previously well served by public transport. Further acceptance in this state will be supported by effective policies and regulations to address privacy issues.

3.3.5.2 Supporting Infrastructure

In the initial state there will be limited dedicated supporting infrastructure for integrating UAM operations into metropolitan areas. This infrastructure will include adaptations of the existing energy infrastructure, as well as facilities repurposed for maintenance, landing spots, and surface operations. The dedicated infrastructure for UAM will be located near a limited number of high-usage areas that will attract potential early adopters. Planning for long-lead constructions projects will be well underway.

In the intermediate state, as UAM use expands and the business case for UAM proves out, there will be an increase in dedicated UAM infrastructure. If required, electrical generation and distribution changes will be made to accommodate more wide-scale use of UAM. The large scale of some infrastructure projects, such as electrical power grid expansion or modification, will require state or federal investment or long-term public-private partnerships. This and other government infrastructure funding, or support such as tax abatement, can be expected to increase as UAM use grows and a positive economic impact is realized.

In the mature state, infrastructure will be available in most metropolitan areas, including the suburbs and some exurban areas. UAM infrastructure will include large numbers of repurposed areas and purpose-built operations control centers and maintenance facilities collocated with other modes of transportation or potentially occupying other areas such as rooftops or ground areas in large apartment complexes. Pervasive dedicated infrastructure will readily support high-volume UAM operations. Large-scale public infrastructure projects will continue, supplemented with private investment as business cases prove out and profitable opportunities are identified.

3.3.5.3 Operational Integration

In the initial state UAM ports will be primarily repurposed areas and will be located in the most economically beneficial and conveniently available locations. As a result, integration with other modes of transportation, such as metro and bus, will likely result from availability of interchange locations rather than dedicated planning. Passenger and cargo screening at these locations will be performed by dedicated individuals or as other duties by location managers. Since there will be limited UAM use during this stage, degradation of the UAM service, such as flight reductions due to weather, or full shutdown of the system, such as in response to severe weather, will have little impact on the overall transportation system.

In the intermediate state, as UAM use increases and implementation becomes profitable, locations for UAM ports and interchange UAM pads will begin to be developed near existing facilities, such as metro stations. Increased use and UAM operation within and over large metropolitan areas will necessitate increased security screening of both passengers and cargo. Both manual and automated security screening will be available at UAM ports and most UAM pads. As UAM use increases, the impact of UAM degradation or shutdown on other modes of transportation will become significant. A shutdown of UAM service during the intermediate state will result in significantly increased demand for other forms of transportation, which is likely to place increased demand on non-UAM transportation service and congestion in limited areas. On the other hand, UAM will begin to be able to satisfy a shift in demand in case of disruption of other modes, such as bridge collapse or train derailment.

In the mature state UAM operations are fully integrated and coordinated with other forms of transportation. UAM ports and UAM pads will be located near or at intermodal transfer points and embarkation and debarkation points for other transportation modes will be built or extended to allow easy access to UAM transportation. As a result of widespread and significant routine use, UAM will become an essential element of the urban transportation system, which must be able to accommodate shifts in demand due to disruption when one or more elements become degraded or shut down. For this reason, UAM systems will be designed to provide for scalability, graceful degradation, and ultra-high reliability.

3.3.5.4 Local Regulatory Environment & Liability

In the initial state, few UAM-specific regulations or statutes will exist at federal or state levels, and regulations and policies governing conventional aircraft in the NAS will be adapted and applied for UAM. Federal regulation will govern overall system development and operations, and local regulations, such as zoning, allowable noise levels, and hours of operation, will be developed at the local level by early-adopter cities.

In the intermediate state, UAM-specific statutes, regulations, policies, and standards will begin to emerge. State and local regulations will either accelerate or impede UAM integration and adoption, and local authorities' zoning and other land use regulations will have a major effect on the growth of UAM. In light of the expected positive impact on the economy and the need for higher level uniform regulation and standardization, federal authorities will tend to take precedence over local authorities in areas where uniform policies nationwide will benefit interstate commerce.

In the mature state, the necessary statutes, regulations, and policies will have been developed and agreed to. Regulatory stability will have been achieved; federal, state, and local authorities will have established their roles; and regulation will be relatively stable. Legislation and case law will have established a basis for assigning responsibilities and determining liability.

3.3.5.5 Community Integration Summary

Table 10 summarizes the projected evolution from initial to mature state for focus areas related to Community Integration.

