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# ASSURE A41/42 – Investigate and Identify the Key Differences Between Commercial Air Carrier Operations and Unmanned Transport Operations/From Manned Cargo to UAS Cargo Operations: Future Trends, Performance, Reliability, and Safety Characteristics Towards Integration into the NAS: Literature Review

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| **16. Abstract**<br>This literature review explored multiple facets of Advanced Air Mobility (AAM), which encompass primary subsets of UAS operations aimed at transporting cargo – i.e., Unmanned Air Cargo (UAC), and passengers – i.e., Regional Air Mobility (RAM) and Urban Air Mobility (UAM). In doing so, the research team explored literature relating to airspace considerations, regulatory constraints, automation, design and airworthiness, Unmanned Traffic Management (UTM), and economic variables.<br>Through this literature review, important aspects of AAM such as the economic drivers, technology advancement, and the overall societal acceptance of this new aviation paradigm. To summarize, the literature identified several gaps in various focus areas that emphasize areas where additional research is needed. The first major hurdle to AAM is the need to establish regulatory constraints regarding the use of airspace, Unmanned Traffic Management (UTM), and aircraft/system certification practices to account for the rapid pace of technological development. There is an emphasis on autonomy, which will ultimately reduce the role of the pilot over time. This in turn will necessitate the need to update current regulations – e.g., 14 CFR Parts 91, 121, 135, etc., as industry seeks to integrate new and novel aircraft into the airspace for transporting both goods and people. Similarly, there will be a role for industry consensus groups to develop and adopt standards for design, airworthiness, and other facets of AAM to supplement either existing regulations or fill gaps such that system manufacturers are able to demonstrate that their aircraft are safe and reliable.<br>Finally, the literature identified numerous economic drivers that may facilitate the integration of AAM. Willingness to pay, regional demand, access to the appropriate infrastructure, power consumption, and direct/indirect costs associated with these aircraft will play a role. While it is anticipated that demand AAM will inevitably increase, there are discrete differences in how UAC, RAM, and UAM are anticipated to evolve. According to the literature, it is anticipated that initial pushes for large-scale UAS operations will begin with UAC, slowly implement greater autonomy, and transition for higher levels of automation to accommodate RAM and UAM. |

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| | |
|---|---|
| AAM | Advanced Air Mobility |
| AGL | Above Ground Level |
| ANSI | American National Standard Institute |
| ANSP | Air Navigation Service Providers |
| ATC | Air Traffic Control |
| ATM | Air Traffic Management |
| ATP | Airline Transport Pilot |
| ATTCS | Automatic Takeoff Thrust Control System |
| BVLOS | Beyond Visual Line of Sight |
| CAA | Civil Aviation Authorities |
| CAGR | Compound Average Annual Growth Rate |
| CBD | Central Business District |
| CFI | Certified Flight Instructor |
| CFIT | Controlled Flight into Terrain |
| CFR | Code of Federal Regulations |
| CNS | Communication, navigation, and surveillance |
| CONOPs | Concept of Operations |
| COTS | Commercial Off-the-Shelf |
| CoW/A | Certificate of Waiver or Authorization |
| CSA | Combined Statistical Area |
| DAL | Design Assurance Level |
| D&R | Durability and Reliability |
| DoD | Department of Defense |
| DOT | Department of Transportation |
| EVAA | Expandable Variable Autonomy Architecture |
| eVTOL | Electric Vertical takeoff and Landing |
| FAA | Federal Aviation Administration |
| FDAL | Functional Design Assurance Level |
| FTD | Flight Training Device |
| GCAS | Ground Collision Avoidance System |
| ICAO | International Civil Aviation Organization |
| IDAL | Item Design Assurance Level |
| IFR | Instrument Flight Rules |
| JARUS | Joint Authorities for Rulemaking on Unmanned Systems |
| JIT | Just-in-Time |
| KPI | Key Performance Indicators |
| MHz | Mega Hertz |
| MM-RTA | Multi-Monitor Runtime Assurance |
| MSCAA | Memphis-Shelby County Airport Authority |
| MTSI | Modern Technology Solutions Inc. |
| NAA | National Aviation Authority |
| NAS | National Airspace System |
| NASA | National Aeronautics and Space Administration |

| | |
|---|---|
| NOA | Notice of Availability |
| NPRM | Notices of Proposed Rulemaking |
| OSO | Operational Safety Objectives |
| PSP | Partnership for Safety Plan |
| RPC | Remote Pilot Competency |
| RTA | Runtime Assurance |
| RTCA | Radio Technical Commission for Aeronautics |
| SAE | Society of Automotive Engineers |
| SCI | Sanmina Corporation |
| SDSP | Supplemental Data Service Provider |
| SOP | Standard Operating Procedure |
| SORA | Specific Operations Risk Assessment |
| SRA | Safety Risk Analysis |
| SRMD | Safety Risk Management Document |
| sUAS | Small Unmanned Aircraft System |
| SVO | Simplified Vehicle Operations |
| TC | Type Certificate |
| UA | Unmanned Aircraft |
| UAC | Unmanned Air Cargo |
| UAH | University of Alabama Huntsville |
| UAM | Urban Air Mobility |
| UAS | Unmanned Aircraft Systems |
| UASSC | Unmanned Aircraft Systems Standardization Collaborative |
| USAF | United States Air Force |
| USC | United States Code |
| USS | UTM Service Suppliers |
| UTM | Unmanned Traffic Management |
| V&V | Verification and Validation |
| VFR | Visual Flight Rules |
| VTOL | Vertical Takeoff and Landing |

# EXECUTIVE SUMMARY

The vision to revolutionize mobility within metropolitan areas and beyond is one of the new frontiers in modern aviation. Building on the gradual successes of 14 Code of Federal Regulation (CFR) Part 135 applications under the Integration Pilot Program (IPP), aviators are paving the way to unmanned air cargo (UAC), followed eventually by unmanned passenger transport. A continuous role for the Federal Aviation Administration (FAA) revolves around engagement with the community to identify and address the key differences between unmanned and manned operations, opportunities, and challenges ahead underlying this likely development. The passenger transportation network ecosystem and its associated technologies are among the most complex aviation endeavors the aviation community has experienced, and the opportunities to facilitate the full integration of Unmanned Aircraft Systems (UAS) into the National Airspace System (NAS) are monumental. As the FAA requires further understanding of this environment to analyze the differences as they compare to traditional manned air transportation and air cargo, these analyses will enhance decision making for future policy development. This research will highlight the anticipated needs of the FAA to support further integration of UAS in air transportation and air cargo operations metropolitan areas across the United States, including suburbs and exurbs.

This literature review explored multiple facets of Advanced Air Mobility (AAM), which encompass primary subsets of UAS operations aimed at transporting cargo – i.e., UAC, and passengers – i.e., Regional Air Mobility (RAM) and Urban Air Mobility (UAM). In doing so, the research team explored literature relating to airspace considerations, regulatory constraints, automation, design and airworthiness, Unmanned Traffic Management (UTM), and economic variables.

Through this literature review, the researchers uncovered important aspects of AAM such as the economic drivers, technology advancement, and the overall societal acceptance of this new aviation paradigm. To summarize, the literature identified several gaps that emphasize areas where additional research is needed. The first major hurdle to AAM is the need to establish regulatory constraints regarding the use of airspace, UTM, and aircraft/system certification practices to account for the rapid pace of technological development. There is an emphasis on autonomy, which will ultimately reduce the role of the pilot over time. This in turn will necessitate the need to update current regulations – e.g., Parts 91, 121, 135, etc., as industry seeks to integrate novel aircraft into the airspace for transporting both goods and people. Similarly, there will be a role for industry consensus groups to develop and adopt standards for design, airworthiness, and other facets of AAM to supplement either existing regulations or fill gaps such that system manufacturers are able to demonstrate that their aircraft are safe and reliable.

Finally, the literature identified numerous economic drivers that may facilitate the integration of AAM. Willingness to pay, regional demand, access to the appropriate infrastructure, power consumption, and direct/indirect costs associated with these aircraft will play a role. While it is anticipated that AAM demand will inevitably increase, there are discrete differences in how UAC, RAM, and UAM will evolve. According to the literature, it is anticipated that initial pushes for large-scale UAS operations will begin with UAC, slowly implement greater autonomy, and transition to higher levels of automation to accommodate RAM and UAM.

# 1 INTRODUCTION & BACKGROUND

The Federal Aviation Administration (FAA) charted a path towards the integration of Unmanned Aircraft Systems (UAS) into the National Airspace System (NAS) from low-risk isolated operations to full integration as a function of airspace management and regulatory activities in its "Integration of Civil Unmanned Aircraft Systems (UAS) in the National Airspace System (NAS) Roadmap" (Federal Aviation Administration, 2020b). The FAA identified the most challenging UAS operations as those related to the movement of passengers and large-scale air cargo in urban and rural environments, collectively known as Advanced Air Mobility (AAM) (Federal Aviation Administration, 2020b; National Academies of Sciences, Engineering, 2020).

The concept of urban-centered travel has existed for decades using conventional helicopter services as a mode of air transportation. Unfortunately, this air transportation paradigm has not scaled accordingly due to the inherent high operating costs and the negative response towards noise pollution. The FAA (2020d) ascertained that recent advances in technologies, specifically, electrical storage technologies, may enable the evolution of urban-centered travel using aircraft that will cost less, emit less noise pollution, and provide enhanced levels of safety through sophisticated levels of autonomy. The FAA (2020d) envisions Urban Air Mobility (UAM) as a highly automated, cooperative paradigm geared to offer air transportation services for cargo transport and passenger travel to relieve the consistent increases in-ground traffic resulting in longer commute times annually. According to FAA (2020d), 8.8 billion hours are spent by Americans sitting in road traffic, with an expected increase of approximately 14 % by the year 2023. The FAA believes as ground traffic demands continue to increase, the potential for UAM as an alternative transportation modality is possible to alleviate the projected congestion.

Certainly, the emerging paradigm of AAM has the potential to revolutionize the multi-modal transportation business model. The concept of AAM captures a continuum of applications from larger cargo-carrying air vehicles to larger passenger-carrying air taxis. The revolutionary vision to change the method in which we move goods and people has led to significant technological developments that include concept ideas for Vertical Take-Off and Landing (VTOL) vehicles, vertiports, and prototype AAM ecosystem(s) to better understand the viability and challenges associated with this market space and to better understand the economic sustainability and infrastructure affordability of AAM.

To date, there are several challenges associated with UAM. Bulusu et al. (2021) suggested the multi-modal travel paradigm is complex, and all mobility today could be described as door to door. For instance, they describe the process in which individuals in our society traverse from their residence to their place of employment, to school, to airports, to subways, and maritime facilities in a uni-modal (e.g., drive their automobile) or multi-modal fashion using one or multiple sources of public transportation. With both described modalities, Bulusu suggests the end-user must accept a level of compromise. Additionally, for UAM to be justifiable in terms of public investment, UAM must relieve the burden on current urban mobility by occupying a large and sizeable portion of urban traffic in a highly cost-effective manner (Bulusu et al., 2021).

Unmanned Air Cargo (UAC) operations possess the potential to significantly improve the quality of life for the residents of remote communities through an increase in the frequency of service and a potential decrease in transport costs; however, they, like UAM operations, have challenges. For

UAC operations to be feasible, commercial operators need to overcome the challenges associated with safely flying long distances beyond the visual line of sight of the remote pilot in command. The operators also must obtain an Air Carrier Certificate from the FAA as specified in 14 Code of Federal Regulations (CFR) Part 135, and a Certificate of Economic Authority from the Office of the Secretary of Transportation to conduct any cargo-carrying operations for hire as outlined in 14 CFR Chapter II. One of the requirements for the Air Carrier Certificate is the use of an aircraft certified as airworthy by the FAA (i.e., type-certified). To date, the FAA has not granted any aircraft this certification for air cargo operations. The technical and regulatory challenges inherent in conducting this type of operation have prevented any large-scale, commercial UAS cargo operations to date.

# 2 LITERATURE REVIEW

This literature review explores the multi-faceted challenges associated with integrating unmanned air transport and cargo aircraft into the NAS. As such, it touches upon key topics where further research is needed to address concerns such as airspace integration, economic impacts, and issues relating to certification and airworthiness. This literature review is intended to inform future tasks for ASSURE A41 and ASSURE A42, and is considered foundational to a market analysis, economic assessment, and a further exploration of plausible use cases.

## 2.1 Definitions and Common Terms

As the research team explored the multiple facets of AAM, UAM, and UAC, challenges arose regarding the use of terminology. Given that AAM, UAM, and UAC are relatively new to aviation, many of the common terms require an explicit definition for the sake of clarity, and in some cases, these terms were coined within the industry. This section identifies common terms and definitions that the research team encountered as part of this literature review, with the goal of providing clarity and a concise understanding of key terms relating to AAM, UAM and UAC operations. Common terms and applicable definitions that were derived through this literature search are shown in **Error! Reference source not found.**

Table 1. Common Terms and Definitions

| Common Term | Definition | Source |
|---|---|---|
| Advanced Air Mobility (AAM) | Represents an ecosystem of emerging aviation technologies and concepts that allows the transportation of people and goods to locations in both rural and urban environments, including those not traditionally served by current modes of air transportation. | (National Academies of Sciences, Engineering & Medicine, 2020) |
| On-Demand Aviation | Refers to an envisaged air taxi service, using small, autonomous, vertical-takeoff-and-landing, battery-powered electric aircraft. | (Brown & Harris, 2020) |

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| On-Demand Mobility | Multi-modal transportation capability in which individuals have access to immediate and flexible high-speed transportation, which can incorporate air travel, to take them safely and efficiently from one location to another over ranges of approximately 10 to 500 miles. | (Patterson et al., 2018) |
| Payload | Payload is related to surveillance, weapons delivery, communication, aerial sensing, cargo, or many other applications needed to accomplish a mission. | (Marshall et al., 2015) |
| Regional Air Mobility (RAM) | An accessible air transport system for passenger and cargo in rural and urban environments. | (NASA, 2021) |
| Remote Vehicle Operations (RVO) | A concept of operations where aircraft are remotely controlled by some combination of one or more humans piloting a single aircraft or operating/monitoring many aircraft with varying degrees of automation support. | (Chancey & Politowicz, 2020) |
| Simplified Vehicle Operations (SVO) | The use of automation coupled with human factors best practices to reduce the quantity of trained skills and knowledge that the pilot or operator of an aircraft must acquire to operate the system at the required level of safety | (Wing et al., 2020) |
| Small Unmanned Aircraft (sUA) | An unmanned aircraft weighing less than 55 pounds on takeoff, including everything that is onboard or attached to the aircraft | (Federal Aviation Administration, 2021a) |
| Small Unmanned Aircraft System (sUAS) | A small unmanned aircraft and its associated elements, including communication links and the components that control the small unmanned aircraft; that are required for the safe and efficient operation of | (Federal Aviation Administration, 2021a) |

| | | |
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| | the small unmanned aircraft in the NAS. | |
| Sub-Urban Air Mobility (SUAM) | These missions extend to UAM missions and aim at connecting the extended suburbs of large metroplexes together. | (Justin & Mavris, 2019) |
| UAS Traffic Management (UTM) | A cloud-based system designed to help keep drones from colliding with one another. | (Federal Aviation Administration, 2020d) |
| Urban Air Mobility (UAM) | Safe and efficient air traffic operations in a metropolitan area for manned aircraft and unmanned aircraft systems. | (Thipphavong et al., 2018) |
| UTM Service Suppliers (USS) | Comparable to traditional ATC services provided to IFR and VFR aircraft. Service providers that ensure safe UAS operations by providing information for operations, communications for activities, and archives to storage operational data. | (Lascara et al., 2019) |
| Vertihub | Contains several vertiports and controls all UAS operations in their local airspace. | (Bharadwaj et al., 2021) |
| Vertistop | A single launch pad facility where customers quickly exchange between drop off and pick up | (Northeast UAS Airspace Integration Research Alliance (NUAIR), 2021) |
| Vertipad | Touchdown and liftoff pads for aircraft landing and take-off. | (Wu & Zhang, 2021) |
| Vertiport | A larger site with several landing pads and also supports the air taxis with charging and repair facilities. | (Northeast UAS Airspace Integration Research Alliance (NUAIR), 2021) |

## 2.2 Introduction to Urban Air Mobility (UAM) and Advanced Air Mobility (AAM)

UAM is a concept meant to encompass a vision of future flight operations, specifically within urban and suburban environments. Operations will use AAM technology and services to transport passengers or cargo. UAM is a subset of AAM according to *Urban Air Mobility (UAM): Concept of Operations*, written and published by the FAA (Federal Aviation Administration, 2020d). AAM is a broad term that defines the future transformation and possibilities of the NAS. Plans for the NAS to grow more complex and house UAM begin with AAM. Outside of urban and suburban areas, AAM "supports operations moving people and cargo between local, regional, intraregional," and other environments (Federal Aviation Administration, 2020d).

## 2.3 National Airspace System (NAS) and Modernization

The NAS is a vast network of airspace classes consisting of both controlled and uncontrolled airspaces (Federal Aviation Administration, 2020c). On any given day, this airspace, "provides traffic service to more than 45,000 flights and 2.9 million airline passengers traveling across the more than 29 million square miles that make up the U.S. national airspace system [sic] (NAS)" (Federal Aviation Administration, 2020c). These 45,000 daily flights consist of different airspace users, ranging from general aviation pilots to commuter flights, cargo flights, international travelers, air ambulances, and more.

Of interest to this literature review is the overall structure of the airspace within the NAS and the scalability of Air Traffic Control (ATC), as it is anticipated that the introduction of high-volume unmanned flight operations will facilitate changes in how air traffic is managed. According to Vascik et al.,

> The scalability of ATC is expected to become an increasingly more significant issue for aviation due to the proliferation of UAS for both commercial and hobbyist purposes as well as the anticipated emergence of large-scale UAM systems that aim to provide passenger services within metropolitan areas. (2018)

As such, changes to the NAS and/or ATC to accommodate new aviation paradigms may be needed for UAM and UAC. Such changes may come in the form of the FAA's ongoing NextGen modernization effort and further exploration of Unmanned Traffic Management (UTM) solutions for handling high volumes of both manned and unmanned air traffic.

> The FAA's Next Generation Air Transportation System (NextGen) is the FAA-led modernization of America's air transportation system to make flying even safer, more efficient, and more predictable" (Federal Aviation Administration, 2021e). While NextGen is not a single technology or system in and of itself, it does represent a series of technological improvements aimed at updating and streamlining three primary facets of the interconnected systems that help the NAS to function, consisting of communications, navigation, and surveillance elements. (Federal Aviation Administration, 2021e)

According to the FAA's website *How NextGen Works*, NextGen seeks to create "new interconnected systems that fundamentally change and improve communications, navigation, and surveillance in the NAS" (Federal Aviation Administration, 2020a). In doing so, NextGen implements the following fundamental improvements to communications, navigation, and surveillance capabilities within the NAS. The following key features of NextGen are extracted from the FAA's website *How NextGen Works*:

> **Communications:** In a modernized NAS, aircraft must be able to receive dynamic, complex instructions from ground systems that can identify where they need to be and at what time. Data Communications help pilots and air traffic controllers to communicate more quickly, more easily, and with less risk of miscommunication than radio messages over busy frequencies.

> **Navigation:** The FAA has switched to a primarily satellite-enabled navigation system that is more precise than traditional ground-based navigation aids. Satellites enable the FAA to create optimal flight paths anywhere in the NAS for departure, cruising altitude, arrival, and landing operations. These precise, efficient procedures can reduce flying time, fuel use, and aircraft exhaust emissions while getting passengers to their destinations at more predictable times.
>
> **Surveillance:** The ongoing implementation of NextGen provides air traffic controllers with the exact location of aircraft and a clear vision of surrounding conditions, including weather patterns and aircraft (Federal Aviation Administration, 2020a).
>
> **Information:** According to the latest NASA framework, information is a key component in Next-Gen Architecture. According to a NASA working group addressing the conceptual AAM ecosystem, "Secure information exchange enables vehicle-to-vehicle and vehicle-to-infrastructure communication for data exchange, vehicle separation, and navigation" (NASA, 2020).

While these technological improvements to the NAS are not directly aimed at unmanned air transport and/or UAC in and of themselves, they are significant as they pave the way for supporting services that would support multiple facets of AAM, including UAM and UAC. Additional dedicated traffic management constructs, such as UTM, are anticipated to address unique needs for unmanned traffic.

According to *Urban Air Mobility Airspace Integration Concepts* by Lascara et al., (2019) UTM is "another construct currently under development for use by UAS operating at low altitudes (e.g., below 400 feet)." UTM is intended to provide "a set of traffic management services via a federated group of UTM Service Suppliers (USS), comparable to traditional ATC services provided to IFR [Instrument Flight Rules] and VFR [Visual Flight Rules] aircraft" (Lascara et al., 2019). UTM as a larger construct within the NAS offers unique functionality to support large volumes of unmanned air traffic and is discussed in more detail later in this literature review.

## 2.4 Title 14 CFR Part 91

Title 14 CFR Part 91 encompasses the general operating and flight rules for aircraft within the NAS. Of particular interest to AAM, UAM, and UAC are portions of Part 91 that govern visual and instrument flight rules. This is especially so when addressing the problem of mitigating the risk of airborne collisions. According to Lascara et al. (2019) "two flight rules constructs are used to mitigate risks of collision and ensure a smooth flow of traffic: Visual Flight Rules (VFR) and Instrument Flight Rules (IFR)" (Lascara et al., 2019). However, to expand the NAS to allow for UAM, the two Part 91 flight rule constructs would have to be altered. Updates to § 91.113, see and avoid regulations, would alter the requirement for the pilot to be in the loop and physically see and avoid other aircraft (Lascara et al., 2019). This implies that under current regulations, AAM concepts, including UAM and UAC are unable to fully expand into the NAS.

## 2.5 Title 14 CFR Part 135

Title 14 CFR Part 135 specifies the process and requirements for a UAS operator to obtain either an Air Carrier Certificate if the UAS operator desires to conduct interstate, foreign, or overseas transportation or will carry mail, or an Operating Certificate if the UAS operator desires to conduct intrastate transportation only. A Part 135 Certificate also specifies the type of operations (e.g., on-demand, scheduled) and scope of operations (e.g., number of pilots, numbers, and types of aircraft) allowed under the operator's certificate. The FAA provides information on the types and kinds of certificates allowed in the Flight Standards Information System (FSIMS) FAA Order 8900.1 (FSIMS FAA Order 8900.1 Volume 2, Chapter 2, Section 1 and Volume 2, Chapter 2, Section 2). If the Part 135 certificate holder is not a single-pilot operator, the Part 135 certificate applicant must develop and maintain manuals, training programs, identify the people responsible for specific management positions (e.g., Director of Operations, Chief Pilot, Director of Maintenance), and possess a Hazardous Materials training program. These requirements are further detailed in FSIMS FAA Order 8900.1, Volume 2, Chapter 4, Section 6. If a UAS operator does not possess a Part 135 Certificate, they cannot carry cargo for hire. Also, a Part 135 Certificate is tied to a type-certified (i.e., FAA has certified as airworthy) aircraft, and there are currently no type-certified UAS available for carrying cargo, so there are no true Part 135 Certificated UAS cargo-carrying operations occurring in the United States.