Table 10: Projected Community Integration Evolution

Barriers	Initial State	Intermediate State	Mature State
Public Approval	Broad engagement; limited acceptance, primarily by innovators and early adopters	Increasing acceptance as the general population begins to use UAM	Wide approval across the majority of the population as use becomes routine
	Limited use based on public concerns with cost, safety, security, non-user risk, autonomy, noise, and privacy	Significant use as high levels of safety and reliability are demonstrated, availability increases, and tangible benefits (e.g., time saved) become evident	Routine use across all levels of the population
	Limited understanding of UAM and lack of public consensus on UAM benefits	Increasing understanding of UAM benefits and general public understanding of the value of UAM	Wide-scale understanding of the benefits of UAM; documented analysis of UAM benefits routinely made available to the public (e.g., travel hours saved per year)
	Limited business models aimed at either meeting high-value needs or capturing market share	Broad proliferation of business model as industry meets existing demand or creates new demand	Business models that prove to be unprofitable are discontinued
Supporting Infrastructure	Very limited infrastructure, primarily in high-potential usage areas and near high concentrations of potential earlier adopters	Increasing availability of infrastructure in diverse usage areas, primarily in high population areas	Ubiquitous infrastructure in all areas supporting profitable operations
	Primarily existing or repurposed infrastructure (e.g., top decks of parking garages as UAM ports)	Expanding repurposed infrastructure and limited emergence of specified and purpose-built infrastructure (e.g., UAM ports and maintenance facilities)	Continued repurposing of infrastructure and large-scale application of special built infrastructure as efficient and profitable deigns are identified
	Energy and utility infrastructure based on existing distribution and transmission facilities	Expanded (electrical) energy and utility infrastructure to serve increasing use of electric-powered air vehicles	Continued expansion of electrical and other utility infrastructure to meet growing demand and enlargement of UAM networks
	Limited investment in infrastructure for unproven UAM, government-subsidized infrastructure to promote use and investment, and private investment to capture market share	Increasing investment in infrastructure as profitable areas of use are identified; stabilized government support of infrastructure as public-private and federal, state, and local responsibilities are defined	Routine private investment infrastructure as standardized models are proven out and profitability is fully documented.

Operational Environment	Limited UAM use	Expanded UAM use as part of intermodal transportation	UAM ubiquitous and used routinely as a standard form of transportation
	UAM ports located where possible, with some limited direct access to other transit modes	UAM and other transit mode integration maturing and value of UAM as an intermodal transportation system significantly increased	UAM fully integrated into the transportation infrastructure
	Minimal impact in the event of UAM system failure or degraded performance	Failure or degradation of UAM system creates significantly increased demand and congestion for other forms of transportation; but increasing system reliability and resilience reduce occurrence and severity of disruptions	High UAM system reliability, graceful degradation procedures, robust transportation ecosystem
Physical Security	Passenger and cargo screening performed by designated individuals	Emergence of automated screening integrated into UAM ports	Unobtrusive security processes integrated into UAM ports and UAM pads
Regulatory Environment	Few UAM-specific regulations or statues	Emergence of federal, state, and local UAM regulations and statutes, with some commonality across states and local areas	Regulatory stability achieved as most necessary regulations and statutes are in place with consistency supporting broad market opportunity
	Policies begin to exhibit acceptance of selected UAM services (e.g., public service missions)	Supportive policy decisions encouraging investment in selected localities	Widespread policy support
	Federal regulations governing system, but local regulation drive implementation (e.g., local zoning ordinances)	Federal preemption of some local regulations to accelerate integration	Federal, state, and local regulation balance achieved
	No clear definition or precedence for responsibility or liability for operations	Operational responsibility and liability generally defined, but new capabilities such as autonomy create regulatory and liability challenges	Responsibility and liability for all modes of operation and contingency defined and understood
Assumptions • Physical and cyber security will be integrated into the system to ensure safety and mission assurance. • No regulations will be enacted that significantly suppress UAM operations.			

3.3.6 Crosscutting Barriers

The UCAT identified seven crosscutting barriers that apply across multiple pillars. Each of these barriers represents a major attribute of UAM, and overcoming these barriers will require integrated cross-pillar solutions. The barriers within each pillar reflect how the elements of the system contribute to achieving these attributes. The crosscutting barriers also help to identify needs for integration across the pillars to achieve the UAM vision.

3.3.6.1 Safety

Safety is a critical concern for implementation of UAM, and each pillar addresses this barrier as it applies to the elements within the pillar. Safety throughout the system is governed by the regulatory framework and assured by the practices of the safety management system.

Safety begins with pillars 1, Vehicle Development & Production, and 3, Airspace System Design & Implementation, which establish the features and details of the system, and safety is the overriding consideration in operation of the system (pillars 2, Individual Vehicle Management & Operation, and 4, Airspace & Fleet Operations Management). Safety is also critical in gaining acceptance of UAM, a major element of pillar 5, Community Integration. Community activities are greatly motivated by perceived safety of UAM operations, and they may impose more stringent requirements in certain areas than are required to meet federal standards.

3.3.6.2 Security

Both physical and cyber security will be critical concerns as UAM effort progresses. Physical security will evolve to address changing threats, and over time new technologies will replace or augment current practices. A May 2015 report on NextGen by the National Research Council (Reference 5), commissioned by the Congress, called for more attention to cyber security in the integration of unmanned aircraft. Cyber security goes beyond protecting the system from active attack: it includes assuring data integrity, which ensures the accurate and consistent transfer of valid information among authorized participants, and it is related to both physical (hardware) and logical (software) aspects of infrastructure. Breach of cyber security may result in loss of safety-sensitive communications, operational information, or propriety data (e.g., customer financial data), and result in reduced efficiency, loss of specific system function or integrity in the ATM system, or potential loss of aircraft and lives.

As with safety, security will require integration of relevant elements across all five pillars. To be effective, security must be designed into the system defined in pillars 1 and 3, and security practices will be integrated into the operations addressed in pillars 2 and 4. Community Integration, pillar 5, must address cyber security concerns in an increasingly interconnected world.

Security will initially rely on current practices to assure safe operation and prevent the use of UAM for nefarious purposes. User authentication will be required to access critical networks, and safety-critical communications will be encrypted or protected by other risk mitigations. UAM will incorporate appropriate technologies and practices to meet evolving security standards, and, in the mature state, autonomous systems will include mitigations and countermeasures to prevent unauthorized access or manipulation.