### *2.5.1 Regional Air Mobility (RAM)*

Regional Air Mobility (RAM) is defined as, "An accessible air transport system for passenger and cargo in rural and urban environments" (NASA, 2021). It offers the potential to re-shape our approach to regional and short/medium haul air transport. According to a National Aeronautics and Space Administration (NASA) report titled *Regional Air Mobility: Leveraging our National Investments to Energize the American Travel Experience*, RAM "will fundamentally change how we travel by bringing the convenience, speed, and safety of air travel to all Americans, regardless of their proximity to a travel hub or urban center" (NASA, 2021). As such, RAM seeks to increase the availability of air transportation by increasing access to America's largely underutilized network of airports by utilizing aircraft with increased autonomy (NASA, 2021).

### *2.5.2 Regional Air Mobility (RAM) and Part 135*

The concept of RAM is viewed as a means to accelerate the adoption of AAM, and it offers the potential for "increasing the safety, accessibility, and affordability of regional air travel while building on the extensive underutilized federal, state, and local investment in our nation's local airports" (NASA, 2021). In short, where RAM differs from concepts like UAM, is that it seeks to fill a broader role, providing cheap, accessible regional air travel while utilizing existing infrastructure. RAM also seeks to capitalize on technological advancements, such as autonomy, electric propulsion, and broad access to air transportation (NASA, 2021).

With the aforementioned advancements, RAM offers the potential to expand on-demand air services and reach a broader cross-section of airports across the U.S. However, with these advancements come regulatory considerations that may affect how RAM evolves. Ultimately, the introduction of RAM into the airspace and the introduction of new technologies to enable its use will be largely determined by regulatory constraints and other considerations, such as airworthiness and type certification.

### *2.5.3 Regulatory Considerations*

While an in-depth review of Part 135 is not in scope for this literature review, elements of Part 135 must be considered when assessing how RAM operations may evolve in the NAS. This is especially true as increasing levels of automation, and new technologies are introduced.

Presently, the concept of RAM is centered around small, lightweight, manned, multi-engine aircraft that are well suited for flights between airports with a nominal number of passengers. This is evidenced by (NASA, 2021), where it is identified that an air carrier has adopted the Tecnam P2012 Traveler, a 9-seat twin-engine aircraft, as a means to update its fleet. According to NASA (2021), the P2012 is, "…designed specifically to meet the needs of the RAM market." As such, this manned aircraft is compatible with the current regulatory environment and consistent with conventional interpretations of what constitutes Part 135 operations. However, new technologies and increasing automation may offer initial challenges for Part 135 operators.

Future visions of RAM that incorporate high levels of automation and use electric motors will likely require special regulatory considerations. For example, *Appendix A to Part 135 – Additional Airworthiness Standards for 10 or More Passenger Airplanes* does not include provisions for electric motors (Operating Requirements: Commuter and On Demand Operations, 1978). Similarly, *Part 135 Subpart E - Flight Crewmember Requirements* sets specific requirements for the number of pilots/crew per the number of seats (Operating Requirements: Commuter and On Demand Operations, 1978). Given that predicted trends in RAM emphasize autonomous (unmanned) aircraft and electric propulsion, regulatory changes will likely be needed to accommodate such technological advances. It should also be noted that the list of regulatory inconsistencies highlighted here is by no means complete. These examples are meant to highlight the likelihood that truly integrated RAM operations may require regulatory considerations in addition to those already published in existing Federal Air Regulations (FARs).

## 2.6 Title 14 CFR Part 121

According to the FAA's summary for regularly scheduled air carriers (14 CFR Part 121), the FAA grants authority to operate a scheduled air service in the form of a Part 121 certificate (Federal Aviation Administration, 2021d). Furthermore, the FAA's summary states that air carriers authorized to operate under a Part 121 certificate are generally large, U.S.-based airlines, regional air carriers, and all cargo operations (Federal Aviation Administration, 2021d). Current Part 121 air carrier operations are constrained to manned aircraft and fill the role of routine flights between major airports, often carrying passengers and/or cargo. While the model for scheduled air carriers is currently based upon conventional manned aircraft and constrained by a need for larger airport infrastructure, RAM and unmanned air transport/cargo operations may also re-shape the landscape for Part 121 operations.

### *2.6.1 Regional Air Mobility (RAM) and Part 121*

RAM has the potential to re-shape Part 121 operations in a similar manner to Part 135, offering increased access to air transportation. According to NASA's *Regional Air Mobility: Leveraging Our National Investments to Energize the American Travel Experience*, "One of the challenges with connecting passengers on longer routes is simply getting them to a major airport in the first place" (NASA, 2021). To compound the problem, nine U.S. airports are currently nearing their capacity (NASA, 2021). As these capacity constraints continue to influence the growth and accessibility of scheduled air services, this will inevitably put greater strain on existing infrastructure. The number of capacity-constrained airports in the U.S. "is projected to grow to at least eleven by 2030, with an additional six considered to be at risk of reaching constraints in this time period" (NASA, 2021). RAM offers the potential to alleviate these capacity constraints by leveraging existing infrastructure at smaller, less congested airports. In this way, RAM offers the potential to be a "tipping point for a large-scale shift in regional transportation towards smaller passenger classes" (NASA, 2021). This shift may help to create additional touchpoints between larger transportation hubs, serving to mitigate capacity constraints by expanding access to air travel and establishing scheduled air services between smaller airports and major hubs. The net result emphasizes a distributed air transportation infrastructure that can alleviate the strain on larger, concentrated airport hubs.

### *2.6.2 Regulatory Considerations*

Like Part 135, the regulatory considerations for Part 121 operations are not conducive to RAM aircraft that rely on (1) novel propulsion systems and (2) high levels of autonomy to function – i.e., operations without a pilot on board. Similar to Part 135, regulations addressing Part 121 operations do not currently allow for fully autonomous aircraft (Composition of Flight Crew, 1996). While this is only a single example of how current regulations do not necessarily align with RAM operational concepts, it is a reminder that the regulatory constructs must maintain pace with technology to achieve integrated operations. In addition, it implies that there must be regulatory changes to requirements for airmen certification, as technology is trending towards increased automation and pilot skillsets must adapt to those trends.

## 2.7 Automation in AAM Vehicles

Automation is a foundational element of AAM, including UAC. According to *Opening Autonomous Airspace – A Prologue* (Vance, 2017), "a fundamental presumption in this discussion of an unstrained air traffic future is a fully networked, autonomous environment in which all air vehicle participants are nodes on the network; and, in the long-range view would operate without human intervention." This presumption is echoed in *Regional Air Mobility: Leveraging Our National Investments to Energize the American Travel Experience*, and it is expressed in terms of a gradual shift from piloted to unmanned aircraft through a series of rational steps, expressed via an increase in sophistication followed by a resulting increase in the simplicity of controls. This enables less reliance on human pilots with a steady increase in system automation. This pathway starts with unmanned cargo aircraft and ends with unmanned air transport. NASA's *Regional Air Mobility: Leveraging Our National Investments to Energize the American Travel Experience* expresses the path to autonomy as follows:

> The path towards increasingly autonomous aircraft operation involves the inevitable increase in sophisticated UAS operations as well as increasingly simplified controls for aircraft with an onboard flight crew. In the former case, autonomous operations for cargo carrying UAS are increasing in scope and frequency, which will help drive the development of fully autonomous operations. In the latter case, passenger-carrying flights, particularly those driven in the Urban Air Mobility space, see a path for simplified onboard operator requirements as a pathfinder for eventual autonomous operations with passengers. In all cases, the ability to demonstrate safe operation – for those on the ground or in the air – will set the pace for adoption of autonomy for operation of different missions and associated aircraft. (NASA, 2021)

The pathway to increased autonomy is highlighted through a concept called Simplified Vehicle Operations (SVO), in which "novel technology that makes aircraft easier and safer to operate" (NASA, 2021) becomes increasingly common. This concept progresses to an unmanned paradigm with time as trust in autonomy is gained. Figure 1 highlights the natural progression from piloted aircraft to unmanned transport and cargo aircraft.

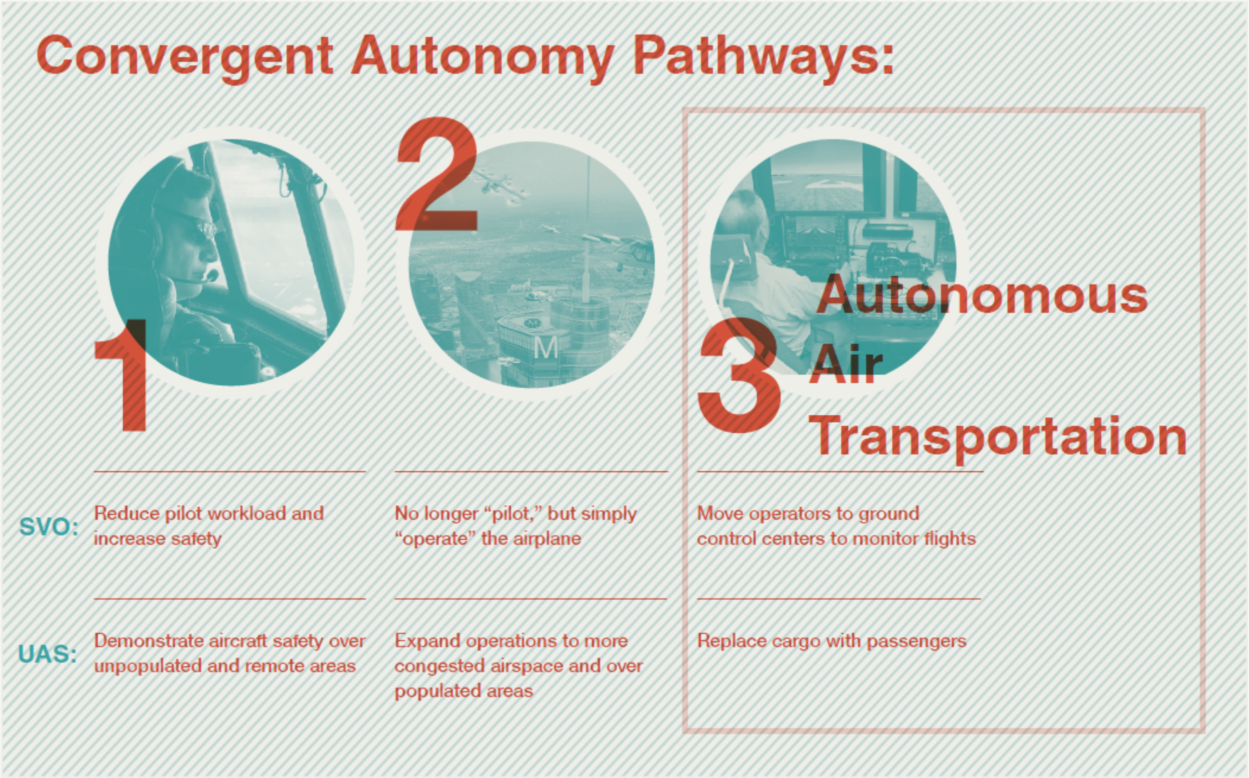


Figure 1. Convergent Autonomy Pathways – Manned to unmanned transition (NASA, 2021)

To summarize Figure 1, the progression to full autonomy begins with SVO and proceeds from cargo operations to manned air transport as operations expand through increasingly complex airspace. This expansion continues as the technology driving the process is validated. This approach has implications for both airman training and developing fundamental trust in automated systems.

### *2.7.1 Implications on Airman Training and Certification*

The gradual transition from piloted to unmanned cargo and transport operations will undoubtedly impact airman training and certification. As implied in *Regional Air Mobility: Leveraging Our National Investments to Energize the American Travel Experience* (NASA, 2021), a shift to autonomous operations will likely involve the simplification of controls with the intent to phase into autonomous flight. With this shift, the training and certification requirements for airmen will likely change as well.

According to NASA (2021), the transition from manned to unmanned aircraft will follow a progression, as shown in Figure 1. The initial emphasis will be on simplifying the cockpit and reducing pilot workload while gradually shifting to a more automated system. This philosophy is reflected in current concepts for unmanned air transport vehicles, including the Bell Nexus (Textron Inc., 2021) family of air taxi concepts. Figure 2 shows an example of the Bell Nexus simplified cockpit schema.

Figure 2. Bell Nexus Concept Vehicle Cockpit

The cockpit layout in Figure 2 is consistent with SVO in that it demonstrates a simplified cockpit layout that emphasizes presenting the pilot with essential information via basic displays. In keeping with the concept of SVO, this cockpit layout serves to "simplify some of the tasks that fall under 'aviate, navigate, and communicate,' enhancing an aircrew's effectiveness by allowing them to focus on fewer, more critical tasks" (NASA, 2021). The transition away from piloted aircraft is echoed in Vascik (2020), referencing NASA's exploration of SVO, "as an approach to reduce the training requirements for new pilots while maintaining at least an equivalent level of safety."

The implication of the transition from the role of a conventional pilot to a remote pilot, and eventually to no pilot at all, points to a trend of skillsets adapting to suit higher levels of automation. However, according to the American National Standards Institute (ANSI) *Standardization Roadmap for Unmanned Aircraft Systems, Version 2*.0, the short-term demand for qualified pilots may increase, as early aircraft will include onboard pilots (ANSI, 2020). However, "over time, the expectation is that these autonomous aircraft will make increased use of artificial intelligence and machine learning technique, not only in a flight support capacity but eventually in-flight control itself" (ANSI, p. 342, 2020).

### *2.7.2 Trust in Automation*

As the level of automation increases within the realm of unmanned air transport and cargo delivery, so too must the level of trust in autonomous systems. According to Vance (2017), "humans must implicitly trust the technology that will be autonomously transporting them." This notion implies that confidence in automated systems, particularly for AAM paradigms, must be high to achieve broad public acceptance. Vance (2017) goes further, identifying key factors that influence trust in technology, such as:

- Prior behavioral history,
- Breaches of expected behaviors,
- The service provider's moral integrity, technology investment, and prior history of fiduciary obligation satisfaction,
- Automation sophistication, and
- The reputation of those who represent the novel technology.

Similarly, NASA (2021), states that "in all cases, the ability to demonstrate safe operation – for those on the ground or in the air – will set the pace for the adoption of autonomy for the operation of different missions and associated aircraft." This being the case, it is apparent that high levels of automation must be achieved over time with:

1. Established operational history for unmanned platforms,
2. Solid integrity behind system Original Equipment Manufacturers (OEMs), and
3. An incremental approach that places an increased level of trust in automation once performance benchmarks have been assured.

The above points are consistent with conventional aviation validation practices and align with the approach described in *Regional Air Mobility: Leveraging Out National Investments to Energize the American Travel Experience* (NASA, 2021). As such, it is reasonable to infer that trust in the high levels of automation inherent in AAM will build over time through incremental trust in greater levels of autonomy.

## 2.8 Airman Certification – 14 CFR Part 61

The FAA is responsible for regulating flight activity in the United States, gaining this authority from the Federal Aviation Act of 1958 (1958). The Federal Aviation Act of 1958 created both the agency and set out the mandates for industry regulation. Aircraft airworthiness and pilot certification are two of the largest responsibilities that the FAA is tasked with overseeing. In the past, pilot certification has focused on manned aviation and centered around demonstrations of knowledge and practical applications of piloting skills. Additionally, flight hour requirements are included for manned pilots to show experience.

With the development and increased use of UAS, more attention and resources have been dedicated to the development of regulation, including pilot certification. Starting in 2005, the FAA began accepting applications for special airworthiness certificates in the experimental category for UAS and issued some of the first interim operational approval guidance. In 2007, there were four special airworthiness certificates for civil UAS issued by the FAA. The demand for public UAS operations began to grow, and the need for Certificates of Authorization (COA) to meet this demand increased. There was a rapid rise in the requests for public COAs for unmanned aircraft as the FAA approved 75 in 2007, but more than quadrupled that to over 300 by 2011 (Banks et al., 2018).

The policies and regulations regarding UAS and their operations are constantly evolving. Recent examples have included restricting operations for unmanned aircraft over military facilities and Department of Interior sites in 2017, and the release of Notices of Proposed Rulemaking (NPRM) concerning UAS operations over people and another NPRM regarding the identification of UAS in 2019. On January 15, 2021, both of these NPRMs resulted in final rules published in the Federal Register (Operation of Small Unmanned Aircraft Systems Over People, 2021; Remote Identification of Unmanned Aircraft, 2021). Even with the changing regulations, UAS operations and applications have continued to grow at a tremendous rate (Banks et al., 2018).

In 2013 the FAA called for UAS operators to have similar training requirements as those for manned pilot certification, consisting of written tests, practical exams as well as currency and proficiency requirements (Pub. L. No. 112-95: FAA Modernization and Reform Act of 2012, 2012). However, that has not happened, and the requirements for a remote pilot certificate with a sUAS rating fall under Part 107, only requiring the completion of a written assessment. The remote pilot certificate requirements, outlined in §107.61(d)(2) below, also include a provision that recognizes manned pilot certifications – issued under Part 61 – if qualified applicants are current and complete an FAA training course.

> §107.61 Eligibility.
> Subject to the provisions of §107.57 and §107.59, in order to be eligible for a remote pilot certificate with a small UAS rating under this subpart, a person must:
> (a) Be at least 16 years of age;
> (b) Be able to read, speak, write, and understand the English language. If the applicant is unable to meet one of these requirements due to medical reasons, the FAA may place such operating limitations on that applicant's certificate as are necessary for the safe operation of the small unmanned aircraft;
> (c) Not know or have reason to know that he or she has a physical or mental condition that would interfere with the safe operation of a small unmanned aircraft system; and
> (d) Demonstrate aeronautical knowledge by satisfying one of the following conditions:
>> (1) Pass an initial aeronautical knowledge test covering the areas of knowledge specified in §107.73(a); or
>> (2) If a person holds a pilot certificate (other than a student pilot certificate) issued under Part 61 of this chapter and meets the flight review requirements specified in §61.56, complete an initial training course covering the areas of knowledge specified in §107.74(a) in a manner acceptable to the Administrator (Title 14 CFR §107, 2021).

Pilot certification requirements, including both Part 61 and Part 107, will need to address the necessary shift in pilot training as automation allows for the transition from piloted to remotely piloted and autonomous aircraft. The development of SVO and associated automation will ultimately lead to fully autonomous operations, which will require changes to the current airman certification requirements (NASA, 2021).

## 2.9 Design and Airworthiness

Aviation of any sort comes with some level of inherent risk. This is especially true for novel aircraft designs and technologies such as those associated with UAM and UAC. To mitigate these risks, “airspace authorities use certification to manage the safety of aircraft, operators, and operations” (Serrao et al., 2018). What follows is a discussion of the anticipated regulatory framework for airworthiness certification for UAM and UAC aircraft, regulatory pathways, and specific design drivers that may facilitate the need for additional industry standards and airworthiness requirements.

### *2.9.1 Airworthiness Certification*

Airworthiness certification is a means to address safety risks through the use of requirements for aircraft design, manufacturing, performance, maintenance, and failure response (Serrao et al., 2018). “Regulatory agencies develop requirements for airworthiness” (Serrao et al., 2018). An applicant must demonstrate that their aircraft meets these requirements to demonstrate some baseline level of safety.

As with manned aviation, unmanned air transport and cargo aircraft are expected to follow a risk-based approach to airworthiness certification – i.e., the level of rigor associated with the requirements for airworthiness is commensurate with the level of risk associated with the operation of the aircraft. Through this risk-based approach, the level of rigor associated with a certification effort increases with the aircraft’s size and performance. Likewise, as the number of passengers increases, so too do the requirements to ensure an adequate level of safety for those on board. Figure 3 highlights the relationship between the rigor associated with a vehicle certification process and the level of risk associated with a given operation/aircraft category. This continuum is a driving factor for consideration regarding vehicle design and airworthiness, as it ultimately influences multiple facets of AAM – including costs. According to Serrao et al. (2018). “Higher certification rigor means more cost and more time,” and as such, it must be considered a significant factor for novel designs and use cases.

With the risk-based approach to airworthiness, there is a need to explore regulatory pathways and standardization efforts that will influence UAM and UAC operations.

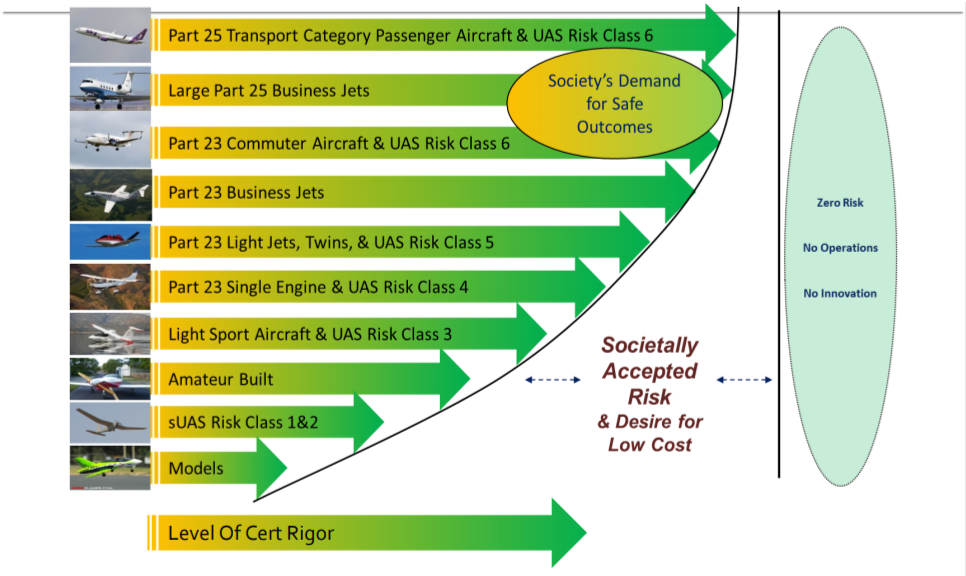


Figure 3. FAA Safety Continuum highlighting the relationship between risk and certification rigor for unmanned aircraft (Gunnarson, 2018).

The continuum shown in Figure 3 highlights an important trend regarding airworthiness certification for unmanned aircraft. As the level of system and operational complexity increases, so too does society's demand for safe outcomes. As a result, it can be reasonably expected that airworthiness requirements for larger unmanned aircraft, such as those used for AAM, UAM, and UAC operations, will require robust certification requirements.