3.3.6.3 Affordability

UAM will achieve increasing affordability as public acceptance grows, markets expand, and technologies mature. More flexible and efficient allocation and use of airspace (pillars 3 and 4) will increase system capacity and enable optimized flight trajectories. Experience in certifying UAM vehicles will streamline certification, reducing the significant development costs associated with pillar 1. Automation will allow more efficient scaled production and enable more precise use of airspace and materiel resources (pillars

1, 2, 3, and 4). Larger production runs will reduce costs through learning curve effects and the ability to spread investment costs over larger numbers of units (pillar 1). These effects will all contribute to lower ticket prices and help to achieve the targeted benefits of UAM.

3.3.6.4 Noise

Noise is a fourth major barrier which cuts across multiple pillars. Vehicles (pillar 1) must be designed to meet targeted noise objectives, and the airspace system design (pillar 3) must consider noise footprint on the ground and noise abatement routes and procedures. System operation (pillars 2 and 4) must assure adherence to noise constraints, especially in terms of fleet noise. Community Integration plays a major role in motivating low-noise design and operations, and noise concerns are a key element of the power of local authorities to regulate UAM operations and land use (pillar 5).

3.3.6.5 Autonomy

Autonomy to meet the long-range goals for affordability and traffic volumes is an essential part of the vision for UAM. Autonomy will evolve over time, moving from automation performing repetitive predetermined actions, to subsystems autonomously performing automated functions without human involvement, to autonomous systems performing complex tasks. This evolution will enable elimination of some human roles and reduction of skills and training requirements for others. For example, a specially trained person may perform functions that would otherwise require a highly trained and proficient pilot, or a remote operator may direct operation of multiple air vehicles, or a traffic manager may oversee a system that manages hundreds of trajectories. Ultimately, autonomous systems will apply machine learning and self-direction to meet high-level goals without direct involvement by humans. Thus, human roles and required skills and training will change throughout this evolution. To assure safety and gain public acceptance, progress will be paced by successful experience with increasing automation and operation of UAS.

ATM autonomy will leverage significant progress made by NASA and the aviation community over the past two decades and projected for the future, including progress in research and development of UTM and revolutionary VTOL vehicle concepts. Autonomous functions will increasingly become part of the design and operation of UAM vehicles (pillars 1 and 2) and the UAM airspace system (pillars 3 and 4). Public acceptance of autonomy (pillar 5), including the legal framework for establishing responsibility for autonomous operations, will play an important role in enabling incorporation of autonomy in UAM.

3.3.6.6 UAM Ports

UAM ports and pads will be located throughout the metropolitan area near high-demand locations, such as large business, shopping, or tourist districts, or at rail, metro, or other public transportation sites for seamless multimodal connections. UAM ports will tend be sited where supporting infrastructure, such as energy, communications, and physical access, is optimal. Some buildings will feature rooftop UAM ports or UAM stops to serve the needs of occupants. Many of these rooftop sites may also serve as emergency UAM landing facilities in case emergency landing is needed. UAM ports will include all supporting systems required for safety, security, and operational support, such as passenger embarking and disembarking, cargo loading and unloading, maintenance, refueling, and recharging. UAM ports may include UAM pads for VTOL air vehicles or short runways to accommodate STOL air vehicles. UAM pads will also be used where there is insufficient demand or operational advantage to locate a UAM port.

The key crosscutting aspects of UAM ports include the vehicle size and capabilities required for safe landing, takeoff, and surface operations (pillars 1 and 2); their impacts on the surrounding airspace (pillars 3 and 4); and integration in established urban settings (pillar 5). Standards for design and construction of UAM ports and UAM pads will be needed to ensure safety and standardization. To accommodate the integration of UAM ports and UAM pads in a metropolitan area, state and local laws and ordinances will likely need to be modified to minimize restrictions that could otherwise impede operations and to address potential emerging issues, such as burying power lines and removing obstructions.

State and local ordinances will also evolve to provide minimum criteria and guidance for the use of expedient landing and takeoffs. Medevac and other public safety operations should be subject to a separate set of criteria and exempted from nominal restrictions when it is safe to do so.

3.3.6.7 Regulations/Certification

Regulations and certification provide the framework that assures safe operation and conformance with established legal requirements. As such, each pillar impacts the framework, and regulations and certification reach into every element of the system. Policy makers and legislators must ensure that federal, state, and local laws (pillar 5) support the demand for UAM services, and that federal and state laws enable a balance between common and unique community requirements. Regulation, based on science and data, must be commensurate with risk to avoid excessive costs, suboptimization, and distortion of the market. Regulatory development must also be timely and responsive to change to ensure that objectives continue to be valid and to maintain market viability.

Certification requirements for pilots and controllers in UAM operations (pillars 2 and 4) will change as vehicle and ATM autonomy mature and functions expand. Certification of dispatchers, maintenance, and operational management personnel (pillar 2) will evolve to fit UAM operational needs and safety requirements. Commercial operators will still be required to obtain operating certificates, but the requirements will be adapted to UAM operations and the use of UAS and autonomous air vehicles.

The roles of air traffic controller and manager in UAM traffic management will not change in the initial state, but they will evolve as automation and autonomy are applied to support high-volume trajectory management and traffic separation in the intermediate and mature states (pillar 4). Consequently, certification and proficiency requirements will change to fit the new roles and responsibilities.

Air traffic automation and supporting information management systems are subject to operational test and evaluation today, but the complexity of autonomous software systems will likely drive a need for software certification processes comparable to those required for air vehicle systems and avionics.

Harmonization of federal and state laws will also be needed to enable commonality across the country. Partnerships, transportation funding, subsidies, and tax incentives must also evolve to enable the investment necessary to make private real estate available for UAM ports and other infrastructure.

4 UAM Stakeholders

Realization of the UAM vision will be possible only though the efforts and contributions of multiple stakeholders, each of which possesses the necessary authority, expertise, or resources to fulfill a critical role in UAM's development, approval, and implementation. This section of the OpsCon summarizes the stakeholders' roles, including a table showing which stakeholders are best positioned to contribute to each pillar of the UAM System Framework. This list is not exhaustive, and it will likely evolve and change as UAM progresses and new challenges arise, but it illustrates the number and breadth of stakeholders that must be engaged to realize the UAM vision.

4.1 Vehicle Development & Production

4.1.1 Vehicle Design & Integration

NASA and the air vehicle and subsystem industry and their trade organizations will work together to enable and test new designs and technologies and new analysis and design tools to address vehicle safety, mission suitability, and environmental compatibility.

4.1.2 Airworthiness Standards & Certification

As the regulator for aviation safety, the FAA will manage vehicle certification and airworthiness standards and certification. NASA and the aircraft industry will play important roles in identifying risks and alternative designs, technologies, and processes to mitigate those risks. These stakeholders and industry trade groups will also participate in standards development by providing expert knowledge and input to inform the standards and requirements that serve as the basis for aircraft component and airworthiness certification and means of compliance.

4.1.3 Vehicle Noise

Although NASA and the aircraft industry have made significant progress in reducing engine and propeller noise, the reduction of aircraft noise continues to be a challenge. NASA will continue to work with the industry to model, prototype, test, and validate new noise-reduction designs, technologies, and tools and to identify and evaluate the most effective and cost-efficient alternatives. Academia will continue research to develop enhanced analysis methods, including the effects of noise on humans.

4.1.4 Weather-Tolerant Vehicles

Both NASA and aircraft and subsystem manufacturers have experience developing weather-tolerant vehicles and components. NASA has tested a variety of systems and aircraft manufacturers have leveraged that work and the work of component manufacturers to implement systems to counter and avoid various weather phenomena such as icing, lightning, heavy precipitation, and turbulence. UAM vehicles will need to routinely cope with such adverse weather to provide reliable services. Rotorcraft are particularly sensitive to icing, gusty winds, and turbulence, and prototype UAM designs share design similarities and those sensitivities. Consequently, these issues will provide a focus for further research and development.

4.1.5 Cabin Acceptability

Industry is best positioned address cabin comfort and convenience. NASA assistance may be warranted for analyzing and testing the crashworthiness of new vehicle and cabin designs and materials, as well as supporting design and analysis methods for reducing vibration and cabin noise.

4.1.6 Manufacturing & Supply Chain

Industry will have the primary lead in developing viable manufacturing methods and quality control processes to ensure safety, affordability, and adequate production rates. Industry will be supported by organizations with expertise in setting manufacturing standards, such as SAE International. NASA and the FAA will provide guidance and input as needed to support those goals. The FAA will have significant influence in overseeing the processes to ensure that parts meet manufacturing standards and requirements.

4.2 Individual Vehicle Management & Operations

4.2.1 Safe Urban Flight Management

NASA and the FAA will develop capabilities for safe, efficient, and responsive flight planning and execution in metropolitan areas. Industry will implement these capabilities in their systems, procedures, and training.

4.2.2 Increasingly Automated Vehicle Operations

NASA and industry will evaluate and test new methods for vehicle operation that leverage autonomy and information sharing to simplify vehicle operation and reduce skill and training requirements.

4.2.3 Certification & Operational Approval

The FAA will work with NASA, the Department of Defense, and industry to develop new standards and methods for certifying autonomous systems and operations that ensure safety, security, and resilience.

4.2.4 Ground Operations & Maintenance

Operators will identify and develop methods and technologies to support UAM maintenance and ground operations such as surface movement, passenger management, vehicle maintenance, and refueling/recharging. The FAA will continue to be responsible for setting certification and training standards for the people and systems performing these functions.

4.3 Airspace System Design & Implementation

4.3.1 Airspace Design

FAA, with the support of NASA, will identify and evaluate revisions to airspace design and management to support UAM operations, including interoperability between manned and UAS operations.

4.3.2 Operational Rules, Roles, & Procedures

FAA, with the support of NASA, will define new and revised operating rules and procedures to support UAM operations, with a focus on redefining human roles and airspace operating procedures for automated and autonomous vehicle operations.

4.3.3 CNSI & Control Facility Infrastructure

Industry will leverage FAA and NASA expertise to define avionic systems performance standards and develop and produce cost-effective ground and airborne equipment that meets those standards. FAA and other service providers will enable the effective application of these systems.

4.3.4 UAM Port Design

Industry, architectural firms, and urban planners, with input from the FAA and local zoning and building code administrators, will develop safe, functional, and compatible UAM port designs and identify viable locations.

4.4 Air Traffic & Fleet Operations Management

4.4.1 Safe Airspace Operations

As the regulator of ATM services, the FAA will work with NASA and UAM operators to identify requirements for the qualification of UAM ATM service suppliers, procedures, and rules for operations and interoperability with traditional ATM operations.