As implied by Figure 3, a method for categorizing AAM, UAM, and UAC aircraft is necessary to determine the level of risk associated with their operation. Novel aircraft designs may represent a challenge, especially due to the wide range of potential vehicles requiring certification (Straubinger, Rothfeld, et al., 2020). Airworthiness standards for different types of vehicles (with different passenger capacities and mission profiles) will likely vary a great deal. Therefore, it is important to develop an appropriate means of compliance along with the regulatory structure as new vehicles are designed. Straubinger et al. (2020) have outlined a 2-step procedure that could be used to classify vehicles based on performance data and characteristics shown in Figure 4.

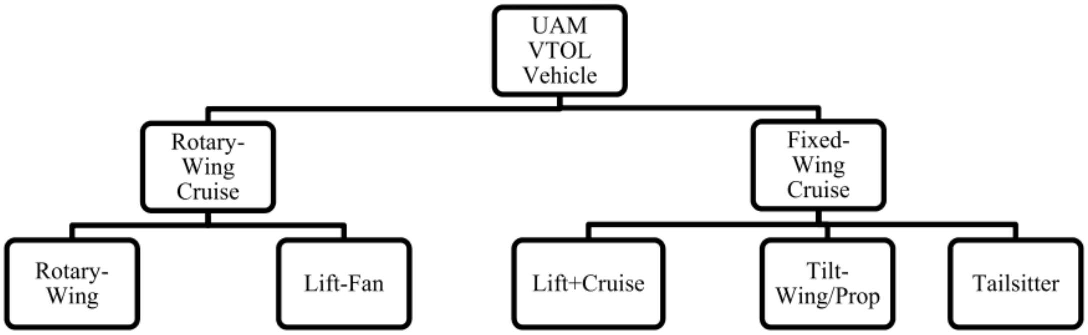


Figure 4: UAM concept vehicle classification system (Straubinger, Rothfeld, et al., 2020).

Another important aspect of airworthiness certification is the development of regulations for electric aircraft and those with novel powerplants and propulsion systems. System-level certification is important (as discussed above) however, the propulsion system itself must be certified. Extensive failure mode, effects, and criticality analysis are important for airworthiness certification of novel propulsion concepts, as well as crashworthiness and adverse events (i.e., power loss) effects (Johnson & Silva, 2018). As with system-level certification, the propulsion system certification must also take into account the various vehicle configurations, classes, etc. For example, what constitutes a catastrophic propulsion system failure may change significantly based on the aircraft configuration (see Figure 5 for an example of complex certification requirements organization). This may lead to special regulations for particular propulsion system/configuration combinations.

### *2.9.2 Regulatory Pathways for Airworthiness Certification – 14 CFR § 21.17(a) and §21.17(b)*

As with sUAS, "UAM aircraft may vary in weight, type of service, propulsion, number of passengers, and speed, which may change their path to certification" (Serrao et al., 2018). Given the novelty of many different vehicle concepts, which will be discussed in future sections of this literature review, paths to airworthiness and type certification may differ.

There are two primary approaches for UAM aircraft type design. These approaches are highlighted in Figure 5. As shown in the figure, these approaches utilize two distinct regulatory frameworks – §21.17(a) and §21.17(b). As implied by Figure 5, there are some specific criteria that a system must meet to pursue an airworthiness certificate under §21.17(a) or §21.17(b). According to the *Legal and Regulatory Assessment for the Potential of Urban Air Mobility*,

> The traditional Part 21.17(a) method can be used for aircraft that fall within existing categories. Additional requirements and special conditions may apply. For example, aircraft certifying under Part 23 or 25 must also comply with Part 33 Engine and Part 35 Propeller if applicable. For aircraft that do not fall into existing categories, Part 21.17(b) may be used. This path is not meant for mass production, so eventually, an update to the regulatory framework may be needed for large-scale UAM deployments for aircraft that take this path. (Serrao et al., 2018)

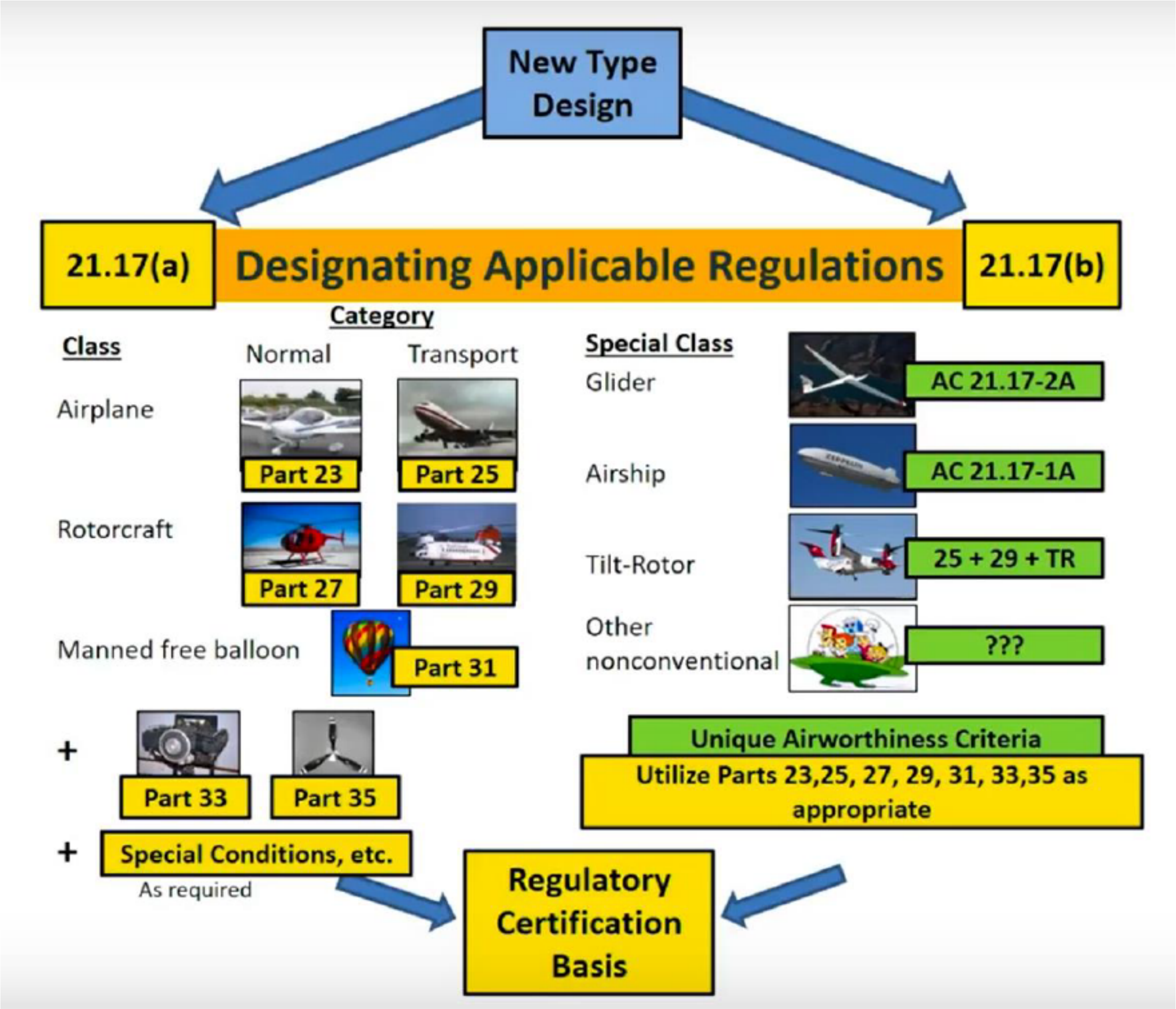


Figure 5. Typical approaches to FAA Airworthiness Certification (Webber, 2018).

As shown in Figure 5, aircraft are funneled down respective certification pathways based upon class. §21.17(a) typically encompasses conventional airplanes, rotorcraft, and manned free balloons. These classes are typically divided into categories, such as normal and transport – apart from manned free balloons covered under Part 31. Similarly, special classes of aircraft are typically covered under §21.17(b). Aircraft like gliders, airships, tiltrotors, and nonconventional aircraft follow this path. For both regulatory pathways, a certification basis is derived based upon aircraft class, category, propulsion (engine and/or propeller), and other special conditions or unique requirements of the design. While this is typically straightforward for conventional manned aircraft, nonconventional aircraft that may not be well defined within any existing regulatory construct may pose challenges when attempting to define a clear path to airworthiness certification. This challenge is echoed in Serrao et al. (2018), where the authors state that the classification is critical, as it will influence the time to bring a new aircraft to market and the associated costs.

Of particular interest is the mention of unique airworthiness criteria within Figure 5. This is a direct reference to a portion of §21.17(b) which references, "… such airworthiness criteria as the FAA may find provide an equivalent level of safety to those parts" (*Certification Procedures for Products and Articles, 14 C.F.R. §21.17(b)*, 2021). In instances where existing parts of Part(s) 23, 25, 27, 29, 31, 33, and 35 may not apply, another set of requirements that provide an equivalent level of safety is needed. This points to a need for design and airworthiness standards, such as those from industry groups like RTCA and ASTM International, to address design and airworthiness considerations that may not be immediately addressed by existing FARs.

### *2.9.3 Need for Design and Airworthiness Standards*

A key enabler (and current major hurdle) for the integration of UAM and UAC into the NAS is the establishment of standards that outline clear guidance for vehicle design and airworthiness (Straubinger, Rothfeld, et al., 2020). This is especially true as concepts that define air transport begin to shift from operations that resemble conventional, piloted flight, and transition into the realm of a single pilot and/or flight operations that may be entirely automated. Such a transition will undoubtedly bring new technologies, design philosophies, and operational considerations that will have a significant impact on aircraft design and airworthiness considerations. This transition will facilitate the need for new and/or revisions to existing design and airworthiness standards. In addition to operational concepts necessitating updated standards, the reverse is also true. The mission profile itself is a significant design driver (Clarke et al., 2019). Thus, evolving air-traffic control regulations will significantly affect optimal vehicle designs. For example, minimum safe altitude clearance regulations will affect the needed climb rate (an added constraint to the optimization problem). Furthermore, various aircraft with different performance may be regulated and handled differently from an air-traffic control perspective, (Straubinger, Rothfeld, et al., 2020) making the certification of aircraft for operation under various conditions depends upon more than just the technical aspects of a design. Thus, design and airworthiness standards (while undoubtedly in need of frequent updates as the UAM/AAM/UAC landscape develops) are crucial to allow entrepreneurs and vehicle designers to have a good understanding of the arena in which their vehicles/services must function.

#### 2.9.3.1 ANSI Standardization Roadmap for Unmanned Aircraft Systems

The ANSI *Standardization Roadmap for Unmanned Aircraft Systems, Version 2.0,* was released in June of 2020. This roadmap outlines current standardization efforts regarding UAS, to include a list of gaps that should be addressed in future standards. While this roadmap does not apply exclusively to UAM and/or UAC, it does address some critical points regarding current and future standardization efforts for various forms of unmanned air transport. Of interest to this literature review, the ANSI Standardization Roadmap for Unmanned Aircraft Systems (ANSI, 2020), addresses standardization efforts for the areas,

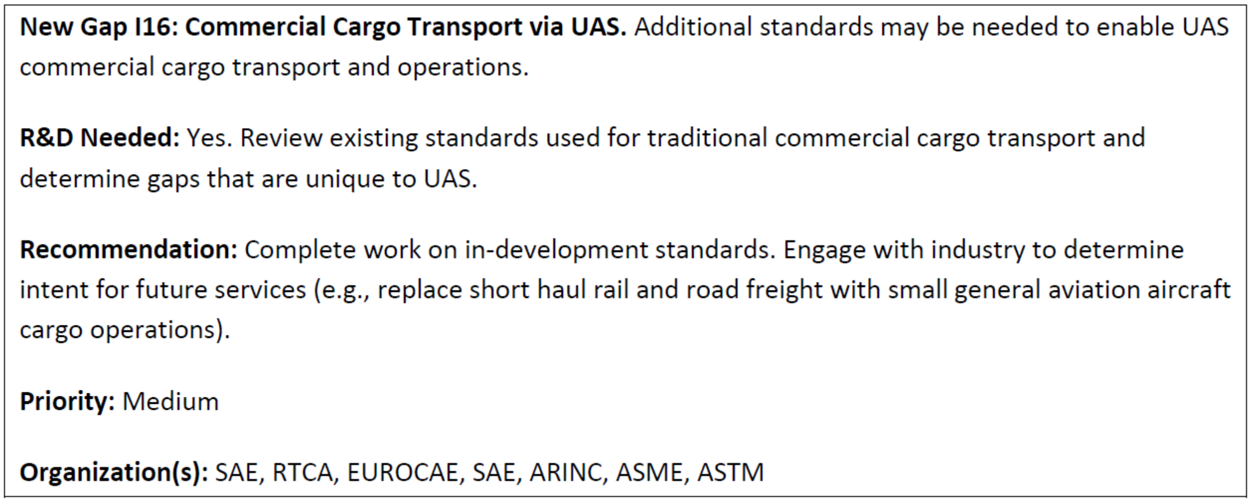
1. Commercial Cargo Transport via UAS,
2. Commercial Passenger Air Taxi Transport via UAS (short-haul flights carrying few passengers), and
3. Commercial Passenger Transport via UAS (long-haul flights carrying many passengers).

While there is no all-encompassing standard that addresses all aspects of design and airworthiness for aircraft that fall within the categories listed above, the ANSI Standardization Roadmap does capture numerous laws, regulations, standards, and documents that define a broad framework for design and airworthiness for UAM and UAC vehicles. This framework consists of a mixture of regulatory guidance and industry standards intended to support and/or supplement existing regulations. However, the ANSI Standards Roadmap acknowledges that existing regulatory constructs may need to change to accommodate UAM, AAM, and UAC. This is especially true as certain technological advancements to enable UAM, AAM, and/or UAC operations may require performance requirements that differ from those already captured in existing regulations. For example,

> The standards and regulatory framework supporting commercial passenger transport operations that include but are not limited to 14 CFR Part 25, 29, 91, 119, 121, 125, 135, and 136, may have to be amended to include the development of performance requirements for communication, navigation, and surveillance (CNS), and UTM. (ANSI, 2020)

In addition, the ANSI Standardization Roadmap implies that many standards written for manned aircraft may apply to UAS (ANSI, 2020). As such, some standards originally written for UAS may have some level of applicability for AAM (ANSI, 2020). However, the variety of potential use cases encompassed by AAM (UAM, RAM, various UAC applications, e.g., last-mile, long-haul) will undoubtedly require many of these standards to be adapted. The ANSI Standardization Roadmap also highlights numerous gaps in standardization efforts where additional work is needed. Within the Roadmap, standardization gaps are identified, assessed for R&D requirements, and prioritized. The following have been identified as gaps for (1) unmanned commercial cargo transport, (2) commercial passenger air taxi, and (3) commercial passenger transport (long-haul flights), respectively.

The gaps identified in Figure 6, Figure 7, and Figure 8 highlight the need for standards bodies to explore additional aspects of UAM and UAC operations. Additionally, these gaps speak to the need for industry involvement to identify critical focus areas and recommendations. Of particular interest are the recommendations identified within Figure 7. The recommendations ranked as high priority speak to the industry's sense of urgency to develop safety and operations standards regarding autonomy for unmanned passenger-carrying aircraft.



**New Gap I16: Commercial Cargo Transport via UAS.** Additional standards may be needed to enable UAS commercial cargo transport and operations.

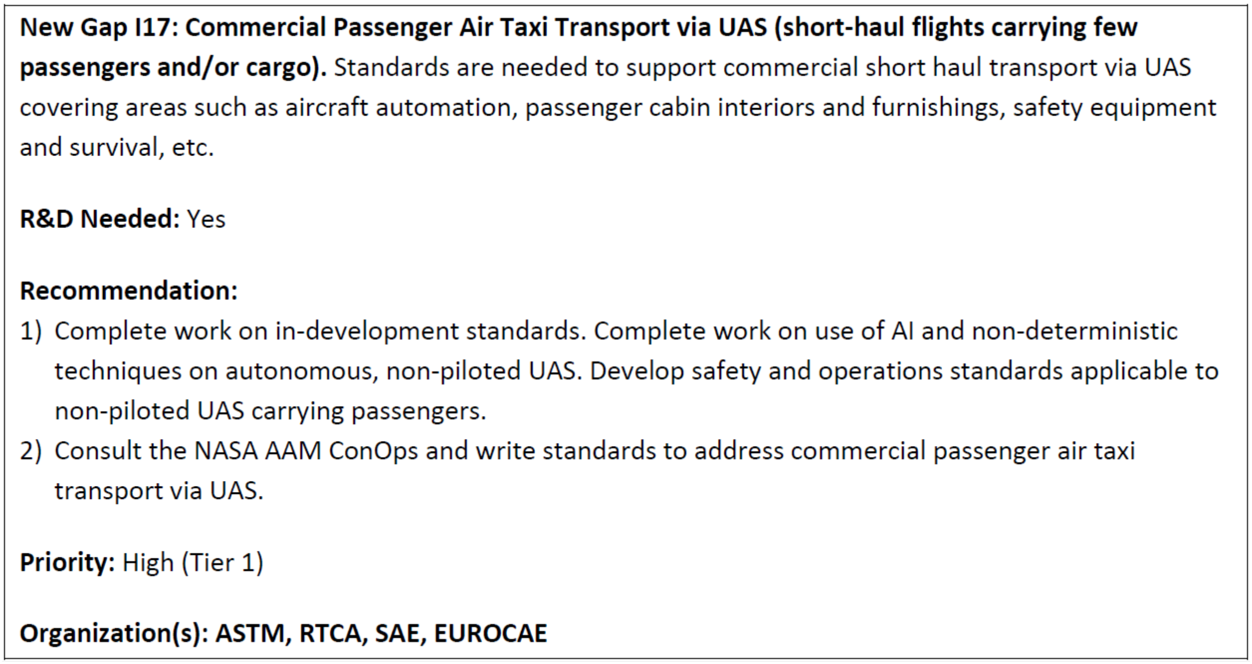
**R&D Needed:** Yes. Review existing standards used for traditional commercial cargo transport and determine gaps that are unique to UAS.

**Recommendation:** Complete work on in-development standards. Engage with industry to determine intent for future services (e.g., replace short haul rail and road freight with small general aviation aircraft cargo operations).

**Priority:** Medium

**Organization(s):** SAE, RTCA, EUROCAE, SAE, ARINC, ASME, ASTM

Figure 6. ANSI Standardization Roadmap Gap I16 (ANSI, 2020)



**New Gap I17: Commercial Passenger Air Taxi Transport via UAS (short-haul flights carrying few passengers and/or cargo).** Standards are needed to support commercial short haul transport via UAS covering areas such as aircraft automation, passenger cabin interiors and furnishings, safety equipment and survival, etc.

**R&D Needed:** Yes

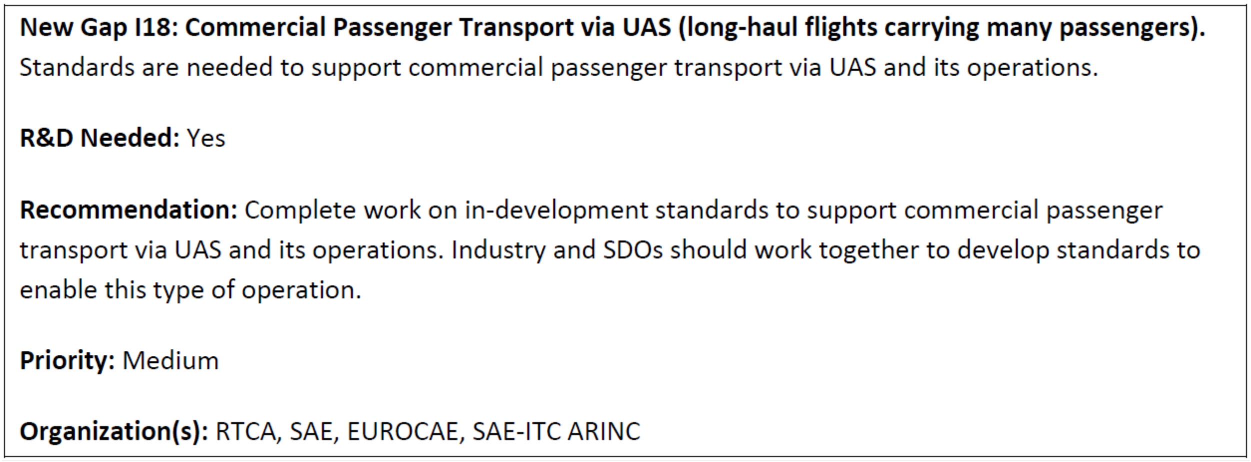
**Recommendation:**

1) Complete work on in-development standards. Complete work on use of AI and non-deterministic techniques on autonomous, non-piloted UAS. Develop safety and operations standards applicable to non-piloted UAS carrying passengers.
2) Consult the NASA AAM ConOps and write standards to address commercial passenger air taxi transport via UAS.

**Priority:** High (Tier 1)

**Organization(s): ASTM, RTCA, SAE, EUROCAE**

Figure 7. ANSI Standardization Roadmap Gap I17 (ANSI, 2020)



**New Gap I18: Commercial Passenger Transport via UAS (long-haul flights carrying many passengers).** Standards are needed to support commercial passenger transport via UAS and its operations.

**R&D Needed:** Yes

**Recommendation:** Complete work on in-development standards to support commercial passenger transport via UAS and its operations. Industry and SDOs should work together to develop standards to enable this type of operation.

**Priority:** Medium

**Organization(s):** RTCA, SAE, EUROCAE, SAE-ITC ARINC

Figure 8. ANSI Standardization Roadmap Gap I18 (ANSI, 2020)

###### *2.9.3.1.1 Standards as a Means of Compliance*

As indicated in (ANSI, 2020), standards, particularly for commercial passenger transport (long-haul flights carrying many passengers), may serve to support existing regulatory frameworks. In addition, existing regulatory frameworks, such as Part 25, 29, 91, 119, 121, 125, 135, and 136, may require amendments to address elements of unmanned aircraft operations that currently remain unaddressed (ANSI, 2020). According to (Maxwell, 2019), existing rule sets allow for detailed means of compliance to be determined through standards. As such, there is potential for industry consensus standards to serve as means for complying with existing regulatory structures and fill regulatory gaps relating to key aspects of AAM, UAM, and UAC, such as Detect and Avoid (DAA) systems, Autonomy, communications links, and UTM systems.