4.4.2 Efficient Airspace Operations

NASA will work with FAA and the operator community to leverage its advanced technology demonstrations, as well as other work on efficient trajectory-planning tools and automation, to identify technologies and applications for efficient airspace operations for all manned and unmanned aircraft operators.

4.4.3 Scalable Airspace Operations

NASA and ATM service suppliers will identify and evaluate alternative approaches and technologies for scaling UAM ATM systems and services to meet demand and maximize efficient use of ATM resources.

4.4.4 Resilient Airspace Operations

As the agency responsible for the overall safety of the NAS, the FAA will work with the Department of Homeland Security (DHS), NASA, and UAM operators to develop, certify, and adopt technologies and implement operational rules and procedures that will help ensure that the UAM ecosystem is capable of graceful degradation in case of failures within the system, as well as mitigating risks to national security.

4.4.5 Fleet Management

Industry will leverage technologies, applications, and new methods for efficiently managing air vehicle fleets and maximizing human productivity.

4.4.6 Urban Weather Prediction

The National Oceanic and Atmospheric Administration (NOAA) will develop new microclimate forecast models to provide the granularity needed for UAM operations. Weather data providers will assemble, process, and distribute this information for use by UAM operators.

4.5 Community Integration

4.5.1 Public Acceptance

The aviation community will work with states, localities, and local organizations and leaders in various forums to address public safety and other community concerns through education and cooperation.

4.5.2 Supporting Infrastructure

Local authorities, city planners, and investors will work together on state and local zoning ordinances, real estate laws, and airport and land use policies to support the installation of UAM infrastructure, including support infrastructure such as battery charging stations and maintenance facilities. As UAM services grow to large volumes, energy infrastructure and Department of Energy plans, policies, and infrastructure will be affected by the large-scale requirements for electric power.

4.5.3 Operational Integration

The Department of Transportation (DOT), TSA, and UAM service providers will work together to develop technologies, methodologies, and procedures to ensure secure UAM operations and system and operational resilience. They will also work with local and public transportation authorities to integrate UAM facilities and operations with other modes of transportation to provide an integrated multimodal transportation network.

4.5.4 Local Regulatory Environment & Liability

The FAA and UAM operators will work with national and local officials to develop new and revised policies, local ordinances, and state laws that are conducive to UAM operations and facilities. Insurers will also play a role by establishing conditions on their liability and being necessary participants in the development of case law.

4.6 Crosscutting Barriers

As described in Section 3.3.6, crosscutting barriers affect most or all of the pillars, and many of these crosscutting barriers will thus involve the same stakeholders. The stakeholders identified below may be viewed as the entities that will lead, be strongly affected by, or most heavily influence each of the crosscutting barriers.

4.6.1 Safety

Safety is of paramount concern to the public. FAA will provide the framework and services for multiple aspects of safe operation throughout the airspace, as well as protection of people on the ground, while industry, in the form of producers and operators, will assure safe operation of their fleets.

4.6.2 Security

Like safety, security is of critical importance to the public. Operations over or near heavily populated urban areas presents many security challenges. The DOD, DHS, and FAA will work together to establish standards for physical and cyber security, and FAA and the UAS industry will implement systems and processes to meet these standards.

4.6.3 Affordability

NASA-developed concepts and technologies will be the major factor in achieving large reductions from today's operating cost for VTOL aircraft. Industry will develop design and production methods to reduce acquisition and operating cost to satisfy and expand market demand.

4.6.4 Noise

Local authorities, in response to public opinion, will play a vital role in determining allowable noise levels for UAM operations over urban areas. NASA, academia, and industry research will help to shape these requirements, as well as developing technologies and flight procedures to meet them.

4.6.5 Autonomy

Implementation of autonomy will depend on public and private research to assure safe autonomous operations and enable public trust and acceptance. FAA will revise existing regulations and create new ones to enable modification or replacement of human roles and responsibilities.

4.6.6 UAM Ports

The establishment and use of UAM ports will depend heavily on public acceptance – hence the involvement of local authorities involved in regulating construction and land use – as well as financing through public agencies, investors, and public-private partnerships. FAA rules and requirements will govern the operation of UAM ports.

4.6.7 Regulations/Certification

Regulations and certification, including enforcement, are largely the province of the FAA, while state and local authorities will impact UAM through their control of land use, construction, and ordinances. A combination of new, modified, and existing certification standards will be required for new vehicle concepts and the evolving roles of automation and autonomy.

4.7 UAM Stakeholders Summary

Table 11, below, summarizes the lead stakeholders for the various barriers within the five pillars of the UAM System Framework.

Table 11: Stakeholder Leads by UAM System Framework Pillar

Vehicle Development & Production	
Vehicle Design & Integration	Industry and NASA
Airworthiness Standards & Certification	FAA
Vehicle Noise	Industry and NASA
Weather-Tolerant Vehicles	Industry and NASA
Cabin Acceptability	Industry
Manufacturing and Supply Chain	Industry
Individual Vehicle Management & Operations	
Safe Urban Flight Management	FAA, NASA, and Industry
Increasingly Automated Vehicle Operations	NASA and Industry
Certification & Operational Approval	FAA
Ground Operations & Maintenance	Industry
Airspace System Design & Implementation	
Airspace Design	FAA
Operational Rules, Roles, & Procedures	FAA
CNSI & Control Facility Infrastructure	NASA, FAA, and Industry
UAM Port Design	FAA, Local Authorities, Industry
Air Traffic & Fleet Operations Management	
Safe ATM Operations	FAA
Efficient ATM Operations	NASA
Scalable ATM Operations	NASA
Resilient Airspace Operations	FAA, DHS, NASA, Industry
Fleet Management	Industry
Urban Weather Prediction	NOAA, Weather Data Service Providers
Community Integration	
Public Acceptance	Industry, Local Officials and Organizations
Supporting Infrastructure	Local Authorities, Investors, City Planners
Operational Integration	DOT, TSA, UAM Service Providers
Local Regulatory Environment & Liability	Local Authorities, State Officials, Government Policy Makers, Insurers
Crosscutting Barriers	
Safety	FAA, Industry
Security	TSA, Other Government Agencies, FAA, Industry
Affordability	NASA, Industry
Noise	Local Authorities, NASA, Academia, Industry
Autonomy	NASA, Academia, FAA
UAM Ports	Local Authorities, Investors, Public-private Partnerships, FAA
Regulations/Certification	FAA, State and Local Authorities

Appendix A – Key References

1. International Organization for Standardization/International Electrotechnical Commission/Institute of Electrical and Electronics Engineers, International Standard – Systems and Software Engineering – Life Cycle Processes – Requirements Engineering, ISO/IEC/IEEE 29148:2011(E), 2011.

2. American National Standards Institute/American Institute of Aeronautics and Astronautics, Guide to the Preparation of Operational Concept Documents, G-043B Revision of G-043A-2012, 2018.

3. Federal Administration Aviation, Flight Standards Information Management System, Order 8900.1, 2014.

4. Uber, Fast-Forwarding to a Future of On-Demand Urban Air Transportation, 2016.

5. National Research Council, A Review of the Next Generation Air Transportation System: Implications and Importance of System Architecture, The National Academies Press, 2015.

Appendix B – Key Terms and Definitions Glossary

As the community matures, many of these terms and their definitions will evolve to better reflect the envisioned concepts, shared community understanding, and evolving technologies. Parentheses at the end of a definition indicate the source of the definition.

4D Trajectory: The trajectory of an aircraft consisting of the three spatial dimensions plus time as a fourth dimension.

Air Traffic Control: A service operated by appropriate authority to promote the safe, orderly, and expeditious flow of air traffic within the NAS. The primary purpose of the ATC system is to prevent a collision between aircraft operating in the system and to provide a safe, orderly, and expeditious flow of traffic, and to provide support for National Security and Homeland Defense. (FAA)

Air Traffic Management: Air traffic management is an aviation term encompassing all systems that assist aircraft to depart from an aerodrome, transit airspace, and land at a destination aerodrome, including Air Traffic Services, Airspace Management, and Air Traffic Flow and Capacity Management.

Airspace: The two categories of airspace are regulatory and non-regulatory. Within these two categories, there are four types: controlled, uncontrolled, special use, and other airspace. The categories and types of airspace are dictated by the complexity or density of aircraft movements, nature of the operations conducted within the airspace, the level of safety required, and national and public interest. (FAA)

Autonomous Operation: An operation during which a remotely piloted aircraft is operating without pilot intervention in the management of the flight. (ICAO). Used generically in this OpsCon to encompass all levels of autonomy from automated functions with human oversight to fully autonomous systems capable of self-governance. (NASA)

Automation: The ability of a system to execute tasks to achieve a predetermined outcome based on fixed set of rules with little or no human interaction.[33]

Autonomy: The ability of a system to achieve goals while operating independently of external control. It requires self-directedness to achieve goals and self-sufficiency to operate independently. (NASA)

Autonomous Air Vehicle: An air vehicle that may or may not be carrying passengers or cargo and that is partially or fully controlled and managed by autonomy, with no onboard or remote human pilot manipulating the flight controls. An autonomous air vehicle does not require a pilot-in-command as currently defined in FAA regulations (e.g. 14 CFR 1.1) as these responsibilities and authorities (e.g. 14 CFR 91.3) are delegated to the air vehicle. It is expected that operational control as defined in 14 CFR 1.1 (i.e., operational control, with respect to a flight, means the exercise of authority over initiating, conducting or terminating a flight) will remain under the authority of an appropriately qualified, informed, and accountable chain of command with the capacity for human oversight and intervention.

Collision Avoidance: Achieved when the aircraft maneuvers after becoming aware of conflicting traffic by one of the following means: Visual observation, Airborne Collision Avoidance System alert, or traffic information provided by Air Traffic Control.

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[33] P. Abbeel et al., Toward a Science of Autonomy for Physical Systems, *Semantic Scholar*, 2016.

Conflict Resolution or Avoidance: The resolution of potential conflictions between aircraft that are radar identified and in communication with ATC by ensuring that radar targets do not touch. Pertinent traffic advisories shall be issued when this procedure is applied.

Controlled Airspace: The generic term that covers the different classifications of airspace and defined dimensions within which air traffic control (ATC) service is provided in accordance with the airspace classification: A, B, C, D, and E. (FAA)

Controller: A person authorized to provide air traffic control service. (FAA)

Expedient Landing Site: A landing site accessible and suitable for safe takeoffs and landings, but lacking the permanent infrastructure normally associated with a purpose-built takeoff and landing area (UAM port/pad), and which may be identified and determined to be acceptable on short notice.