### 2.9.4 *Design Drivers for UAM and UAC*

UAM vehicles represent a radical departure from conventional aircraft designs, incorporating novel technologies to broaden the reach of air transportation while maintaining affordability and accessibility. As such, there is no single archetypical model that defines what these aircraft must look like, creating "multiple avenues in which different technologies and design concepts converge to create a high degree of variance in system design" (Antcliff et al., 2019). This challenge is echoed in Clarke et al. (2019), in which the authors noted that the variety of UAM concept vehicles, and a lack of historical precedent upon which to draw, makes the design problem quite difficult. The lack of historical precedent and novel technologies incorporated within UAM concepts conveys a need to identify and understand the unique drivers that influence UAM design. Straubinger et al. (2020) have conducted a review of current UAM vehicle design constraints. Figure 9 shows the key design drivers they compiled. Although this study specifically addressed UAM design constraints, these are all relevant (with minor modifications and varying levels of importance) to AAM vehicles. Note the tri-part categorization of design drivers into "requirements," "external boundary conditions," and "further important drivers." For the purposes of this literature review, these categories will be renamed "mission-related," "constraint-related," and "operations-related," respectively. Additionally, evolving ATC regulations will significantly affect optimal vehicle designs (Clarke et al., 2019), adding a third design driver to the constraint-related category.

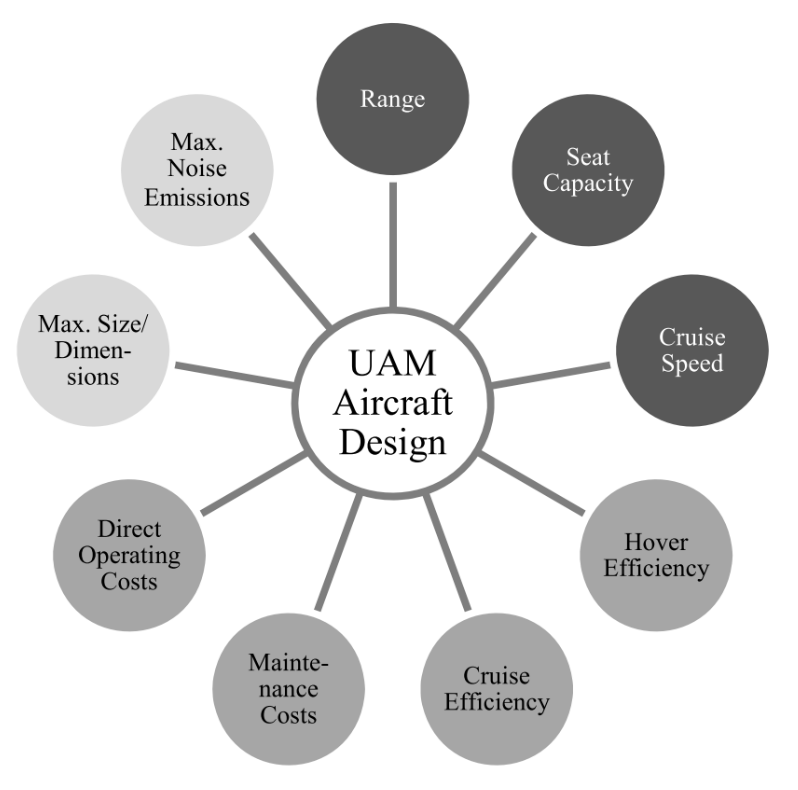


Figure 9: UAM vehicle design divers: requirements (dark gray), external boundary conditions (light gray), and further important drivers (gray) (Straubinger, Rothfeld, et al., 2020).

Mission-related design drivers are design attributes/capabilities required for the vehicle to fulfill its mission (e.g., intracity passenger transportation). These can and will vary significantly based on the intended application (Johnson & Silva, 2018). For instance, inter-city vs. intra-city trips pose very different vehicle requirements (Straubinger, Rothfeld, et al., 2020). The intended range is a very significant design driver, as it has implications not only for vehicle components (e.g., battery capacity) but also for the vehicle configuration itself. Multi-copter configuration vehicles are more efficient during VTOL, potentially saving charging time (an operational improvement) for short trips (Shamiyeh et al., 2018). However, lift and cruise vehicles (including fixed wings) are substantially faster, improving passenger time savings for longer trips (Shamiyeh et al., 2018). Payload is another critical design driver, especially for UAC (Volocopter, 2021). For transport operations, this means the number of passengers and permitted baggage. For UAC, the cargo volume and allowable mass determine cargo capacity. Silva et al. (2018) note that aircraft weight (directly related to payload capacity) is a critical design driver: "The exceptionally rapid growth of battery weight with vehicle weight for a given mission means that small changes in weight will cascade quickly into a much larger aircraft." Additionally, the scaling relationship (i.e., battery storage density, energy per unit weight) between payload and vehicle size also imposes a major design constraint (Silva et al., 2018), and these choices also affect efficiency and operating cost (operations related constraints). This is especially crucial considering their observation that the performance of batteries in VTOL aircraft applications is currently unknown. Furthermore, for UAM operations, Straubinger et al. (2020) note that vertiport space is likely to be a highly limiting factor, imposing an additional constraint on the aircraft size. Heavy-lift vehicles (for UAC) are a relatively unaddressed area (Volocopter, 2021).

Constraint-related design drivers are those imposed upon the vehicle by non-mission related interests, notably operational regulations and public acceptance of operations. Clarke et al. (2019) found that the mission profile itself was a significant design driver. This is especially true as noise and safety may require increased vertical climb segments (Shamiyeh et al., 2018), and "vertical climb altitude has a major impact on the vehicle performance" (Shamiyeh et al., 2018). Thus, evolving ATC regulations will significantly affect optimal vehicle designs (Clarke et al., 2019). Operational altitude and climb rates also affect the noise levels to which the surrounding area will be subjected, a very important consideration (Johnson & Silva, 2018). Note that the importance of some of these constraints (e.g., noise levels) will vary based on the mission profile: low noise levels and VTOL capabilities are critical for intra-city trips through highly populated areas (Straubinger, Rothfeld, et al., 2020). To facilitate community acceptance, UAM vehicle noise level must be at least 15 dB below that of conventional helicopters (Straubinger, Rothfeld, et al., 2020). Aircraft configuration also affects noise levels: due to higher disc area, multirotor configurations will produce lower noise than a lift and cruise (which includes a fixed wing) type vehicle (Shamiyeh et al., 2018). Within the multirotor configuration, low tip-speed is key to maintaining low noise levels (Silva et al., 2018), however, this alone may be insufficient to achieve acceptable noise levels (Johnson & Silva, 2018). Environmental considerations are also important to consider (Johnson & Silva, 2018). However, due to high levels of emissions from the USA electric grid, batteries are not a particularly environmentally friendly option (Johnson & Silva, 2018). Vehicle designs must also account for off-design operation (e.g., autorotation [Johnson & Silva, 2018; Silva et al., 2018]) and operation in adverse conditions (e.g., in regions with frequent poor weather conditions [Johnson & Silva, 2018]) for safety reasons.

Operations-related design drivers are those relevant to the business or passenger operations side of UAM/AAM/UAC service. Efficiency is a major factor here. Silva et al. (2018) specifically call out “good hover efficiency, reasonable cruise efficiency, and a vehicle empty weight fraction which does not pay too much for the cruise efficiency” as important design drivers for UAM vehicles. The relative importance of these drivers will vary for AAM operations. Johnson and Silva (2018) note that more attention to vehicle drag is warranted. This makes sense as battery limitations can both reduce potential range and decrease vehicle trip capacity through frequent charging cycles. The energy efficiency (energy per passenger kilometer) of small (2-seater) and large (4-seater) multirotor and lift and cruise (which include fixed wings) vehicles was evaluated in a simulation of a small town in Sioux Falls, USA (Shamiyeh et al., 2018). Both multirotor designs were found to be more efficient than the lift and cruise designs, with the smallest being the most efficient. Note, however, that the simulated scenario did not take significant advantage of the higher cruise speed of the lift and cruise vehicles. This study highlights not only the effect of configuration on efficiency (energy costs) but also on cruise speed (not particularly influential on UAM operations (< 35 km (Volocopter, 2021)), but increasingly important for longer operations (Rothfeld et al., 2021). The importance of relatively short passenger process times has been observed (Garrow, German, et al., 2020). This places some (albeit less constraining) demands on vehicle design (e.g., vehicle charging time). Maintenance costs and passenger comfort (e.g., on-board vibration) will also play a role in determining vehicle design (Johnson & Silva, 2018).

As is true of many/all aspects of AAM, these design drivers are all highly coupled. For instance, payload capacity, range, battery technology, and maximum climb rate cannot be adjusted independently. As with any aircraft design, multiple factors must be considered, and the proper balance struck. Clarke et al., (2019) propose a design method to aid designers in properly balancing the relevant design constraints. This method uses SUAVE (an open-source conceptual design tool) and a component-by-component load-driven weight build-up. They then demonstrate the efficacy of this method with a case study optimization of a UAM vehicle. Using SUAVE, Clarke et al., (2019) suggest that minimizing the following quantities are all important UAM vehicle design drivers: mission time, maximum take-off weight, energy consumption/battery efficiency, and range. These drivers are affected by various mission and operations-related constraints such as: how many passengers a vehicle can carry or what time savings will be realized by those who choose to use a UAM service. It is also worth noting that, in addition to varying external levels of importance, different design drivers carry varying levels of importance from a system perspective. In their case study, Clarke et al., (2019) found that minimizing mission time was the most constrained objective and required significant sacrifices in other design drivers (e.g., maximum take-off weight). Given most UAM flights are projected to be relatively short Ploetner et al., (2020) noted this may not be as important of a design driver. However, for AAM, where longer-distance trips (> 35 km (Volocopter, 2021)) are projected, the importance of mission time will significantly increase. Adding to the complexity of this design problem, Johnson and Silva (2018) note that new technology developments may open options for vehicle design that are currently not feasible. While some UAM/AAM/UAC constraints may be more stringent than those imposed on traditional aircraft, the most unique feature influencing this design process is the number of constraints that are unknown or only vaguely quantified (e.g., ATC operational requirements or vertiport space constraints).

## 2.10 Unmanned Traffic Management (UTM)

Although not a formal definition, the International Civil Aviation Organization (ICAO) recognizes UTM as managing “UAS operations safely, economically and efficiently through the provisions of facilities and a seamless set of services in collaboration with all parties and involving airborne and ground-based functions" (ICAO, 2020) . The unmanned aircraft industry has grown at a record pace, and with continued growth at this pace, civilian UAS operations will surpass the number of manned aircraft operations, and air navigation service providers need to be prepared for this influx of operations. The UTM concept was first proposed in 2016 to allow for support real-time organization, coordination, and management of UA operations (ICAO, 2020).

It is envisioned that UTM will enable civilian aviation authorities (CAAs) and air navigation service providers (ANSPs) to provide necessary real-time information about airspace and possible restrictions on the intended flight to UAS operators. The responsibility would then be on the UAS operator to safely operate within these restrictions without positive control from the ANSP (ICAO, 2020). The primary means of communication would not be via voice communications as pilots of manned aircraft, but through highly automated systems and application program interfaces.

Air traffic management (ATM) has a long history and well understood system for safe and efficient operations based on principles for space design and cooperative systems between pilots and air traffic controllers. Due to limitations on airspace, unmanned aircraft will need to coexist with manned aircraft without jeopardizing safety. ICAO considers the following principles to be of high importance to the integration of unmanned aircraft into the current system:

1. Oversight of the service provider, either UTM or ATM, remains the responsibility of the regulator.

2. Existing policies for aircraft prioritization, such as aircraft emergencies and support to public safety operations, should remain applicable, and practices unique to UTM should be compatible with such policies.

3. Access to the airspace remains equitable provided that each aircraft is capable of complying with the appropriate conditions, regulations, equipage requirements, and processes defined for the specific airspace in which operations are proposed.

4. The UAS operator should be appropriately qualified to perform the established normal and contingency operating procedures defined for the specific class of airspace in which operations are proposed.

5. To meet their security and safety oversight obligations, States should have unrestricted, on-demand access to UAS operators and the position, velocity, planned trajectory, and performance capabilities of each UA in the airspace through the UTM system (ICAO, 2020).

### *2.10.1 UTM – Related Work*

Many studies have shown the benefits and applications for UAM that will require UTM development to meet the needs of the large number of short-range flights that will occur in urban airspace using autonomous aircraft. These aircraft will operate in an unpredictable mode and require smaller separation standards than currently allowed with ATM but will still need to operate safely without compromising performance (Bharadwaj et al., 2021). The cost effectiveness and reasoning for these operations have been shown in numerous studies (Raffaelle, 2014). The problems and potential conflicts have also been detailed, including route planning and scheduling (Murray & Chu, 2015).

While it is recognized that UTM will need to coexist and utilize some fundamentals of large-scale ATC, there will be many differences that need to be addressed. The main adjustments will involve the "method of control, maneuverability, function, range operational constraints" (Jiang et al., 2016). Possibly the largest difference may be the decentralization of governing authority when compared to the pilot-controller interaction of manned ATC.

The need for ATM service in the United States resulted from the 1956 mid-air collision of two commercial flights over the Grand Canyon, where all passengers and flight crew perished (Kopardekar, 2014). In 2012 the FAA recognized the need for safety and efficiency in UAS operations. The FAA Modernization and Reform Act of 2012 is aimed at avoiding a similar accident with unmanned aircraft and creating a viable UTM system.

According to *Urban Air Mobility Airspace Integration Concepts* by Lascara et al., (2019) UTM is "another construct currently under development for use by UAS operating at low altitudes (e.g., below 400 feet)." UTM is intended to provide "a set of traffic management services via a federated group of UTM Service Suppliers (USS), comparable to traditional ATC services provided to IFR [Instrument Flight Rules] and VFR [Visual Flight Rules] aircraft" (Lascara et al., 2019). UTM as a larger construct within the NAS offers unique functionality to support large volumes of unmanned air traffic and is discussed in more detail later in this literature review. It is crucial for UTM that operators understand where they can and cannot safely operate. The initial operations of unmanned systems operate in Class G (uncontrolled airspace), but as the number of operations increase, this airspace will need to be managed, and as operations increase in scope, the aircraft will need to enter controlled airspace, operating with manned aircraft. One proposal for managing operations in uncontrolled airspace is provided by Jiang et al. (2016) for UTM clients to use web-based software applications that provide access to airspace data while providing flight planning and flight plan review of proposed flights. UTM clients will be provided with information from ground-based radar, GPS, local weather stations, and any relevant agencies that can provide flight-related information, while the UAS will need to have onboard sense and avoid technology such as ADS-B or TCAS (Jiang et al., 2016)

### *2.10.2 Routing and Scheduling Management*

A major consideration for UTM is deciding on centralized or decentralized organization and management. While UAS operations may appear to be very similar to traditional ATM, there are significant differences that need to be addressed. Primary differences between ATM and UTM include ATM consisting of scheduled, predictable airport-to-airport flights, while UTM flights are highly variable, with takeoffs and landings occurring almost anywhere (Sedov & Polishchuk, 2018).

Additionally, limitations on airspace and operational requirements will necessitate the sharing of airspace between unmanned and manned aircraft for larger UAM missions. This interaction will be crucial in the success of UAM. The air parcel model is used in the UTM system to divide low-altitude airspace. Foina et al. (2015) propose a UTM method of using the air parcel model consisting of three components: a UAS electronic identification plate, ground identification equipment, and a traffic routing system. With the air parcel model system, landowners possess the air space above their real estate and approve or disapprove over flights. Foina et al. (2015) determined "the UTM using the air parcel model is a viable solution for the UAS regulation issue."

There may be elements of a sUAS UTM that could be scalable or useful to large unmanned aircraft operations. Although the UTM system proposed by Foina et al. (2015) is designed for aircraft that fly for 30 minutes or less, there is still the need to share resources of airspace and landing requirements that can be considered for larger aircraft operating in controlled airspace.

#### 2.10.2.1 Centralized Systems

Sedov and Polishchuk (2018) considered centralized and decentralized UTM systems with airspace incorporated in the form of a single-layer or multi-layer. With single-layer airspace, all the aircraft operate at the same altitude, while multi-layer airspace allows for various altitudes to be flown but would require accurate altitude capabilities of the UAS. For centralized systems, the management body needs to know all current and planned UAS operations in its area. A ground delay was utilized in the centralized system with the single layer, where the lower priority operation would have to wait on the ground when a higher priority operation was in conflict (airspace, takeoff, or landing site). With the multi-layer system, UAS were provided with an assigned layer for the flight, but again all current and potential flights needed to be known in advance. After several simulations, it was determined "a centralized approach does not always exhibit the best performance" (Sedov & Polishchuk, 2018). The ground delay method was found to cause excessive delays, and the multi-layer approach led to several traffic conflicts, even when all flights were known in advance of departing.

#### 2.10.2.2 De-Centralized Systems

For the decentralized portion, Sedov and Polishchuk (2018) chose to have the single-layer airspace aircraft hover in position until the conflict was clear, and for the multi-layer airspace option, the lower priority operation would descend to a lower layer then continue at that new altitude. Both decentralized options provided much better movement of aircraft in the simulations as they kept aircraft moving and it was determined that different airspace structures and use of various conflict avoidance maneuvers could increase capacity and safety and "that horizontal maneuvers will form the basis for the future UTM deconfliction algorithms" (Sedov & Polishchuk, 2018).

Bharadwaj et al. (2021) propose a decentralized ATM method that includes vertiports that are in charge of takeoffs and landings, while a vertihub contains several vertiports and controls all UAS operations in their local airspace (Bharadwaj et al., 2021). Their proposal provided preflight authorization and dynamic aerospace management. The simulations showed that this method could allow high volume operations "in a scalable fashion that is not attainable via centralized synthesis" (Bharadwaj et al., 2021).

### *2.10.3 Current Outlook*

Feasibility studies should be conducted to study whether UTM utilized by sUAS operating in uncontrolled airspace can be scaled up to study UTM implications for larger aircraft. Should larger UAS operate in controlled airspace, they would use traditional aircraft communications as well as all the required equipment. Equipage considerations and UAS competition for the same airspace and airport operations needs to be considered in future research (Foina et al., 2015).

## 2.11 Urban Air Mobility (UAM)

UAM is a system of safe and efficient air transportation that will carry passengers and air cargo at lower altitudes within urban and suburban areas (Federal Aviation Administration, 2020b). UAM operations are anticipated to be achieved through a "crawl-walk-run" approach (Federal Aviation Administration, 2020d), which relies on changes in regulatory frameworks, ground infrastructure, and the realization of economies of scale for UAM operators (NEXA Advisors, 2019). Near-term projections demonstrate a 0.1 percent utilization of all daily work trips taken across the United States (55,000 daily trips) with a potential ramp-up to 20 percent of all daily work trips (11 million daily trips) in the next few decades (Reiche, et al., 2018). A number of analytical and modeling techniques have been used to estimate the UAM market in the near and long-term.

### *2.11.1 Demand for UAM*

Estimating demand for UAM requires a comprehensive evaluation of the variables that affect consumer choice. This involves taking inventory of the enabling infrastructure such as heliports, airports, vertiports, and the underlying electric grid, as well as projecting the availability of infrastructure over time. Demand modeling also requires accounting for public acceptance barriers that affect an individual's willingness to fly, such as safety, noise, and comfort with automated flight. In addition to public acceptance barriers, the overall cost of using UAM flight services is also an important consideration. Both generalized costs (value of time) and direct user costs (tickets, transit fares, and vehicle ownership and maintenance costs) influence an individual's decision-making process for transportation mode selection. As such, UAM services compete with an array of transportation options. UAM will likely be most competitive, attracting users who have high generalized cost thresholds or a willingness to pay to save time and avoid travel delays.

### *2.11.2 Assumptions, Guideposts, and Modeling Techniques*

Several research efforts or private industry practices have laid the foundation for estimating demand for UAM. These efforts have either constructed a key component of the demand modeling process, or they have estimated UAM demand in its entirety.

Volocopter (2021) projects a 241 billion euro market share by 2035 with a potentially realizable market share of over 11 trillion euros. Rimjha et al. (2021) found that, depending on trip cost, there was the potential for over 40,000 trips per day in the San Francisco Bay area alone. Such high potential-demand highlights the significant changes/advancements which must take place to achieve such large-scale operations. Given that commuter trips are projected to be such a significant source of demand, this will result in highly concentrated demand, both in time, and destination. This highlights an ultimate need for highly efficient operations which will likely require significant adjustment as UAM is phased in and more concrete information becomes available and more technical solutions are developed. Although the demand is centered in a few metropolitan areas, an analysis by Haan et al., (2020) of the top 40 composite statistical areas in the United States showed that the potential demand for UAM services is relatively widespread as shown in Figure 10.

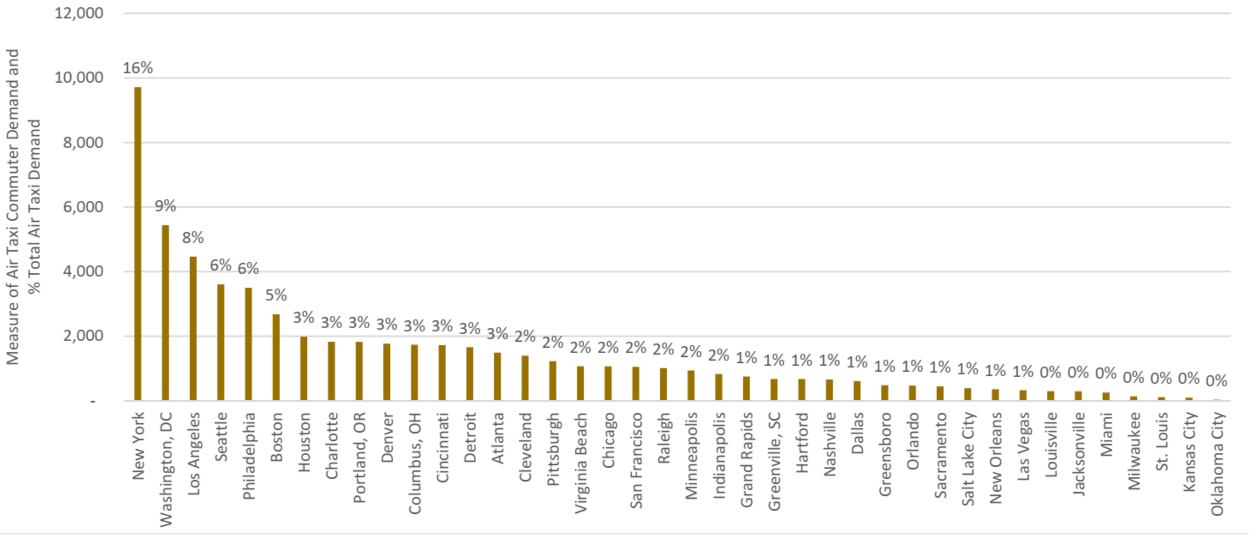


Figure 10: Projected UAM Demand in the Top 40 Composite Statistical Areas in the United States (Haan et al., 2020)

In addition to the direct economic impact, large-scale (i.e., high volume) UAM operations could have far-reaching economic consequences: for instance, altering housing and company locations due to newly available, fast transportation (Rothfeld et al., 2020). This remains an area in which the current body of knowledge is quite small.