Exurb: A region or settlement that lies outside a city and usually beyond its suburbs and that often is inhabited chiefly by well-to-do families. (Merriam-Webster)

Fixed-wing: Denoting aircraft of the conventional type as opposed to those with rotating wings, such as helicopters. (Merriam-Webster)

Flight Crew Member: A licensed crew member charged with duties essential to the operation of an aircraft during a flight duty period. (ICAO) ...A pilot, flight engineer or flight navigator. (U.S. Code of Federal Regulations)

Flight Plan: Specified information relating to the intended flight of an aircraft that is filed orally or in writing with an FSS or an ATC facility. (FAA)

General Aviation: That portion of civil aviation that does not include scheduled or unscheduled air carriers or commercial space operations. (FAA)

Helipad: A small, designated area, usually with a prepared surface, on a heliport, airport, landing/takeoff area, apron/ramp, or movement area used for takeoff, landing, or parking of helicopters. (FAA)

Heliport: An area of land, water, or structure used or intended to be used for the landing and takeoff of helicopters and includes its buildings and facilities if any. (FAA)

Industry: The network of enterprises that produces aviation and aviation-related products.

Instrument Flight Rules: Rules governing the procedures for conducting instrument flight. Also, a term used by pilots and controllers to indicate type of flight plan. (FAA)

Instrument Meteorological Conditions: Meteorological conditions expressed in terms of visibility, distance from cloud, and ceiling less than the minima specified for visual meteorological conditions. (FAA)

Landing Area: Any locality either on land, water, or structures, including airports/heliports and intermediate landing fields, which is used, or intended to be used, for the landing and takeoff of aircraft whether or not facilities are provided for the shelter, servicing, or for receiving or discharging passengers or cargo. (FAA)

Metropolitan Area: A major city together with its suburbs and nearby cities, towns, and environs over which the major city exercises a commanding economic and social influence. (Encyclopedia Britannica)

National Airspace System: The common network of U.S. airspace; air navigation facilities, equipment and services, airports or landing areas, aeronautical charts, information and services, rules, regulations, procedures, technical information, and manpower and material. Included are system components shared jointly with the military. (FAA)

Operator: A person, organization or enterprise engaged in or offering to engage in an aircraft operation. (ICAO)

Operator In Charge: A person who is responsible for the safe conduct of a semi- or fully autonomous vehicle system flight when there is no pilot in command (PIC), and that serves as the available point of contact for management of that vehicle and flight.

Passenger: A traveler on a public or private conveyance other than the driver, pilot, or crew.

Payload: The part of a vehicle's load, especially an aircraft's, from which revenue is derived; passengers and cargo.

Pilot (flying): A person who operates the flying controls of an aircraft and is responsible for the flight trajectory of the aircraft. (ICAO)

Pilot-in-Command: The pilot designated by the operator, or in the case of general aviation, the owner, as being in command and charged with the safe conduct of a flight. (ICAO) The pilot responsible for the operation and safety of an aircraft during flight time. (FAA 14 CFR Part 91.)

Remote Pilot in Command: The official term given by the FAA for the individual who either directly operates the UAS or directly supervises another individual operating the UAS. The Remote Pilot in Command must have a Remote Pilot Airman Certificate and otherwise abide by the necessary FAA regulations and this policy.

Remote Pilot: The person who manipulates the flight controls of a remotely piloted aircraft during flight time.

Remotely Piloted Aircraft: An aircraft where the flying pilot is not on board the aircraft. This is a subcategory of unmanned aircraft.

Remotely Piloted: Control of an aircraft from a pilot station which is not on board the aircraft.

Rotary Wing: An airfoil that rotates in an approximately horizontal plane, providing all or most of the lift in a helicopter or autogiro. (Merriam Webster)

Semi-autonomous: Performing automated functions without direct human involvement as part of a larger system with human oversight.

Separation: In air traffic control, the spacing of aircraft to achieve their safe and orderly movement in flight and while landing and taking off. (FAA)

Short Takeoff and Landing Aircraft: An aircraft which, at some weight within its approved operating weight, is capable of operating from a runway in compliance with the applicable STOL characteristics, airworthiness, operations, noise, and pollution standards. (FAA)

Speech Interference Level: Arithmetic average sound pressure levels at the 500, 1,000, and 2,000 Hz center frequencies as a measure of the degree to which background noise interferes with speech; 90 dB corresponds to a very loud voice at a distance of 1 ft.

Stakeholder: One who is involved in or affected by a course of action. (Merriam Webster)

Suburb: A smaller community adjacent to or within commuting distance of a city. (Merriam Webster)

Taxi: The movement of an airplane under its own power on the surface of an airport. Also, it describes the surface movement of helicopters equipped with wheels. (Related rotorcraft terms: Air Taxi, Hover Taxi). (FAA)

Traffic Alert and Collision Avoidance System: An airborne collision avoidance system based on radar beacon signals which operates independent of ground-based equipment. TCAS-I generates traffic advisories only. TCAS-II generates traffic advisories, and resolution (collision avoidance) advisories in the vertical plane.

UAM Community: Entities who share a common interest and exchange information toward the implementation and evolution of UAM.

UAM Pad: An area suitable for the landing and takeoff of a single UAM vehicle; stand-alone UAM pads (i.e., those which are not a part of a larger UAM port) include at least the minimum infrastructure necessary to safely land, takeoff, and load or unload passengers or cargo.

UAM Port: A purpose-built facility with multiple UAM pads, designed for simultaneous use by multiple manned and unmanned air vehicles, including all supporting systems required for safe operations, such as ground support and landing aids, and to enable operations in accordance with the operator's strategy (e.g., passenger embarkation and debarkation, cargo loading and unloading, maintenance, refueling or recharging). UAM ports include multiple UAM pads for vertical takeoff and landing (VTOL) vehicles or short runways to accommodate STOL vehicles.