Booz et al. (2018a) conducted a robust UAM market analysis estimating demand for UAM services within the Airport Shuttle and Air Taxi markets in the United States. Starting with the total universe of commuters, a series of constraints were applied to estimate demand for these use cases. The methodology of Booz et al. (2018a) as shown in Figure 11 identified key modeling parameters that, when comprehensively assessed, could generate UAM demand estimates.

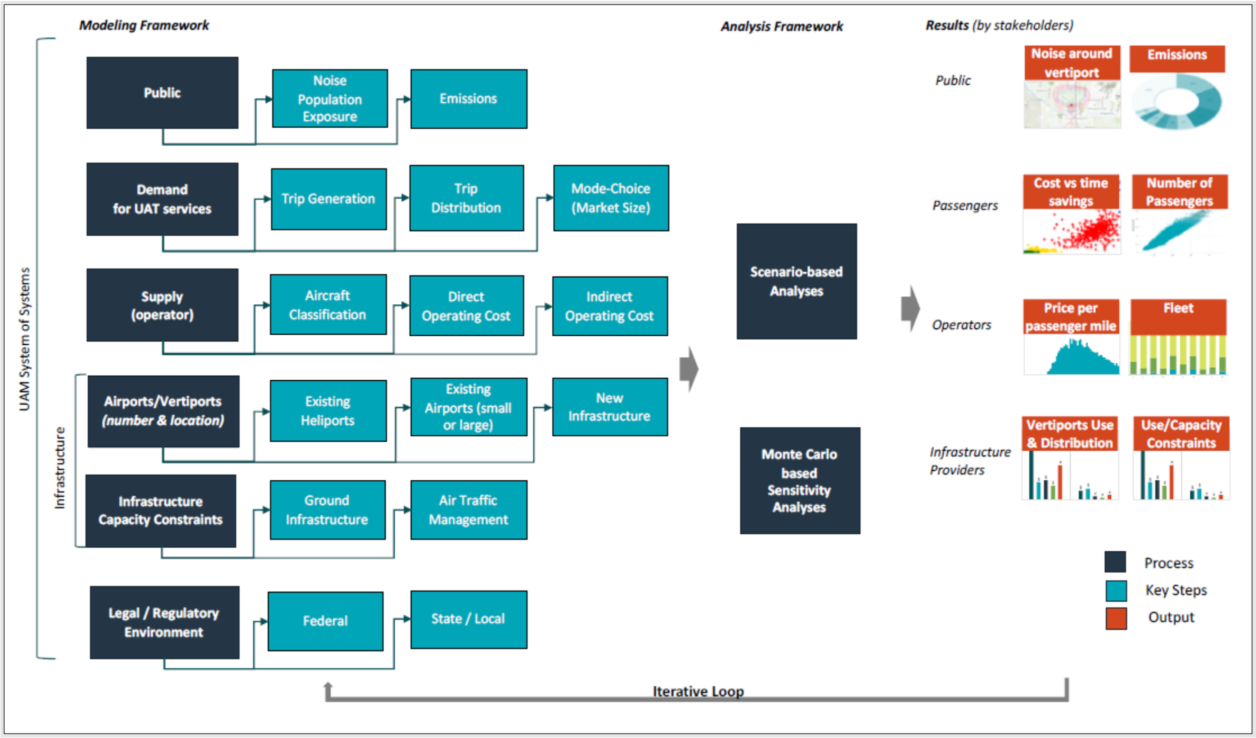


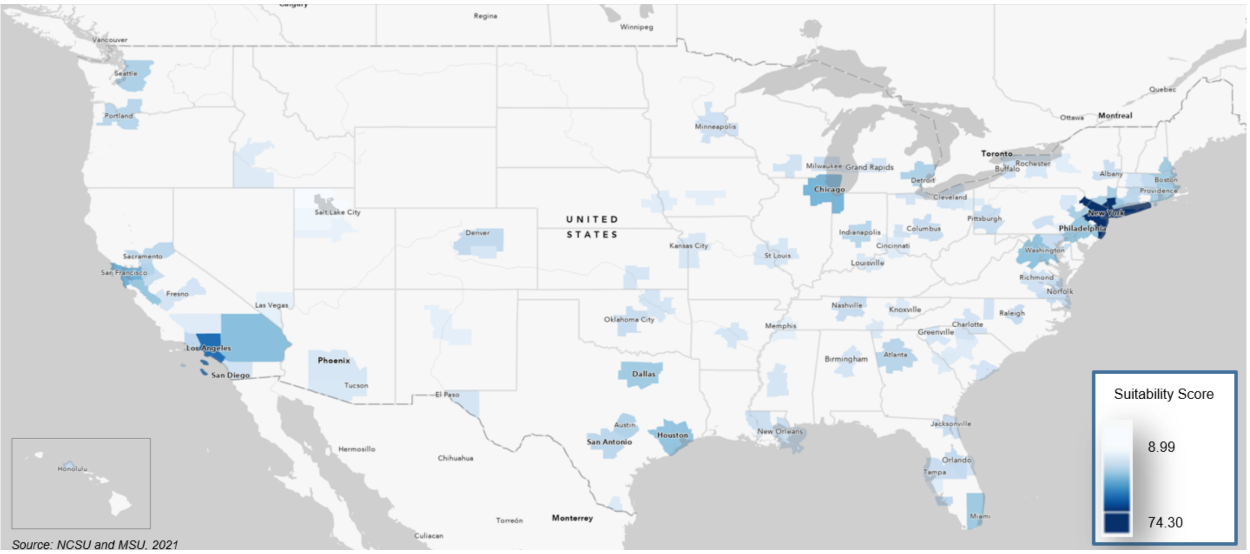
Figure 11: Booze Allen Hamilton (2018) Urban Air Mobility Demand Modeling Framework

As discussed within the work of Booz et al., (2018a) and supported throughout the UAM literature, there are a number of essential factors that contribute to UAM utilization. These factors ultimately determine the extent of demand for UAM services and may include:

- Public acceptance
- Direct and indirect user costs
- Relative attractiveness of UAM compared to other modes of transportation
- Availability of UAM enabling infrastructure

These factors serve as key modeling parameters for estimating UAM demand. In addition to the aforementioned demand parameters, UAM research also indicates the potential for UAM market growth via medical transport. According UAM Geomatics (2021), An estimated 400,000 patients are transported by rotor wing aircraft every year in the United States (Greenshaw and Jamali 2021) with each flight costing $25,000 on average. Medical flight services enlisting UAM capabilities have the potential to substantially reduce hospital and healthcare costs as well as increase service capacity. Additionally, EMS aviation safety is a significant concern: Greenshaw and Jamali (2021) found that “fatal accidents accounted for a much higher proportion of EMS helicopter accidents than non-EMS accidents (rates for non-EMS helicopter accidents were essentially twice that for EMS accidents)”.

Also, as part of an ongoing research effort (ASSURE research project A36) demand for UAM passenger flight services is being evaluated through a site suitability analysis and a bass diffusion model. More than eleven site selection criteria, developed through an extensive literature review, were used in the analysis. These criteria include: population density, polycentrism (number of central business districts within a specified area), presence of fortune 1,000 companies, gross domestic product by metro, average commute time to work, relative level of surface transportation congestion, airport to central business district drive time, heliports per capita, airports per capita, existing short haul demand, and a number of airspace congestion variables. The overlapping incidence of these variables within a metropolitan statistical areas (MSAs), denotes locations particularly favorable for UAM services in the United States. The first iteration of the site suitability analysis results in shown in Figure 12. It should be noted that the A36 project team is continuing to modify the analysis based on additional variables under review. Once the analysis is complete, initial demand estimates will be forecasted and paired with a bass diffusion model to forecast market penetration over time.



Source: NCSU and MSU, 2021

Figure 12: A36 - First Iteration of Site Suitability Analysis Results

### 2.11.2.1 Public Acceptance

With any emerging technologies, public trust is essential. Gaining public confidence is especially pertinent with unmanned flight (Community Air Mobility Initiative, 2021; Lascara et al., 2018). Department of Transportation representatives expected that this public opposition would especially create challenges as firms such as Talyn (a prospective eVTOL manufacturer) interacted with local regulatory environments (e.g., zoning for vertiports). Across all unmanned aircraft use cases, public concerns for unmanned flight fall into five (5) major categories: safety, privacy, job security, environmental threats, and noise & visual disruption (Booz Allen Hamilton, 2018b). Within human transport use cases, consumers are most concerned about the safety of both passengers and bystanders, and this concern may be most acute during the initial transition period when aircraft are expected to be manned by pilots and assisted by onboard automation systems (Bauranov & Rakas, 2019).

Willingness to pay (WTP) is the maximum price a customer is willing to pay for a product or service (Stobierski, 2020). WTP can vary substantially from customer to customer based on extrinsic or intrinsic differences (Stobierski, 2020). Extrinsic differences are factors that can be deduced from an individual without having to ask them directly, which can include a customer's age, gender, income, education, and where they live (Stobierski, 2020). Meanwhile, intrinsic differences are difficult to observe and would not be able to be understood without directly asking an individual. Intrinsic differences include an individual's risk tolerance, desire to fit in with others, and level of passion about a given subject (Stobierski, 2020). For example, Garrow et al. (2020) note that multiple studies have highlighted the importance of social factors (e.g., travelers would adopt autonomous vehicles when their friends did) to new transportation mode adoption.

Public acceptance barriers and economic cost considerations are examples of intrinsic and extrinsic differences affecting individuals' WTP for unmanned air passenger services. UAM research indicates that actual and perceived safety, noise, weather, comfort with technology, cost of available alternatives, and convenience of unmanned passenger services are all factors into WTP (Booz Allen Hamilton, 2018a). Disentangling which factors have the most profound effect on consumer choice, or WTP can be approached with stated preference surveys and revealed preference experiments. These methods can be used to elicit how each public acceptance barrier or economic cost consideration associates with an individual's WTP.

##### *2.11.2.1.1 Public Perceptions of Safety and Acceptance for Autonomy*

The public's perception of UAM operational safety will play a crucial role in UAM acceptance (Straubinger, Kluge, et al., 2020). According to Rothfeld et al., (2020), "social acceptance remains one of the less predictable components and, therefore, a main challenge to UAM's introduction to the market." Thus, building a culture of trust and confidence in autonomous aircraft is essential for adoption. Research indicates that public perception of safety is a key psychological barrier to UAM adoption (Rothfeld et al., 2020) and was found to be the most important factor in the adoption of UAM, when compared to the trip cost, trip duration, service reliability, and operation characteristics (Al Haddad et al., 2020). Garrow, German, et al. (2020) note that a survey of current airline uses showed that reducing the perceived risk (as well as providing more information) was "critical to increasing trust and positive attitudes toward electric airplanes and [potential clients'] willingness to pay." Familiarity with autonomous vehicles, as well as information about such vehicles' capabilities and limitations, fosters trust in such vehicles (Garrow, German, et al., 2020). Counter to public perceptions, the implementation of autonomy in UAM is likely to increase safety, as pilot error is the leading cause of aircraft accidents (Volocopter, 2021).

Several UAM stated preference studies have been undertaken to gauge individuals' "willingness-to-fly," or their level of comfort using unmanned flight. Findings from one public acceptance survey demonstrated that 80 percent of respondents had concerns about UAM safety (Garrow, German, et al., 2020). Another public perception survey demonstrated mixed results for UAM adoption. Approximately 22 percent of responses indicated that they would adopt UAM within the first year it was available, 37 percent would adopt within 2-3 years, 14 percent within the first 4-5 years, and most of the remainder were unsure of when or whether they would adopt the technology (Al Haddad et al., 2020). Another study found that, though current research shows conflicting results regarding the effects of personal and household attributes on the willingness of individuals to adopt UAM (Straubinger, Kluge, et al., 2020), certain trends have emerged within the collection of stated preference research. Early adopters of UAM are more likely to be wealthy, male, and prone to technology adoption (Boddupalli et al., 2020; Booz Allen Hamilton, 2018a; Garrow, German, et al., 2020). Garrow et al. (2020) report that males were 1.2 times more likely to take an air taxi, while those over age 65 were 4.6 times more likely to take transit.

Meanwhile, frequent rideshare use was negatively associated with ground transit (0.6 times less likely) and positively associated (1.2 times more likely) with choosing an air taxi (Garrow, Roy, et al., 2020). In an online stated choice experiment comparing an eVTOL service to current commuting habits, Boddupallli et al. (2020) found that being male was related to choosing an air taxi, while having children was related to not choosing to travel by automobile. The oldest respondents were most likely to choose transit, while those in middle age were more likely to choose air taxis; those between 18 and 34 were most likely to choose private automobiles. Relationships to household income, level of education, current number of annual air trips, and current commute characteristics were not significant, though the minimum income threshold was $100,000. Current rideshare usage and pro-car and pro-technology attitudes were associated with a choice of air taxi (Boddupalli et al., 2020).

One study found that the two factors with the most distinct adoption behaviors were gender (with men being more likely to adopt earlier) and the language in which the survey was taken (with English-speakers more likely to adopt sooner than German speakers). In general, individuals who took the survey in English (rather than German) were found to have a higher trust in and enjoyment of automation, greater perception of the usefulness of UAM (Al Haddad et al., 2020). Another stated preference survey found that younger individuals and higher-income households were more likely to accept UAM (Ploetner et al., 2020).

Research also indicates that travelers prefer piloted vehicles over fully autonomous aircraft (Straubinger, Kluge, et al., 2020; Rothfeld et al., 2020). Furthermore, when flying in autonomous aircraft, travelers generally prefer having a remote operator available. Women were more likely to desire a remote operator than men (Al Haddad et al., 2020). This finding may suggest a stepping-stone through which the public would be able to gain the requisite familiarity to accept autonomous transportation on a broad scale.

Before partially or fully autonomous UAM is widely adopted, autonomous technologies will require safety enhancements. Lascara et al. (2018) list autonomous “detect and avoid” capabilities as one of the primary challenges currently facing UAM. Though they note that there do exist current standards and technologies for UAS and sUAS, they also suggest that such systems may require “better performance and reliability for UAM operations due to the criticality of protecting passengers onboard.” Regulations (e.g., separation and well-clear definitions) must also be assessed to determine their suitability in light of the involvement of passengers in UAM operations. The development of such systems/procedures is challenging due to virtually non-existent data sets of actual trajectories which have been used to build current detect and avoid systems (Katz et al., 2019). Additionally, the logistics of arrivals and departures is critical to ensure needed flexibility in the event of low-battery events, which necessitate emergency landings (Garrow, German, et al., 2020). Volocopter’s goal is to make UAM as safe as current commercial airlines and plans to incrementally implement autonomy into their UAM system (Volocopter, 2021). This approach may enable the public to gradually gain comfort with UAM autonomy. Under this type of paradigm, Lascara et al. (2018) suggests that remote pilots may be supervising multiple aircraft simultaneously.

#### *2.11.2.1.2 Public Desire for Privacy and Security*

Sharing a flight with a stranger may inhibit UAM adoption in the United States. Booz et al. (2018a) found that the public contains discomfort with sharing an unpiloted vehicle with strangers, which is amplified by automated operations overall. According to research findings from Garrow et al. (2020), privacy is a main deterrent to pooled ride-hailing services, with non-Hispanic whites being more privacy-sensitive than individuals of other ethnicities.

Security has been found to be a primary concern for UAM operations and is more important to women than men (Al Haddad et al., 2020). Additionally, women are more likely to express a desire for on-board cameras (Al Haddad et al., 2020). Findings from a stated preference survey conducted by Al Haddad et al. (2020) demonstrated that those who took the survey in English (rather than German) were more likely to have concerns about cyber-security.

#### *2.11.2.1.3 UAM Weather Constraints and Associated Public Perceptions*

Weather can directly affect UAM operations. Poor weather can reduce ATC capacity, significantly increasing separation requirements and decreasing throughput (Vascik, 2020). Typical adverse weather conditions will vary greatly from location to location. In the early morning, fog may disrupt the morning commute and have a greater impact on UAM usability than mid-day thunderstorms (Reiche et al., 2021). An analysis of the ten large U.S. urban areas for potential UAM adoption (Booz Allen Hamilton, 2018a) found that weather barriers were significant. With the operational day presumed to be constrained to between 7 am and 6 pm, the authors found that in five of the ten markets analyzed, half the operational day or more on average would be constrained by weather conditions (Booz Allen Hamilton, 2018a). Even weather patterns that are not typically considered adverse could significantly hamper UAM operations. For example, Ploenter et al. (2020) noted that, in the Upper Bavarian region, average wind-speeds suggest that operation must be possible for up to 20 m/s headwinds. Significant headwinds may reduce trip time savings by decreasing effective cruising speeds and increasing required recharge times. In areas with typical wind directions, this could prove particularly detrimental (or beneficial) for directional use cases (such as commuting).

The weather may also influence public perceptions of UAM safety. In a stated preference survey, Reiche et al. (2021) found that survey respondents were most fearful of snow, fog/low visibility, and turbulence, with near indifference toward outdoor temperatures. As a result of their survey, mitigation techniques were recommended to account for the weather. One technique called for using a variety of aircraft with different capabilities that could help maximize operational capabilities. Another technique involved in integrating timely weather reporting into UAM travel plans so that passengers could be quickly rerouted to non-aerial transport options.

#### *2.11.2.1.4 Noise Constraints*

In a question-and-answer session following a presentation by the CEO of Talyn Air, a prospective eVTOL manufacturer, representatives from two state Departments of Transportation (DOT) raised relevant regional and economic equity and community opposition concerns. The DOT officials expressed concern that this would potentially be a bespoke technology and that there would be significant public opposition to what could be a large fleet of noise-making vehicles that ultimately move a small number of people. Noise pollution complaints may result in regulations that curtail UAM hours of operation (Lascara et al., 2018) or limit the accessibility of UAM enabling infrastructure (Cohen et al., 2021; Joby Aviation, 2021; Vascik, 2020). Research indicates that communities which have had exposure to aviation noise pollution are more predisposed to enact restrictions that limit throughput and take-off/landing site development (Vascik, 2020).

UAM operators and field experts are currently working to reduce noise impacts. Some approaches have involved implementing engineering improvements on aircraft. The VoloCity, and air taxi designed by Volocopter, sets a noise benchmark with a 65 dB noise level at a distance of 120 m (flyover) and 75 dB at a distance of 30 m (takeoff/landing) (Volocopter, 2021). They compared this benchmark to various qualitative noise sources: big-city road noise exposure, a heavy truck, and a helicopter flyover. Volocopter believes that "quiet operation is essential for aircraft flying in populated areas" (Volocopter, 2021). Joby Aviation, a UAM manufacturer, recognizes that making the system as quiet as possible is "critically important for public acceptance" and for allowing the placement of vertiport facilities close to origins and destinations (Joby Aviation, 2021). Joby aircraft have a predicted takeoff noise of 65 dBA and cruising noise of 40 dBA. UAM aircraft configurations, such as the multirotor, will produce lower noise than a lift and cruise (which includes fixed wings) type vehicle due to their higher disc areas (Shamiyeh et al., 2018).

Early research indicates that annoyance levels will be much higher for UAM aircraft due to the specific frequencies and tonal nature of the acoustic signatures (Cohen et al., 2021). As a result, "eVTOL aircraft will need to be imperceptible at cruising conditions to gain widespread acceptance" (Cohen et al., 2021). Increased utilization, even of existing airports, may cause "NIMBY" or "Not In My Backyard" opposition, but such concerns may be alleviated by being "a good neighbor" and through technical advancements (NASA, 2021).

In addition, to aircraft improvements, other noise mitigation strategies have included undertaking carefully planned field operations. Ploetner et al. (2020) cite routing UAM traffic along existing major roads and railways as a way to reduce their noise impacts. However, this may be a challenge as 56 percent of the defined reference missions involve flight segments at low altitudes over residential or tourist areas, exposing previously quiet communities to aircraft noise (Vascik, 2020). UAM benefits must outweigh their cost and nuisance profile to the communities they serve (NASA, 2021). Achieving this requires reducing (monetary) costs and mitigating noise and emission concerns through new technologies (NASA, 2021).

### 2.11.2.2 Direct and Indirect User Costs

Users of UAM services will eventually be subjected to both direct and indirect costs. The former consists of ticket prices, while the latter refers, primarily, to the time required. It seems likely, at this early stage, that the latter will actually be a cost saving relative to current transportation methods. Even should this not be the case, the autonomous nature of the transport will allow users to use the transport time productively (Rothfeld et al., 2020).

#### *2.11.2.2.1 Effect of Direct User Costs on Willingness to Pay*

As expected, direct user costs are a key driver of public demand for UAM services, and costs must be kept relatively low for UAM to become a significant competitor to other modes (Rothfeld et al., 2020). Al Haddad et al. (2020) found that to attract the wider public, UAM costs must be competitive with ground transportation (e.g., taxis). Furthermore, transparency in the trip cost will improve the user's experience. Rimjha et al. (2021) calibrated a mode choice model and applied it to the commuter population in Northern California to analyze the demand for UAM services for commuting. Note that roughly 80% of the trips within their driving trips validation data set were 20 miles or shorter. Virtually none were longer than 60 miles. The results of this model indicate that demand is heavily price-sensitive: the authors found that 42,140 round-trips would be demanded at a cost-per-mile of $1, but this demand falls by 34% at $1.20, at which point the system would be unable to cover fixed costs (Rimjha et al., 2021). Ploetner et al. (2020) also found the cost to be a dominant factor in the number of predicted UAM trips. As the per-kilometer cost approached five times that of a ground taxi, Ploetner et al. (2020) estimated a decrease of UAM trips of more than 60 percent. Volocopter's "longer-term goal is to provide affordable urban air mobility to everyone by further decreasing prices over time to within the range of regular taxi prices for identical routes" (Volocopter, 2021). However, there are still so many unknowns, that feasible UAM fare structures, based on projected operating costs (including, for example, aircraft cost, engine overhaul cost, and flights to reposition aircraft), are still being researched (Tarafdar et al., 2019).

While low UAM prices are required to reach the general public, specific markets will vary in terms of an effective price point. For example, certain businesses might be willing to pay a premium for their employees to utilize faster transportation. Fadhil (2018) suggests that the office rent price may reflect the business trip budget of particular companies, providing a means of assessing potential demand in various areas. Different locations will also reflect different attitudes about what attractive UAM cost is. "The majority of Australians are currently not willing to pay more for a fully autonomous vehicle than a conventional car" (Garrow, German, et al., 2020).

While trip costs must be kept low, UAM must also be economically viable for the service provider. Rimjha et al. (2021) believe that, in order to balance high system demand during peak hours with the necessity of marginal off-peak trips to cover high fixed costs, a congestion or peak pricing system will be necessary. Additionally, the implementation of autonomy, as it is eventually accepted by the public, will aid in the (economically sustainable) reduction of UAM trip costs (Volocopter, 2021).