Unmanned Aircraft: A device used or intended to be used for flight that has no onboard pilot. This device can be any type of airplane, helicopter, airship, or powered-lift aircraft. (FAA)

Unmanned Aircraft System: An unmanned aircraft and its associated elements related to safe operations, which may include control stations (ground, ship, or air based), control links, support equipment, payloads, flight termination systems, and launch/recovery equipment. It consists of three elements: unmanned aircraft, control station, and data link. (FAA)

Urban Air Mobility: The combination of ATM, UAM ports, air vehicle systems, and other support systems necessary to conduct safe and efficient air passenger and cargo operations, including small package delivery and other urban services, in an urban or broader metropolitan environment.

Urban Air Mobility Air Traffic Management: ATM systems dedicated to assisting UAM vehicles to depart from a designated area, transit airspace, and land at a destination area, including Air Traffic Services, Airspace Management, and Air Traffic Flow and Capacity Management.

Urbanized Area: Area with a population of over 50,000 (Census)

Vertical Takeoff and Landing Aircraft: An aircraft that can hover, take off, and land vertically. This classification includes helicopters, fixed-wing aircraft with direct-lift capability, tiltwing and tiltrotor aircraft, and other configurations.

Visual Flight Rules: Rules that govern the procedures for conducting flight under visual conditions. The term VFR is also used in the United States to indicate weather conditions that are equal to or greater than minimum VFR requirements. In addition, it is used by pilots and controllers to indicate type of flight plan. (FAA)

Visual Meteorological Conditions: Meteorological conditions expressed in terms of visibility, distance from cloud, and ceiling equal to or better than specified minima. (ICAO)

Weather-tolerant Operations: Takeoff, departure, approach, or landing operations where visual reference is limited by weather conditions or atmospheric conditions.

Appendix C – Acronyms and Abbreviations

4D: Four-dimensional

5G: Fifth generation cellular mobile communications

A&P: Airframe and Powerplant

AC: Advisory Circular

ACARS: Aircraft Communications Addressing and Reporting System

ACAS: Airborne Collision Avoidance Systems

AD: Airworthiness Directive

ADS-B: Automatic Dependent Surveillance – Broadcast

AGL: Above Ground Level

AIAA: American Institute of Aeronautics and Astronautics

AOC: Airline Operations Center

ARMD: (NASA) Aeronautics Research Mission Directorate

ARTCC: Air Route Traffic Control Centers

ATC: Air Traffic Control

ATCSCC: Air Traffic Control System Command Center

ATCT: Airport Traffic Control Tower

ATM: Air Traffic Management

ATP: Air Transport Pilot

CDM: Collaborative Decision Making

CNS: Communication, Navigation, and Surveillance

CNSI: Communication, Navigation, Surveillance, and Information

ConOps: Concept of Operations

dB: Decibel(s)

DHS: Department of Homeland Security

DME: Distance Measuring Equipment

DOT: Department of Transportation

EMT: Emergency Medical Technician

ETOPS: Extended Operations

eVTOL: Electric Vertical Takeoff and Landing

FAA: Federal Aviation Administration

FAR: Federal Aviation Regulation

FOC: Flight Operations Center

ft: Foot/Feet

GLONASS: Global Navigation Satellite System (Russia)

GNSS: Global Navigation Satellite Systems

GPS: Global Positioning System

HFACS: Human Factors Analysis and Classification System

Hz: Hertz

IA: Inspection Authorization

IASMS: In-time Aviation Safety Management Systems

ICAO: International Civil Aviation Organization

IEEE: Institute of Electrical and Electronics Engineers

IFR: Instrument Flight Rules

ILS: Instrument Landing System

IMC: Instrument Meteorological Conditions

INS: Inertial Navigation System(s)

lb: Pound(s)

MOA: Military Operations Area

MSL: (Above) Mean Sea Level

NAS: National Airspace System

NASA: National Aeronautics and Space Administration

NDB: Non-Directional Beacon

NIH: National Institutes of Health

NM: Nautical Mile(s)

NOAA: National Oceanic and Atmospheric Administration

OIC: Operator In Charge

OpsCon: Operational Concept

OpsSpecs: Operating Specifications

PIC: Pilot in Command

RADAR: Radio Detection and Ranging

RCO: Remote Communications Outlet

RNAV: Area Navigation

RNP: Required Navigation Performance

SHF: Super High Frequency

STOL: Short Takeoff and Landing

SUA: Special Use Airspace

sUAS: small Unmanned Aircraft System

STC: Supplemental Type Certificate

TAF: Terminal Area Forecast

TCAS: Traffic Alert and Collision Avoidance System

TFM: Traffic Flow Management

TFR: Temporary Flight Restriction

TRACON: Terminal Radar Approach Control

TSA: Transportation Security Administration

UAM: Urban Air Mobility

UAS: Unmanned Aircraft System(s)

UCAT: UAM Coordination and Assessment Team

UHF: Ultra High Frequency

UTM: UAS Traffic Management

V/STOL: Vertical/Short Takeoff and Landing

VFR: Visual Flight Rules

VHF: Very High Frequency

VMC: Visual Meteorological Conditions

VOR: Very High Frequency Omni-Directional Range

VTOL: Vertical Takeoff and Landing