##### *2.11.2.2.2 Value of Time*

The indirect cost to UAM adopters is the cost of time, as well as hassle in transport to the UAM access point. This second point will be covered further in Section 2.11.2.3.3. Intuitively, increased time savings would result in a more attractive service. The value of time was found to be one of the parameters with "high explanatory power" for the time-to-adoption of UAM (Al Haddad et al., 2020). Garrow, Roy, et al. (2020) found that a non-trivial proportion of the population possessed a very high value of time. "The travel time for UAM was found to be more sensitive than that for train," which perhaps suggests that time savings will be a primary motivator for the use of UAM (Ploetner et al., 2020). This could further emphasize the importance of time savings for UAM in particular.

However, current research is somewhat conflicting with wait-time being sometimes found to be an important factor in mode-choice, while in other cases, it is insignificant (Rothfeld et al., 2020). One important point is that there is a significant variation in the value of time across individuals (Boddupalli et al., 2020; Garrow, German, et al., 2020; Garrow, Roy, et al., 2020). Additionally, autonomous vehicle controls could decrease the overall value of time as time previously spent transiting could now be spent engaging in other activities while transiting (Garrow, German, et al., 2020; Rothfeld et al., 2020).

Increasing the time savings of UAM depends greatly on what services are offered and to whom. For instance, multi-copter configuration vehicles are more efficient during VTOL, potentially saving charging time for short trips (Shamiyeh et al., 2018). However, lift and cruise vehicles (which include fixed wings) are substantially faster, improving time savings for longer trips (Shamiyeh et al., 2018). For smaller study areas (presumably shorter trips), it is imperative that the wait-time at the vertiport be kept quite short (Rothfeld et al., 2020). The sensitivity analysis Ploetner et al. (2020) found that the number of vehicles per vertiport was a dominant influence on the number of predicted UAM trips. This was because “the fleet size has a significant influence on agents’ waiting times.” In some areas, the added time required to service other passengers is a stronger deterrent to ride-sharing, while in others, the burden of riding with strangers is a more important factor (Ploetner et al., 2020). Finally, minimizing the distance to access points is key to providing customers with time savings (Volocopter, 2021).

#### 2.11.2.3 Relative attractiveness of UAM compared to other modes of transportation

In addition to public acceptance of UAM and willingness to shoulder the costs, to be viable, UAM must successfully compete with other modes of transportation. Target clientele will determine in large part the major factors controlling UAM’s attractiveness. Fadhil (2018) notes that “the experts from real-time AHP Delphi analysis tend to perceive non-commuting trip as the main trip generator for the initial phase of UAM operation.” On the other hand, “two ‘super-experts’ [with more than 15 years' experience] favors [sic] commuting trip as the trip generator.” The dominant market, and therefore the most attractive features of UAM service, will vary from place to place. In ranking the relative demand for UAM across 40 large US markets, Haan et al. (2020) find that New York, Los Angeles, and Washington, DC, rank highest for overall air taxi demand, with 33% of all predicted trips occurring in these combined statistical area (CSA)s. The top six CSAs account for half of all demand. The authors write that, “This is an interesting finding, as it suggests that a commuter air taxi service may be viable in only a handful of cities and/or that port infrastructure investments will be required in order to support a commuter air taxi service in smaller cities” (Haan et al., 2020). However, one can also reverse the question, examining projected features of UAM to determine the market potential. Garrow, German, et al. (2020) found a significant number of papers examining “the potential of UAM for providing an effective and scalable means of reducing travel time in cities, assessments which lend to understanding the market potential of UAM and its value to society”.

Despite the potentially large range of attributes, which might allow UAM to successfully compete with other transportation modes, some are consistently important. Reliability and availability are two key factors in determining mode choice (Garrow, German, et al., 2020). Straubinger, Kluge, et al. (2020) produced a compilation of frequently mentioned factors that affect mode choice. The top five (in order of frequency of appearance in literature) are travel time, travel cost, income, gender, and age. Furthermore, travel time has always been one of the top two mode choice factors (Straubinger, Kluge, et al., 2020). Rothfeld et al. (2020) identified mode-choice modeling as a key area in which the current body of knowledge is lacking. Most current research focuses on cost and time savings; however, there are other important factors that must be considered. For example, socioeconomic variables, such as gender, age, and income, have an impact on mode choice behavior (Rothfeld et al., 2020). Travelers also display more interest in flying taxi services for business or recreational trips compared to commuting, shopping, or education-related trips. Rothfeld et al. (2020) noted that individuals more inclined to UAM also tend to display more concern for the environment. The broad spectrum of individual values and decision-making strategies makes mode choice problems quite complex. Rothfeld et al. (2020) recommended

MATSim for examining UAM problems as it follows a microscopic approach: simulating the mode choice of each traveler. The subsections below describe some important factors in mode choice decisions. These must be a consideration in the successful implementation of UAM.

#### *2.11.2.3.1 Congestion*

Ground traffic congestion can be a major source of frustration for travelers. Depending upon the target market and location, avoidance of congestion could be a highly attractive attribute of UAM. Indeed, Bulusu et al. (2021) found that there were time savings for almost 45% of commuters when congestion was heavy, even with the most conservative time savings and transfer time estimates. Those savings were dependent on congestion as the number dropped to about 3% of commuters who could benefit from UAM when the roads were relatively clear. This discrepancy highlights the importance of congestion as a potential influence on transportation mode choices, and further increases the importance of high-throughput capacity of vertiports, as significant demand will be concentrated during typical rush hour times.

Lascara et al. (2018) mention that traffic congestion is projected to increase by 6% by 2030, resulting in an increased cost from \$200B to \$293B from 2013 to 2030. Garrow, German, et al. (2020) note that one survey found that nearly half the respondents think that UAM may be a solution to roadway congestion. However, an important, unanswered question is whether the introduction of UAM will create additional travel demand or absorb some demand currently handled by cars (Rothfeld et al., 2020). Regardless, UAM cannot completely avoid the effects of congestion. Rothfeld et al. (2020) found that, though congestion affects car trips far more than UAM, there is an effect on UAM trip times as well due to station access times.

#### *2.11.2.3.2 Length of Commute*

The physical layout of different cities and the distance between residential and business districts could have a significant effect on the potential time savings (i.e., attractiveness) of UAM. In general, research has concluded that longer trips tend to favor UAM. Garrow, German, et al. ( 2020) note that there may be demand for UAM for those with commutes longer than 45 minutes. Rothfeld et al. ( 2021) found that UAM travel time savings would be competitive with car trips of approximately 50 minutes or longer. However, this is not necessarily good news for UAM, as “the vast majority of UAM trips would be below 50 km in range” (Rothfeld et al., 2021). Ploetner et al. (2020) also found that the majority of trips (for which UAM was predicted to be selected as the mode of choice) were shorter than 20 km. Even current “air taxi trips need to be at least 15 to 25 km (about 9 to 16 miles) to provide travel time savings over existing modes” (Garrow, German, et al., 2020). The modal share of UAM was greatest for trips between 50 km and 120 km, with a maximum of about 6% of all the trips of that distance (for the lowest ride cost) (Ploetner et al., 2020). Note that for the 0-20 km trips (which represent the majority), the modal share did not rise above 2%. However, the effects of the COVID-19 pandemic may increase demand for commute trips using UAM due to the relocation of travelers to the suburbs and their potential need for occasional trips to the office.

Not only does the trip length affect mode choice decisions, but also the reliability of the UAM service. In analyzing the potential market for UAM in Northern California, Rimjha et al. (2021) find that commuting demand is extremely sensitive to time delays. While demand is concentrated in a small number of vertiports, there is a clear relationship between the number of vertiports and demand. The authors considered both a many vertiports, lower-cost scenario, and a fewer vertiports, high-cost scenario. In each instance, a ten-minute delay would halve demand. While, as discussed above, there is a disagreement between experts regarding commuters as a potential market for UAM, the information included here certainly seems to impose stringent requirements on the timeliness and speed of UAM services targeting commuters.

#### *2.11.2.3.3 Ease of Access*

While the time savings of the trip itself form an important part of ensuring UAM is an attractive transportation mode, access to the service itself and the time required to do so, will also be factored into mode choice decisions. Rothfeld et al. (2020) believe that UAM cannot be considered on its own and that future studies need to consider how it will be incorporated into the existing transportation network. Integrating UAM into existing public transportation networks could certainly maximize the convenience of the service (Volocopter, 2021); However, to integrate UAM into the existing public transportation system, UAM access locations (e.g., vertiports) must be co-located (Straubinger & Fu, 2019). Additionally, multi-modal trips must have integrated fares (i.e., one ticket for all modes), the various services (e.g., bus and UAM) must be able to share data (e.g., real-time arrival/departure tracking), and potential users must be able to access such information on a single platform (Straubinger & Fu, 2019). A business model similar to Voom, which merely connects potential clients with air-taxi operators, could aid significantly in the integration of UAM into existing public transportation networks (Lascara et al., 2018). UAM access to airports (i.e., integration with existing air transportation networks) will require special considerations regarding ATC (Vascik, 2020).

The number and placement of UAM access points and the amenities of those access points also affect the attractiveness of UAM as a transportation mode. Rimjha et al. (2021) found that while demand in the San Francisco Bay Area is concentrated in a small number of vertiports, there is a clear relationship between the number of vertiports and demand, as the number of vertiports increased the demand also increased due to the number of commuters in the catchment area. In their mode choice model, Haan et al. (2020) also created a scenario where access, egress, and wait times are zero in order to understand the importance of existing infrastructure in their findings. Under these conditions, Chicago and San Francisco become significantly more viable markets. This highlights the importance of access as a crucial parameter in determining the attractiveness of UAM services. Additionally, Garrow, German, et al. (2020) note that the effect of parking availability on UAM mode choice is worth exploring in future research.

#### *2.11.2.3.4 Competing Technologies*

A current major competitor for UAM is public transportation. Rothfeld et al. (2021) showed that a significant number of trips for which UAM is eligible are drawn from public transportation. Unfortunately, those who regularly use public transportation were found to be likely later adopters of UAM (Al Haddad et al., 2020). Rothfeld et al. (2020) corroborated these findings, observing that current car users are more likely to adopt shared UAV transportation than current users of public transportation. Straubinger and Fu (2019) note that lower demand for public transportation will result in public transportation being less attractive (as departure frequencies are reduced, for instance). Using UAM to supplement, rather than compete with, existing public transportation would avoid this issue. This could be accomplished by introducing UAM routes that facilitate trips that otherwise require lengthy or complex transfers between existing public transportation lines.

“Welfare changes should hereby not only consider shifts directly related to the transport market but also adjustments on other markets due to the introduction of UAM” (Rothfeld et al., 2020).

Personal vehicles (cars) are another current transportation mode with which UAM services may come into competition. In 2017 the American Automobile Association estimated the total cost of car ownership to be between $0.46 and $0.61 per mile (note that ride-sharing is quite common using cars) (Garrow, German, et al., 2020). However, cost savings due to ridesharing will likely not play an important role in transportation mode choice. 90% of all taxi/ride-hailing trips only transport 1-2 passengers (Volocopter, 2021). Modern-day air taxi services charge between $10 and $30 per-passenger mile (Garrow, German, et al., 2020). In attempting to estimate demand for UAM commuting in the San Francisco Bay Area, Rimjha et al. (2021) argue that any such system must minimize delays in order to avoid losing commuters to private cars (and, even so, “it will be difficult for the system to be profitable on commuting trips alone”).

The (likely) higher cost of UAM may be offset somewhat by Garrow, Roy & Newman’s (2020) observation that “a significant proportion of the population has a high VOT [Value of Time], which in turn will translate into higher willingness to pay to take an air taxi that saves time over other modes.” However, an apples-to-apples comparison of time savings may not be appropriate as expectations may make one transportation service attractive for different reasons than another. Ploetner et al. (2020) completed a stated-preference survey in which it was found that “a lower weight for the costs of UAM compared to the costs for train, while the travel time for UAM was found to be more sensitive than that for train.” The authors of this literature review suggest that this may reflect on the expectations (more expensive but faster) placed on UAM.

To further complicate the issue of mode choice, values of time (in a stated preferences survey) for autonomous vehicles were always less than those of conventional automobiles, while VOT was highest for air taxis (Garrow, Roy, et al., 2020). Previous research found that VOT for new modes are related to any productivity increases, and therefore the VOT for AVs should be smaller than conventional autos. This can be seen as drivers can more freely make calls, take notes, and conduct other business activities that were not previously available during their commutes with conventional autos.

> Research findings indicate that AVs will compete more with air taxis than conventional autos. In this competitive environment, the time savings that air taxis provide over an AV will need to be greater than those provided over a conventional car in order to compensate for the lower VOT seen with the AV. (Garrow, Roy, et al., 2020)

Garrow et al. (2020) build upon their other work (including [Boddupalli et al., 2020]), another source reviewed for this project) and conduct another stated choice in the same five cities, this time asking about not only air taxis and traditional alternatives but also about autonomous vehicles (AVs), a question that had previously not been addressed except by Fu et al. (2019). Some respondents always chose the same method: 16.3% always chose a traditional mode, 2.1% always chose autonomous vehicles, and 5.4% always chose air taxis. Respondents somewhat disfavored modes that would require a transfer and somewhat favored modes that had a ride guarantee; they were much more likely to choose transit if they departed for work between 7 and 8:59 am (Garrow, Roy, et al., 2020).

### *2.11.2.3.5 The Effect of Congestion on Transportation Mode Selection*

The COVID-19 pandemic caused the global economy to contract by 3.5 percent in 2020, making it the deepest global recession since the end of World War II (Yeyati and Filippini, 2021). The pandemic not only changed global economic output, it also substantially altered the way people work. According to a Pew Research Center Survey conducted in December 2020, about four-in-ten U.S. adults who are employed full time or part time (38%) say that, for the most part, the responsibilities of their job can be done from home; 62% say their job cannot be done from home (Parker, Horowitz, and Minkin, 2020).

As the workforce continues to evolve and enlist more teleworking options, this likely to reduce peak congestion transportation costs associated with traveling during the morning, lunch, and evening peak periods. According to the semi-regular Urban Mobility Report, throughout 494 U.S. urban areas, each driver experienced an average delay of 27 hours last year, just half of the 54 hours of average delay in 2019 (Schrank et al., 2021). The cost (the cost of extra time and fuel) of congestion for each auto commuter in the nation's urban areas was $605 — a 48 percent savings from $1,170 the year before (Schrank et al., 2021). Congestion, travel time, and transportation cost reduction provide valuable outcomes for U.S. commuters; however, the alleviation of these stressors negatively impacts UAM market penetration. As the overall cost of transportation falls for anticipated UAM substitutes, such as limousines, UberLUX, or autonomous vehicles, it creates a larger price disparity that needs to be overcome to attract UAM customers. Though return-to-work behavior is still largely being determined, data shows that teleworking has substantially lowered commuter transport costs. For example, it is estimated that Houston drivers collectively paid $3.7 billion in transportation costs in 2019, whereas their congestion costs fell to $1.5 billion in 2020 (Olin, 2021). Availability of UAM Enabling Infrastructure

UAM services require dedicated infrastructure. UAM infrastructure not only encompasses physical ground infrastructure for the vehicles (helipads, heliports, vertiports, and vertistops), but also includes flight communications technology and equipment (Fadhil, 2018). Take-off and landing, ATC, charging, parking, and maintenance, among other facilities, are widely accepted as foundational components of the UAM infrastructure network (Baur et al., 2018; Booz Allen Hamilton, 2018a; Community Air Mobility Initiative, 2021; Grandl et al., 2018). In addition to physical infrastructure, personnel (pilots, maintenance personnel, and ground crews) are essential to facilitate UAM operation (Volocopter, 2021).

While UAM is possible with the current infrastructure (as evidenced by the operation of several air-taxi companies), it will require more to achieve full-scale operation (Volocopter, 2021). Indeed Fadhil (2018) notes that the deficiency of ground infrastructure is "the biggest operational challenge of implementing UAM." Which infrastructure needs are most urgent depends greatly on the scale and target audience of particular UAM services. As observed by Straubinger and Fu (2019), UAM access locations (e.g., vertiports) must be co-located. This places significant constraints on UAM access locations, many of which would, for this case, need to be located in high-rent districts.

In addition to the importance of UAM access location (Rothfeld et al., 2020), the maximum throughput of access points is also a major factor (Vascik, 2020). There are many aspects to this concern: high throughput will require sophisticated logistics, which could be eased through the addition of extra staging space (Vascik, 2020). Additionally, maximum throughput is highly dependent on ATC attributes (Vascik, 2020).

The question of infrastructure is perhaps further complicated by the traditionally large role the government has played in infrastructure maintenance. In an industry-affiliated report, Lineberger et al. (2021) call for direct financial support by the Federal government, including through purchasing and subsidies, as well as substantial infrastructure upgrades by state and local governments. This raises the question of who will pay for the infrastructure and how quickly it will be developed. Additionally, Lascara et al. (2018) note that it must be determined whether the management and oversight of UAM access facilities will be private or public.

Regardless of the complexities and uncertainties, it remains clear that infrastructure development is a key step that must be taken to realize large-scale UAM operations. Due to infrastructure constraints, including both ground infrastructure and ATM, as well as the high cost of operation and the current state of UAM technology, Booz et al. (2018) determined that market potential for air taxi and airport shuttle operations is only 0.5% of the total available market in the near-term, though they believe many of these constraints can be addressed in the long term. By 2050, however, Mayor and Anderson (2019) project that UAM journeys may make up 4% of all domestic trips.

##### *2.11.2.3.6 Helipads*

Helipads may prove instrumental in the development of UAM infrastructure in multiple ways. First, existing helipads may be used to provide takeoff/landing space, though the development of additional takeoff/landing sites is imperative, given the anticipated demand (Lascara et al., 2018). Second, in the absence of specific vertiport regulations, helipad regulations can provide a guide to help better understand the eventual operation of future takeoff/landing sites (Ploetner et al., 2020).

##### *2.11.2.3.7 Airports*

There is currently significant infrastructure for aviation operations in the form of existing airports. In addition to already being established, airports tend to be centrally located: “most Americans live within 16 minutes of an airport” (presumably by car) (NASA, 2021). Airports may provide a huge untapped resource in terms of location and infrastructure: while the US has over 5,000 existing airports, only nine are currently considered capacity constrained (NASA, 2021). This may provide ample opportunity for UAM to leverage existing airports.

Additionally, airport access by passengers of commercial airlines may be another source of demand for UAM. Ploetner et al. (2020) felt that “given the importance of the airport located in the study area (Munich international airport), and the potential of UAM for trips that connect the airport with the rest of the study area,” it was worthwhile to specifically expand a model that they utilized to include UAM access to the Munich International Airport. However, Vascik (2020) points out that UAM flights to and from airports come with their own special set of ATC challenges.

##### *2.11.2.3.8 Vertiports*

While leveraging existing infrastructure in the form of helipads and airports is critical, to effectively implement large-scale UAM operations, more infrastructure must be developed (Volocopter, 2021). Two of the most pressing questions, when considering the development of additional takeoff/landing sites (hereafter termed “vertiports”) are: 1) How many are needed? and

2) Where should they be located? (Rothfeld et al., 2021). As with most of the UAM problems, the answers to these questions are complex and highly coupled. In particular, it is worth noting that, in the case of existing public transportation, higher demand results in a more attractive service (Straubinger & Fu, 2019). This is because higher demand results in more routes, more frequent stops, etc., making the service overall more attractive to users. Rimjha et al. (2021) believe that something similar will be true of UAM. Additionally, Rothfeld et al. (2020) agree, noting that it is important to have enough vertiports. This seems intuitive, as lack of capacity to meet demand will divert potential travelers to other modes of transportation. This makes a straightforward answer to the key questions quite difficult, as the answer depends on projected demand, but demand is coupled to the answer itself. Recognizing the complexity of this problem, the approach adopted here is to draw connections between various researched factors and the answers to the key questions ("how many?" and "where?"). This will hopefully begin to build up a picture of the dynamics involved in this complex, highly coupled problem.

The physical size of vertiports is an important point to consider. In some cases, the capacity of vertiports may prove more of a challenge than the number of physical locations. The projections of Ploetner et al. (2020) suggest that high-capacity vertiports may be required in an urban environment. This could be a challenge as increasing vertiport capacity depends, to some extent, on increasing the physical size of the vertiport. However, space is at a premium in urban environments, exactly where the increased capacity could be most helpful. As a sample of the physical space requirements, Fadhil (2018) lists several projected vertiport physical sizes. A "by-eye" average shows the typical vertiport is likely to require a 15 m-square touch-down/lift-off area, a 35 m-square final-approach area, and a 60 m safety area. The conclusions state that at least 361 $m^2$ is required for a landing pad. Another estimate by Volocopter projects a physical size of 500 $m^2$ for simple take-off/landing vertiports, and 1000 $m^2$ for a full vertiport (Volocopter, 2021). The physical layout is also a critical component of capacity. To maximize throughput, vertiports should be designed to allow multiple simultaneous arrivals/departures (Boddupalli et al., 2020). This, however, is also coupled to air-traffic control regulations, minimum safe clearances, potential approach/departure vectors, etc.

A wide array of factors have been considered in relation to the suitability of particular sites for vertiport locations. When constructing a composite vertiport location suitability metric, Sheth (2021) considered the following factors: zoning, environmental impact, existing transportation network locations, route structure, frequency, and density, and possibly also ground-traffic congestion. Fadhil (2018) cited several important factors for evaluating vertiport locations: population density, median income, office rent price (a surrogate for companies' travel budget), points of interest, major transportation network node, annual transportation cost, job density, presence of long-haul commuters, existing helipads/potential locations, existing noise pollution, and airspace restrictions/regulations. Major transportation network nodes, points of interest, and job density were weighted highest (in that order) by the AHP-Delphi expert survey.

There have also been many specific case studies in which UAM service scenarios are simulated and some type of performance metric applied. Bulusu et al. (2021) performed an analysis of the number of vertiports required for the San Francisco Bay area as a case study. They balanced the estimated demand (based on time savings) with whether the cost of adding another vertiport was justified for the company. When the roads were highly congested, a significant distribution of vertiports could handle the demand while meeting the cost justification requirements. For the scenario in which congestion was low, it was much more important to ensure transfer times were low. Ploetner (2020) noted that increasing the number of vertiports may not always make sense from a business perspective, as more than tripling the number of vertiports (in Munich, Germany, metropolitan region) resulted in only about a 40% increase in predicted trips. Fadhil (2018) did a study of both Los Angeles, CA, and Munich, Germany. Fadhil notes, “the suitable areas to site UAM ground infrastructure are dispersedly located, mainly in the downtown of Los Angeles, CA surrounding major transport nodes, and along the highway towards periphery area” (Fadhil, 2018). Regarding the Munich case study, he found “the inner-city part, major transport nodes, and highway ring road as suitable sites for UAM ground infrastructure.” In attempting to rank 40 US CSAs as potential markets for UAM, Haan et al. (2020) attribute the poor performance of Chicago and San Francisco to the paucity of existing vertiports in their respective central business district (CBD). Similarly, the lack of vertiports in downtown Miami results in the CSA’s most viable routes in South Florida being shorter ones in the northern suburbs, particularly around the Palm Beach County cities of Boca Raton and West Palm Beach.

Conversely, cities in Ohio that had not been previously identified for their potential are highlighted, in large part due to their high number of vertiports per capita, as well as, in Cleveland, the lack of limited-access highways in proximity to populous lakefront communities (Haan et al., 2020). One conclusion drawn from all these case studies is that the answers to the highly complex key questions are themselves quite complex. Each metropolitan area will have a different physical arrangement, ridership concentrations, and transportation mode-choice motivations. This will require vertiport distribution and quantity to be individually tailored to each metropolitan area.

#### *2.11.2.3.9 Electric Grid*

Not only is space for UAM aviation operations a crucial part of the required infrastructure, but, as with any type of transportation network, delivering fuel supplies as needed is critical to maintaining network operations. This will be a more novel challenge for UAM as the envisioned aircraft are all-electric vehicles. “The amount of electricity required to power an electric fleet of aircraft is not trivial and will likely have significant impacts on the electric grid, which may not be able to be supported by the current electric grid” (Garrow, German, et al., 2020). The cost to upgrade the grid to support this demand is also non-trivial (Garrow, German, et al., 2020) The upgrade cost is highly coupled to demand, number of vertiports, etc. However, Garrow et al. (Garrow, German, et al., 2020) note that just to add a sub-station (not including feeder lines and service lines) which can support 30 chargers to be $40M to $80M.

The potential energy demand is, in some senses, exacerbated by the rate at which that energy will be required. It is intuitive that long wait times will cancel the potential time savings associated with UAM. Additionally, the current state of battery technology will likely require UAM vehicle batteries to be charged after each mission (Garrow, German, et al., 2020). This means that Recharge/refueling rates could play an important factor in the ability of a given fleet size to meet demand (Rothfeld et al., 2020). Rapid charging will also help increase vertiport capacity, which is, as previously discussed, a primary UAM scaling constraint (Vascik, 2020). Some estimates note that the added need of UAM could be as much as 1 MW (on the order of demand of 1000 households) at peak demand for a given city (Garrow, German, et al., 2020). Another study notes that minimum UAM ground infrastructure requirements include a 400 kW charge for 5 minutes at

2C rates (presumably per vehicle) (Fadhil, 2018). These observations highlight the need for UAM infrastructure to interface with the electric grid. Overall, the electric grid will likely need major upgrades to support large-scale UAM operations (Groom & Bellon, 2021; Plumer, 2021; Stith, 2018).

###### *2.11.2.3.10 UAM Access Point Operational Efficiency*

The operational efficiency of UAM take-off and landing sites is a key driver of the infrastructure requirements and the attractiveness of the UAM service to potential users. Rothfeld et al. (2021) found that most travelers would not obtain time savings by switching to UAM due to the long process times. Ploetner et al. (2020) corroborated this with their finding that passenger processing time had a significant effect on the total number of UAM passengers. Garrow et al. (2020) found that several previous studies noted the importance of vertiport process times. This highlights the need for efficient operation of UAM access points. In fact, Rothfeld et al. (2021) note that UAM providers should "focus on UAM stations' accessibility and distribution, rather than maximizing UAM vehicle cruise flight speed." Ploetner et al. (2020) found that nearly half the cost of UAM came from vertiport fees. This, combined with the dominant influence of price-per-kilometer, suggests that well-designed vertiports could be key to achieving a greater market share for UAM. These factors (time and money), combined with the relationship between space and capacity/throughput makes the efficient operation of the vertiports quite important. Operational logistics will play a key role in vertiport capacity determination. In a simulation of vertiport capacity, the largest simulated vertiport (6 vertipads and 38 parking spaces) could theoretically handle 90 operations per 15 minutes, it was expected to be able to achieve only 76 operations per 15 minutes (Guerreiro et al., 2020). Findings from AAM research demonstrate that an estimated 75-300 vertiports will be required per metropolitan statistical area (Hasan, 2019; Rimjha et al., 2021) and approximately 2,500-3,500 total vertiports will be needed to establish a mature AAM passenger network in the United States (Hasan, 2019; UAM Geomatics, 2021).

Vertiport throughput is a primary constraint to UAM scalability (Vascik, 2020). UAM vehicle turnaround time will be critical to enabling physically small, high demand facilities (i.e., in city centers) to maximize their capacity. This makes the energy efficiency (energy per passenger kilometer) important, as recharge time can be a significant factor in overall network efficiency and passenger ground process times.

In addition to the characteristics of individual aircraft, fleet logistics can become extremely important to maintaining high UAM access-point throughput. There are some highly directional use-cases (e.g., commuting) for UAM which will make logistics (not to mention fleet size and "hanger" space) even more critical to ensure the profitability of UAM businesses (Garrow, German, et al., 2020). Shihab et al. (2019) developed a model to assess the effects of fleet size and CONOPS (scheduled or on-demand) on the UAM problem. While the model has yet to be implemented/tested, it could provide valuable information regarding UAM logistics/operations in the future.

UAM operational regulations and oversight will also have a major effect on the capacity and efficiency of UAM access points. The majority of papers Garrow et al. (2020) examined, which had a Market/Operations thrust, were focused either on air-traffic management or aviation operations. This concentration highlights the importance of operations and logistics to the successful implementation of UAM. Safe trajectory separation is an obvious example of the influence of such regulations on operational efficiency. Fadhil (2018) notes that a particular reference Alexander and Syms (2017) believe only 120° separation is required for approach and departure vectors. Vascik (2020) considers the provision of ATC to be one of the principal near-term constraints on UAM scalability, suggesting and demonstrating that the "development of procedurally segregated airspace cutouts for UAM" significantly increases the portion of the population which can be serviced. Rothfeld et al. (2021) found very little sensitivity of the travel time savings to whether direct point-to-point routes or those following existing ground transportation routes were followed. The authors cited potential fly-over restrictions, as well as noise pollution, as reasons to follow existing routes but did not discuss the potential increase in close-encounters between UAVs. Finally, Fadhil (2018) suggests that having no fuel on-site could reduce fire hazard requirements, but the authors of this literature review note that high-performance batteries and rapid charging rates could present a significant fire hazard as well. If fire hazard requirements were decreased, this might decrease required ground separation, thereby increasing capacity or decreasing overall vertiport size. Operating costs might also be positively affected.

## 2.12 Unmanned Air Cargo

Air Cargo plays a key role in the globalization and evolution of supply chains and has enabled supply chain managers to shrink their firms' "time-space continuum." That is, geographically dispersed and distant markets are being served in ever-less time, overcoming such obstacles as perishability, inventory requirements, stringent order and replenishment lead times, and high inventory carrying costs. Firms are thereby able to cover broader markets both nationally and internationally because air cargo makes it possible for them to quickly fulfill the needs of their customers in a cost-effective manner.

Part of the air cargo industry's success can be attributed to the growth of internet and web applications, which have driven supply chains to new levels of efficiency. This is not only due to the speed of communication but also to more efficient inventory management and lower net production and delivery costs. The use of air cargo also enables efficient supply-chain strategies—such as just-in-time (JIT) and postponement—by reducing carrying costs through lower inventory requirements. It further enables sellers to take advantage of both lower-cost labor markets and economies of scale in production since they are now able to produce farther from their markets.

Thus, air freight's more responsive service justifies higher costs for many commodities. It has also enabled the growth of value-added services offered by third-party logistics (3PLs) providers and integrators. (National Academies of Sciences Engineering and Medicine, 2014) shares visible examples illustrating contributions of the air cargo industry in the global supply chain, which include:

- Helping to speed time-sensitive products to market
- Improving the reliability of assembly lines by enabling rapid JIT delivery of parts for processing machinery as well as production inputs.
- Delivering quick-order, bio-medical products, and equipment to hospital emergency wards and operating rooms
- Deploying large project equipment to remote airfields
- Enabling small businesses across America to compete in major foreign markets

- Enabling remote communities and installations without surface transportation to timely access supplies and life safety products necessary for productive and healthy lives.

Air Cargo Industry Air Cargo services are provided to customers in a highly complex and competitive environment to producers. Many parties are involved to ensure air cargo is shipped on time and safely from one place to another, either domestically or internationally. Parties such as freight forwarders, 3PLs, airlines, airports, ground handlers, and truckers are responsible for packing and transporting commodities to and from airports or on and off aircraft. Below are brief descriptions of the services provided by each of the key industry participants referenced from (National Academies of Sciences Engineering and Medicine, 2014):

- Airports—offer infrastructure and services to air carriers for transporting and sorting commodities, such as runways/taxiways, aircraft parking, cargo handling land and facilities, roads and utilities, cargo security, aircraft maintenance, and other support.
- Airlines—provide airport-to-airport freight services either via lower deck space on passenger aircraft or via all-cargo freighter space using both scheduled and supplemental or charter services; provide pickup and delivery services in airport regions or to more distant markets.
- Air cargo terminals—process air cargo and mail that is transferred between air carriers, trucks, trains, and marine vessels. The terminals may be operated by airports, air carriers, surface transportation carriers, or third parties.
- Airfreight forwarders and 3PLs—provide consignment, transportation handling, documentation services to shippers and consigners, as well as value-added logistics, transportation, and trade services. The largest are global companies that also offer a truck, maritime steamship, barge, and rail services.
- General sales agents—sell air freight capacity on behalf of airlines.
- Integrators—offer direct selling of door-to-door services to businesses and individuals based on time-definite products handling shipment sizes from letters to heavy cargo that are comprised of a mix of air, truck, and intermodal. Integrators typically own and operate aircraft or lease on a dedicated basis.
- Consolidators—work with or may function as a freight forwarder providing assembly points for cargo prior to its delivery to a carrier at the airport.
- Container freight stations—are typically located off-airport and handle the breakdown of inbound international freight. Their function is similar to a consolidator (see above) in that they provide space for short-term storage and redistribution to a number of clients.
- Ground handlers—provide aircraft loading/unloading, short-term freight storage, fueling, technical maintenance, deicing, crew support, and liaison with support parties.
- Air cargo truckers—specialize in road transportation services for air freight shipments, typically requiring specialized roller-bed equipment.
- Brokers—buy capacity from airlines and sell it to small- and medium-sized forwarders.
- Customs brokers—assist importers and exporters in meeting federal requirements governing imports and exports.

### *2.12.1 Demand for Unmanned Air Cargo*

Air cargo is a key enabler of global trade and an essential mode of transport for high-value commodities. Though air cargo is responsible for transporting less than one percent of global trade by volume, its share accounts for 35 percent of global trade by value (International Air Transport

Association [IATA], 2017). This equates to transporting approximately 657 million packages worth $17.8 billion are transported in a single day, or $6 trillion worth of goods annually (IATA, 2017).

Airport ground infrastructure and designated trade routes form the foundation for international air cargo movement. Across the globe, there are 3,200 airports with 60,000 trade lanes (IATA, 2017), with the largest flows of air cargo occurring between East Asia and the United State (Mazareanu, 2021). Airport ground infrastructure and designated trade routes form the foundation for international air cargo movement. Across the globe, there are 3,200 airports with 60,000 trade lanes (IATA, 2017), with the largest flows of air cargo occurring between East Asia and the United States (Mazareanu, 2021). Over the next two decades, air cargo is projected to continue growing steadily as the world's air freighter fleet is estimated to grow by 70 percent from 1,770 to 3,010 airplanes (IATA, 2017).

Air cargo demand has been growing steadily, and research indicates that healthy growth will continue in the future (IATA, 2021a). In 2001, approximately 28.8 million freight tonnes were transported compared to 61.3 million freight tonnes in 2019 as shown in **Error! Reference source not found.**. Though the global pandemic reduced air cargo transport to 51.0 million tonnes in 2020, IATA (2021a) forecasts project a full recovery in air cargo transport with approximately 63.5 million tonnes being transported (3.6 percent increase from pre-pandemic levels).

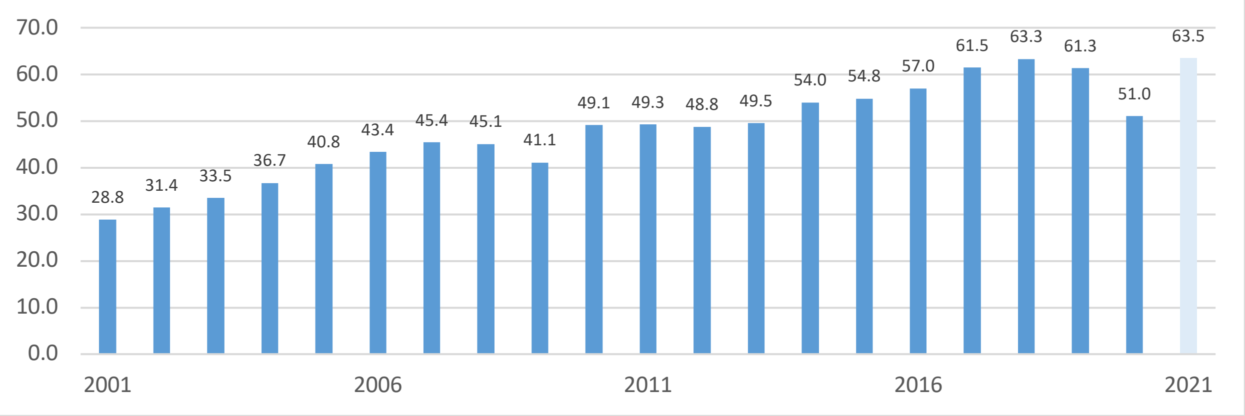


Figure 13. Millions of Freight Tonnes Carried

*Source: IATA, 2010, 2015, 2021*

The overnight parcel shipping business established by UPS and FedEx has become a substantial part of national and worldwide commercial air traffic (NASA, 2021). Amazon Prime and Walmart are also driving the need for next-day deliver, as Amazon already offers same-day/one-day service to 72 percent of the U.S. population (NASA, 2021).

As demand continues to grow, it is anticipated that UAC will fulfill an increasing share of cargo transport over time. Though the international UAC market is currently in its nascent stages, the next stage of industry development is expected to occur from 2022-2025 (Kovalev et al., 2019). During this stage, the United States and the world will begin to see large-scale applications of UAVs for commercial purposes and the expansion of their functionality. Thereafter, unmanned cargo transport is projected to gradually become more and more mainstream (Kovalev et al., 2019).

According to an analysis sponsored by the Aerospace Industries Association of America (2018), large unmanned aircraft are projected to generate $150 billion in total spending and sustain up to 60,000 jobs in research and development, manufacturing, and related services through the year 2036. Another projection from Volocopter (2021) estimates that the market potential for logistics mobility is 100 billion euro in 2035.

Since there is no current infrastructure in place for UAC operations, the ability to convert existing traditional air cargo infrastructure will create an economical way to start to supplement traditional delivery methods. Also, UAC operations and manned air cargo operations will have many similar needs for support infrastructure so the conversion can occur without disrupting current air cargo operations (National Academies of Sciences Engineering and Medicine, 2014).

### *2.12.2 Assumptions, Guideposts, and Modeling Techniques*

There are a number of different approaches that are used to forecast economic demand for UAC services. Collins (2017) discusses a future where all high-value cargo (including perishables) that is currently transported on manned aircraft could be shipped via large unmanned aircraft. Unmanned flights taking-off and landing using short runways, grass runways, industrial parks, and corporate offices, while traveling distances of four to six thousand miles, are viewed as a key segment within the future market for UAC (Collins, 2017). There seems to be a convergence in the research that the economic impact of large UAC will outpace sUAS responsible for package delivery (Aerospace Industries Association & Avascent, 2018).

Though cost is often the dominant factor for cargo shipment, delivery speed is also an essential mode choice factor (Kloss & Riedel, 2021). In 2021, the schedule reliability of ocean carriers was around 40 percent, compared to 70-80 percent prior to the global shipping crisis, which has led to transportation cost escalation (Goodman et al., 2021; IATA, 2021a). These recent losses of reliability in freight shipping are largely due to strained diplomatic relations between U.S. and China in 2019 and a pandemic-related halt on shipping containers (Chouinard, 2021). Shipping reliability losses have been exemplified by an unforeseen closure in the Suez Canal and the shutdown of the Ningbo-Zhoushan port (China’s third-largest port). Though air cargo supply chains are not exempt from their own difficulties, container shipping remains severely congested. This has made air cargo supply chains more attractive internationally, as air cargo has become more affordable in recent years relative to container shipping (IATA, 2021b), effectively reducing mode competition as a potential barrier.

Air cargo demand stems from a number of factors which include:

- Product inventories relative to sales volumes (historically, low inventory to sales ratios has meant that businesses have had to quickly refill their stocks, for which they also used air cargo)
- The relative attractiveness of air cargo relative to other modes of transport (i.e., supply chain disruptions or delivery delays via ocean transport cause manufacturers to use air transportation to recover lost time)
- Regulatory barriers to entry
- Domestic and international economic variables, including trends in the air cargo industry, trade flows, economic output, supply chain efficiencies, and projected growth, among others

In addition to the aforementioned air cargo research, a recent NASA study demonstrated the economic assumptions and market forecasts for automated air cargo (Crown Consulting et al., 2021). The research projected the change in market share of heavy / long range (HLR), heavy medium range (HMR), and light / regional air cargo aircraft from 2020 through 2040. The NASA study accounted for low, base, and high case adoption scenarios subject to the aircraft automation levels anticipated during the 2020-2040 timeframe (automation levels are shown in Figure 14). Based on fleet turnover for HLR, HMR, and light aircraft use cases, US GDP, and the price of air cargo services, a market analysis was conducted. Analysis findings demonstrated that by 2040 approximately 31 percent of the HLR fleet will be automated with SVO technology, 15 percent of the HMR fleet will be automated with SVO technology, and 78 percent of the light / regional fleet will be remotely supervised, containing higher levels of automation (Crown Consulting et al., 2021).

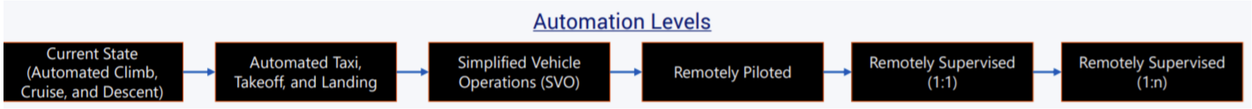


Figure 14: Automation Levels of Air Cargo Aircraft Over Time (Crown Consulting et al., 2021)

#### 2.12.2.1 Product Inventory to Sales Ratios

As of August 13, 2021, developments in air cargo and supply chains were continuing to propel strong air cargo performance. Inventory-to-sales ratios have reached record-low levels, while air cargo has become more affordable than in recent years relative to container shipping (IATA, 2021b). Another metric that sheds some light on the strength of air cargo is the supplier delivery times purchasing manager index. Supplier delivery times matter for businesses, as an increase indicates that supply chains are getting slower with higher risks that stocks may not be sufficient to meet demand (IATA, 2021b). Supply chains have become highly congested since 2019 due to strong demand for goods, lack of shipping container availability, and manufacturing or port disruptions related to the pandemic (Chouinard, 2021; IATA, 2021a). This encourages businesses to turn to air freight, which offers faster delivery.

#### 2.12.2.2 Relative Attractiveness of Air Cargo Relative to Other Freight Options

Last mile delivery refers to the final step of the delivery process when a parcel is moved from a transportation hub to its final destination, which is usually a retail store or personal residence (Onfleet, 2021). Often times, white glove delivery services are paired with last mile delivery, so that heavy household items such as couches, dishwashers, dryers, etc. are delivered and assembled on site. Due to some of the assemblage complexities, it appears that last-mile delivery is likely not a logical first step in the realization of UAC operations; however, some consideration at least is given to the public acceptance of last-mile delivery services. Market location may be a pertinent part of this question. Consumers in India and China were most willing to pay an additional cost to have an item delivered within 1 to 2 hours, while those in the United States displayed the least interest in such a service/cost (Kloss & Riedel, 2021). Demographics will likely also play an important role in identifying the market for last-mile deliveries. Kloss and Riedel (2021) found that younger respondents and those living in a larger household and men were more likely to be willing to use drones for delivery. An added benefit of last and middle mile type deliveries is that UAC operations in these capacities could significantly reduce traffic congestion (Volocopter, 2021). Finally, as with all unmanned aircraft operations, safety is a dominant concern (by a wide margin) regarding drone deliveries (Kloss & Riedel, 2021). Their wording suggests the survey questions may pertain to a last-mile scenario.

#### 2.12.2.3 Regulatory Barriers to Entry

UAC will have a substantial impact on the logistics and logistical support industries. A report from Lineberger et al. (2021) estimates that the AAM cargo mobility market will reach $58 billion by 2035. A main factor in the transition to UAC will be the ability to use drones in traditional Part 135 certificated operations. Being Safety focused, the FAA has regulatory processes in place to enhance the outcome of a safe operation. The most commonly attained certificate is the Part 135 operator certificate. A traditional Part 135 certificate is an extremely detailed regulatory process administered by the FAA for the safety standards and compliance obligations for commercial operations.

The main barrier to entry into the Air Cargo Industry is operating under a Part 135 certificate. Currently, the only way to legally carry cargo in the NAS is with an operation under a Part 135 certificate. Obtaining a Part 135 Certificate is often lengthy and cost endeavoring process. This already places extreme limitations on the manned aviation sector and there are only two extremely limited drone Part 135 certificates. Rulemaking language from the FAA regarding Part 135 certification is included below:

> The Federal Aviation Administration (FAA) grants the authority to operate on-demand, unscheduled air service in the form of Part 135 certificate. Air carriers authorized to operate with a 135 certificate vary from small single aircraft operators to large operators that often provide a network to move cargo to larger Part 121 air carriers. Many Part 135 operators offer critical passenger and cargo service to remote areas, providing a lifeline to populations that would not otherwise exist. Most Part 135 air carriers are required to have a FAA approved hazardous materials (dangerous goods) program. This program must cover all aspects of the acceptance and transportation process, as well as training for all employees.
>
> Regulations outlining the acceptance, handling, transport of dangerous goods and required training are found in the Hazardous Material Regulations (49 CFR Parts 100-185) and the ICAO Technical Instructions for the Safe Transportation of Dangerous Goods by Air. Compliance with the regulations is mandatory for all Part 135 air carriers.
>
> In addition to the regulations and guidelines issued by FAA Flight Standards, Part 135 air carriers work closely with the FAA Office of Hazardous Materials Safety to develop, maintain, and implement approved hazardous materials (dangerous goods) programs.
>
> Hazardous Materials Aviation Safety Inspectors inspect Part 135 air carriers at multiple locations throughout the United States and its territories and identify any regulatory violations, process, and procedural findings, or program deficiencies. (Federal Aviation Administration, 2021c)

Currently, there are only a handful of applicants that are pursuing the Part 135 Certificate. Most of those are pursuing under the FAA Beyond Program (Federal Aviation Administration, 2021b). This program is still limiting the size of aircraft as of now. Because the Part 135 certificate is the only existing route for commercial cargo operations, that also requires a Type Certified by the FAA for the National Airspace aircraft. At this point, only four exist.

The FAA Type certification for UAS is not an established process at this point. There are some that are pursuing under the FAA Beyond program. Some under an STTR. There are also many variations of aircraft from fixed-wing to rotor copters, to all-electric power trains to hybrids and all fossil fuel consumption. This vast variety and ever-changing of aircraft are going to make it difficult for aircraft to get through an arduous and lengthy type certification process. Even for traditional operations, the timing and cost can be the barrier to entry.

> Applying for a type certificate is the next step, and the timing is important because this is where the clock starts ticking. Part 23 airplanes generally have three years from the date of application to be certified; Part 25 airplanes have five years. This is a critical stage for any aircraft program because of something called "certification basis." (Thurber, 2006)

In addition to evaluating certification compliance, FAA personnel will also pre-audit production facilities during this stage to help spot any problems that could hold up the program.

Before the OEM flies a prototype of the design, the FAA will need to issue an experimental type certificate. FAA personnel will conduct a safety review and check that the airplane conforms to its design. A plan for test flying will cover all requirements. And before FAA test pilots fly in the airplane, it must have flown through its full flight envelope. Flight testing is a challenging part of the certification program and can take a year or more, meeting requirements for compliance with various certification standards, noise testing, reliability testing, human factors analysis, and qualitative assessments of the flying qualities to make sure it meets the standards for pilots to receive type ratings. "Proof-of-concept prototypes, which don't conform to the final design, can be used for flight testing in areas where they do conform if the test isn't in an area where non-conformity is an issue" (Thurber, 2006).

Another barrier to the safe operation of large aircraft in air cargo operations is the challenge associated with the prohibition on the use of transponders by UAS. Due to concerns about overwhelming ATC's bandwidth by putting transponders on all UAS, UAS operators cannot transponder their aircraft. A large UAS carrying cargo will probably operate at altitudes corresponding to those used by General Aviation and could have close to the same size and maneuverability as traditional aircraft. A transponder would increase traditional aircraft and ATC's situational awareness by providing the location of the UAS, therefore, the prohibition does not appear to make sense for the UAC operation. Currently, an operator wishing to fly an aircraft with a transponder must receive a waiver to do so.

#### 2.12.2.4 Logistics and Integration

A great deal of the information that exists for the integration and logistical implementation of cargo capable aircraft operating at an airport is, in large part, conceptual. The primary focus of the research material being discovered speaks mainly on the "how" to get cargo delivered and the best vehicle to do that and exists almost exclusively as operational test subjects. Due to the lack of Beyond Visual Line of Sight (BVLOS) certification, companies participate in programs such as FAA's ASSURE, Test Site, and Partnership for Safety Plan (PSP), which affords some latitude to experiment and document best practices of flight events with elevated risks. Several companies such as Xcel Energy, UPS, and Florida Power and Light are currently participating in the PSP program. Very few participants in these programs have attained a waiver to operate their aircraft in BVLOS conditions. The BVLOS certification is reported as a difficult hurdle for most unmanned programs seeking to earn certifications from the FAA. This is specifically suggested to be causing some delays in the progress of integration and logistics for unmanned aircraft cargo purposes.

Based on the material available and the limitations imposed on flying organizations, the tested areas have not produced information significant or relevant enough to adequately determine best practices for integration and logistics certification of cargo UAS at a functional multi-role airport. Other companies that are not affiliated with the FAA programs are implementing lessons learned internally and evolving their way of thinking to suit their individual goals. Some level of success is being seen with companies that team with Department of Defense (DoD) customers with restricted airspace available to conduct tests. This is not available or ideal for most companies as it is time restrictive, competitive, or cost-prohibitive to operate in the restricted areas. There have been some instances of small-scale, small-weight cargo being delivered by sUAS; however, this has not typically been tested on airport premises. The aircraft used are outfitted with cargo compartments or apparatus and flown from isolated yet very controlled test locations. Companies that are aiming to develop the ideal cargo operation have certainly placed logistics and integration in their scope of research; however, their focus seems to be primarily on discovering the best vehicle by which to conduct these operations, closely followed by finding a solution to operating their aircraft safely into the NAS. The testing activity being conducted on active airports is small-scale, very controlled, and conducted at a pace that is commensurate with the comfort of FAA and industry technology advancements. One instance of a test conducted on an airport was in Tennessee, with the Memphis-Shelby County Airport Authority (MSCAA).

> Memphis, TN (November 2, 2020) – On Friday, U.S. Secretary of Transportation Elaine L. Chao announced the three-year Unmanned Aircraft Systems (UAS) Integration Pilot Program (IPP) successfully concluded on Oct. 25. Eight of the nine state, local and tribal governments that participated in the program – including MSCAA — have signed new agreements with the FAA to continue to tackle remaining UAS integration challenges. (MEM - Memphis International Airport, 2020)

Partners in the Memphis program include FedEx, City of Memphis, 901Drones, Tennessee Department of Transportation Division of Aeronautics, Asylon, and DJI (MEM - Memphis International Airport, 2020). These groups are working with the FAA to develop procedures to benefit the FAA's pursuit of regulations for UAS in the NAS. The FedEx flight testing began with a rigorous internal review of capabilities, safety protocols, and processes for all stages of flight, as well as developing a comprehensive mishap response plan. According to FedEx, having a Standard Operating Procedure (SOP) specifically for operations at the Memphis-Shelby airport was essential, thus required before any unmanned aircraft left the ground on airport property. The FedEx team conducted sit down meetings with airport safety to discuss unmanned aircraft operations at the field, and a cooperative relationship between Memphis-Shelby ATC, other commercial airlines operating at MSCAA, and FedEx have provided valuable information on what unmanned aircraft cargo operations on an airport may look like in the near-future (Warr, Noel, Murdock, et al., 2021).

As FedEx representatives move further into this effort, they also suggest that the lack of certification and the FAA's tight restrictions on BVLOS flights contribute to the throttled pace of progress. Another factor indicated as a limitation for progress is the weather tolerances of commercially available aircraft. FedEx reports that they employ several models of the DJI suite of aircraft, however, these aircraft are not constructed with all-weather capabilities in mind. Considering that some airports have unfavorable weather conditions for several months a year, an aircraft's ability to operate in various conditions appears to be a profound consideration regarding the success of unmanned cargo operations (Warr, Noel, Murdock, et al., 2021).

Another prominent contributor to developing processes, procedures, and regulations for unmanned cargo aircraft is UPS. UPS has been experimenting with new ideas of cargo delivery between various sizes of aircraft using FAA's Part 135 rules. UPS does not currently utilize the FAA's Part 107 program. One significant difference is that UPS is not testing their new ideas at an airport but instead employing the idea of a fixed-point location away from an airport that services a smaller area. They described it as the "last mile" delivery. Several considerations for this stand-alone concept to be successful are meeting the manufacturer's maintenance and operations requirements for the air vehicle, having an area that meets minimum operational requirements for launching, landing, and recharging, and establishing and maintaining the power generation requirements. UPS has teamed up with clients such as a medical district in Wake Forest NC, and CVS pharmacy to experiment with this unique method of cargo delivery. UPS employs the authority to operate this way from the Secretary of Transportation's risk-based approach to determine whether an airworthiness certificate is required for a drone to operate safely in the NAS. The details of this authority can be found in *49 USC 44807: Special authority for certain unmanned aircraft systems*. By using this as their approach to the research effort, UPS will test certain UAS capabilities and work towards an airworthiness certification for the aircraft that best suits their needs. UPS is currently partnered with BETA aircraft to explore larger cargo movements but is challenged by the lack of a BVLOS authorization. UPS has suggested that for this to be successful, and more consideration must be put towards risk mitigation, ground operations with coordination at ATC, and more available ground services. One hurdle for UPS while using Part 135 rules is the singular use intentions of the Part 135 construct. When those rules were developed, certain technology and aircraft with such capable performance were not available. A continuous assessment of the industry and available technology is mandatory. UPS also suggests that a continuous approach to finding a means to comply with Ground-Based Sense & Avoid (GBSAA) requirements and utilizing sensors with infrastructure already in place would be growth in the right direction. A major consideration to UPS's testing efforts has been risk mitigation and safety. UPS employs aircraft with failsafe measures such as a Return to Home function, and for the more advanced safety responses, they use an aircraft that can be shut down in flight and safely brought down by parachute (Warr, Noel, & Valdez, 2021).

#### *2.12.2.4.1 Noise*

Current practices in the aeronautics industry for certification of vehicle noise are ground and flight testing. Current practices should be considered for UAC standardization; however, research is also needed in understanding the human response to noise UAM will produce in the community. The paper also calls for further development in validated noise prediction tools to support vehicles' research and development and operations (Rizzi et al., 2020). Regarding future regulation and policy, the paper calls for the FAA to collaborate with industry to address these needs:

> This is needed so that local communities are not panicked into the establishment of ordinances that will both limit the growth of the market and potentially create operationally restricted zones... Because many of the UAM vehicles being proposed involve some level

> of autonomy, it will be important to consider the influence of this on the noise generated by these aircraft. At the very least, additional instrumentation onboard the aircraft may be required so that the true state of the aircraft is known. In many instances, the instrumentation requirement needed to implement autonomous operation successfully may make this very simple. (Rizzi et al., 2020)

Laboratory psychoacoustic testing provides information regarding how humans perceive the noise environment created by UAM. The human feedback by this research would influence certification criteria for UAM noise generated (Krishnamurthy, 2021).

##### *2.12.2.4.2 Avionics*

As unmanned cargo aircraft emerge in the NAS, the development and implementation of advanced avionics solutions will be required to support such operations. Current industry standards for avionics certification are well documented. However, the increased production of unmanned aircraft and the request for unique UAS operations have elevated the demand for state-of-the-art sensors and communication systems. Therefore, industry standards for certification of avionics need to be congruent with the ever-changing UAS landscape. Knowledge of current avionics certification standards and working with aerospace technology leaders will assist in the transition of manned to unmanned cargo vehicles.

The procedures for receiving certification of avionics software and hardware are similar. RTCA DO-178, "Software Considerations in Airborne Systems and Equipment Certification" is referenced for avionics software verification, validation, and certification. DO-178 was developed in the 1980s and is considered the "bible of avionics software development" (Hilderman et al., 2014). This standard has evolved over three separate iterations; DO-178C is the latest revision replacing 178B in 2011 (QA SYSTEMS, n.d.). DO-254 (2005) is a formal avionics hardware standard and is similar to DO-178C's predecessor, DO-178B. Since avionics are composed of both hardware and software, and each has an equal effect on airworthiness, many avionics projects fall under a DO-254 for certification or compliance mandate (ConsuNova Inc., n.d.). DO-178 and DO-254 require all software and hardware on board an aircraft to be assigned a Design Assurance Level (DAL) or "criticality level." Criticality level refers to the effort put into software planning, development, and its correctness. The criticality level of a developed software or hardware directly correlates to its assigned DAL. There are five separate DAL levels that range from the most critical (Level A) to the least critical (Level E). Level A criticality indicates that a hardware or software failure would result in the aircraft's 'catastrophic' failure. Level E criticality indicates that a hardware or software failure would have 'no effect' on the aircraft's safety. After a software or hardware's criticality level has been determined, DO-178 and DO-254 assign specific required objectives, and the avionics software or hardware certification process begins (Hilderman et al., 2014).

ARP-4754A, "Guidelines for Development of Civil Aircraft and Systems," provides a system safety assessment (SSA) that defines two types of DALs for avionics development. Functional DAL or FDAL determines the DAL of the function of the item. Therefore, the Functional Design Assurance Level (FDAL) defines the DAL for 'what' the item is designed to do. Required development objectives are provided in Appendix A of ARP-4754A. Item DAL or Item Design Assurance Level (IDAL) is the DAL assigned to the hardware and software of an avionics product. The objectives required for hardware and software for each IDAL are provided in DO-178C. It is important to note that most aircraft and system developers build or buy ARP-4754 planning documents and checklists (Hilderman & Hilderman, 2014).

Currently, there are no such DAL levels for cargo UAS or DO-178/254 language that mentions such operations. FedEx's BEYOND program is currently using UAS for small deliveries (<5 lbs.) at the Memphis-Shelby County Airport. In an interview with the University of Alabama in Huntsville (UAH), FedEx representatives stated that their UAS avionics do not hold DO-178 standards. To ensure hardware integrity, they do a spectrum analysis on the area of operations (AO). Additionally, they closely monitor the weather and any obstructions, e.g., wake turbulence, in the AO. Their delivery drones use commercial off-the-shelf (COTS) avionics to successfully complete their visual line of sight (VLOS) cargo UAS missions (Warr, Noel, Murdock, et al., 2021). UPS, similar to FedEx, uses COTS aircraft for their delivery UAS operations. UPS utilizes optically assisted landing pads for precision landings and a payload box for cargo. To ensure hardware integrity, UPS deploys aircraft with redundant parts and components (Warr et al., 20 September 2021). In a separate discussion between the University of Alabama in Huntsville (UAH) and Sanmina Corporation (SCI), an advanced avionics design and manufacturer, representatives from SCI stated that certification for advanced avionics requires an abundance of time, effort, and money. For clarity, SCI develops avionics for DoD applications, therefore, they do not seek DO-178C/254 certification for their products as their customer base does not require them. However, SCI expressed that achieving certification for developing state-of-the-art avionics is nearly impossible. When asked about avionics certification for cargo UAS in the NAS, representatives from SCI posed aircraft integrated with the developing software/hardware with a pilot-in-the-loop as a fail-safe. This way, a highly sophisticated system (e.g., fully autonomous BVLOS) could be tested safely. Additionally, it was noted that the use of NAS integrated UAS flight lanes would benefit high autonomy demands required for cargo operations (Warr, Noel, Klien, et al., 2021).

#### *2.12.2.4.3 Autonomy*

UAS are sophisticated and stochastic systems. A UAS vehicle's attitude, trajectory, and position are influenced by its unpredictable environment. In the scope of cargo operations for UAS, the deployment of complex autonomous systems in diverse environments pose significant challenges to their verification and validation (V&V). Any software onboard an aircraft is considered a subsystem. All subsystems onboard an aircraft require full approval in order for certification to be finalized. V&V of flight code and software criticality level is addressed in Society of Automotive Engineers (SAE) ARP-4754A, "Guidelines for Development of Civil Aircraft Systems" and ARP-4761, "Guidelines and Methods for Conducting the Safety Assessment Process on Civil Airborne Systems and Equipment." DO-178C, "Software Considerations in Airborne Systems and Equipment Certification," is referenced to verify flight code design and operation. Classically, V&V is accomplished through vigorous scenario testing and simulation. Though advances have been made in design-time V&V, certification of cutting-edge control system algorithms can prove difficult. Advanced and adaptive control systems outreach current design-time V&V techniques for autonomous vehicles (Schierman et al., 2015). According to *Runtime Assurance Framework Development for Highly Adaptive Flight Control Systems*, published by the Airforce Research Laboratory (Schierman et al., 2015), "such systems are impossible to fully analyze at design time, and it is impossible to explore, study or simulate every possible state or outcome." Hence, in addition to traditional V&V techniques, runtime monitoring, or runtime assurance (RTA) will be essential for the certification of cargo UAS with advanced onboard autonomous systems.

"It is expected that through the combined use of new advances in design-time V&V approaches along with the use of runtime assurance (RTA) systems during online operation, the system behavior can be provably bounded" (Aiello et al., 2010; Rudd, 2099; Schierman et al., 2008, 2015; Schierman & Schlapkohl, 2014). RTA is a defense mechanism employed to ensure the appropriate behavior of complicated autonomous systems (De Niz, 2017). RTA allows the benefits and capabilities of advanced autonomy while protecting against unpredictable and unsafe system activities that can compromise a mission. Runtime assurance schemes monitor a platform's state parameters during operation. RTA uses tests to determine whether unsafe conditions will emerge due to an error in the advanced system. If an error is detected, RTA disables the advanced system and switches operation to a revisionary or system that is certified at design time (Schierman et al., 2015).

RTA systems for UAS are being developed and seeking certification. In 2018, NASA and Modern Technology Solutions, Inc. (MTSI), under the Resilient Autonomy project, started the development of a framework that can be used to achieve FAA certification for autonomous aircraft. The project's goal is to develop an architecture for the certification of a fully autonomous system's software using a technique called multi-mode runtime assurance (MM-RTA) (AUVSI News, 2018). NASA Armstrong Flight Research Center's Resilient Autonomy project is also currently developing collision-avoidance software that can be applied to future UAS. Expandable Variable Autonomy Architecture (EVAA), a predecessor of the F-16's Automatic Ground Collision Avoidance System (Auto GCAS) and Automatic Collison Avoidance System (ACAS), is designed to be utilized in UAS to prioritize human safety and avoidance of property damage. EVAA utilizes refashioned GCAS and ACAS algorithms as separate monitors. These separate monitors are guided through a central function that controls the aircraft to the highest consequence task. EVAA is currently in development and seeking approval and certification from the FAA. EVAA can potentially be utilized in general aviation and future UAS platforms (NASA Armstrong, 2020).

The use of revisionary systems like RTA are not new concepts to the aerospace domain. Early versions of runtime assurance concepts were utilized for NASA/USAF experimental aircraft control system testing. These flight tests often employed revisionary back-up controllers for more stable flight in the case of control system failure. This early work gave rise to triple or quadruple redundant flight control systems that have been utilized for years. Therefore, back-up control concepts have been key in safety assurance for certified flight hardware and software (Hook et al., 2018). The accumulation of work related to RTA like EVAA, and multi-monitor runtime assurance (MM-RTA) have led to runtime assurance-based verification concepts to be included in the civilian aircraft certification process.

Runtime catastrophe avoidance software like EVAA and MM-RTA are leading the way in advancements in autonomy certification for UAS. The aforementioned DO-178C contains language that allows for reduced design assurance levels for systems that include operational monitoring. Based on the avionics and related testing of software and hardware, the cost will vary. This cost will impact both the aircraft's weight, performance, as well as resources needed for certification. Additional literature research will be required to understand the specific quantity of these costs. The ASTM F38 committee, in collaboration with government, industry, and academics, has created an industry-standard document that recognizes RTA for the certification of highly-autonomous, unpredictable, or highly complex piloting systems for sUAS (ASTM F3269-17, 2017; Cook, S., 2017; Hook et al., 2018). These advancements in autonomy certification will benefit in favor of complex autonomy endeavors and cargo UAS platforms alike.

#### 2.12.2.5 Trends in the Air Cargo Industry

The U.S. air cargo industry handles 32.7 percent of exports and 27.6 percent of imports by value, and 0.5 percent of exports, and 0.7 percent by weight of the nation's freight transportation, according to data reported by the Freight Analysis Framework. Comparatively, trucking represented the largest mode by weight (61.6 percent) and value (54.7 percent). The percentage of U.S. commodity value, including import and export, shipping by air freight grew from 6.5 percent in 2007 to 7.3 percent in 2011 and is forecast to reach 12.8 percent by 2040 (National Academies of Sciences Engineering and Medicine, 2014).

In terms of annual growth rates, U.S. air cargo grew 3.1 percent by value and 7.5 percent by weight from 2007 to 2011. The annual growth rates for air cargo are higher than the growth rates in the same period for total U.S. freight transported, which are 0.2 percent by value and -1.7 percent by weight (National Academies of Sciences Engineering and Medicine, 2014).

Currently, there are no UAC Operations, also there are no current Type Certified Aircraft with a Part 135 certificate to perform cargo operations. Large UAS platforms over 55 lbs. that can handle significant loads over long durations, and challenging weather conditions will be needed. These will range in types from new aircraft, e.g., Elroy Air, Phenix Solutions, to existing aircraft conversions, e.g., Merlin Labs, Reliable Solutions, X-wing. It will be a mix of VTOLs and standard takeoff and landing aircraft. DoD also will be integrating their new platforms and converted equipment, e.g., C-130s (National Academies of Sciences Engineering and Medicine, 2014).

By incorporating UAC, the economy will be greatly impacted by a more responsive supply chain. In traditional air cargo, the total tonnage CAGR is 1.2 percent from 2012 to 2045. Growth will be highest through 2014, reflecting the United States economy's rebound from the Great Recession as well as manufacturing and exports growth during the historical forecast years of 2012- 2014. Growth in tonnage will slow from 2015-2020 to 1.7 percent, reflecting the strong but modest economic growth forecasted for the short- and medium-term (National Academies of Sciences Engineering and Medicine, 2014).

Over the final 25 years of the forecast period, freight growth rates moderate further to 1.0 percent, reflecting a longer-term structural analysis of the U.S. economy. Between 2020 and 2045, imports and exports grow more rapidly, at 2.5 and 2.7 percent, respectively. However, domestic flows fall to 0.8 percent, partially reflecting lower long-term growth in U.S. domestic output as well as changing energy consumption patterns. Total tonnage increased from 17.0 billion tons in 2012 to 25.3 billion tons in 2045 (Fullenbaum & Grillo, 2016).

For traditional air cargo physical capacity is needed to accommodate growth: The most obvious criterion for the future success of an air cargo program is the physical capacity to accommodate the airside and landside requirements of both tenants and users. This includes aeronautical infrastructure, physical facilities, landside parking and queuing, and roadway geometry. The latter two elements are important to ensure that the airport functions efficiently as an intermodal facility. While the cargo operations continue to experience solid growth, there are some very real constraints facing airports as buildings age and carrier requirements change (National Academies of Sciences Engineering and Medicine, 2014).

For many UAC operations, no traditional forms of infrastructure will need to be developed. These updated needs for infrastructure will include anywhere from the physical building to updated and advanced communications capabilities. Similarly, new forms of infrastructure are needed to support the new operations but the support personnel. Such as in rural Alaska, most operations are a load and unload of freight by the pilot. In a UAC operation, new support staff and infrastructure may be needed on the receiving end as none currently exists. These technologies will help transform the industry into the next wave of AAM (National Academies of Sciences Engineering and Medicine, 2014).

##### *2.12.2.5.1 Alaska as a Unique Air Cargo State*

Off-Road Alaska's Aviation Lifeline Communities are not connected to the national highway system and depend on the aviation industry for the movement of goods and people in ways that Lower 48 communities depend on a road system. The average number of annual enplanements per capita for off-road communities in Alaska was found to be eight times higher than the number of enplanements per capita for even the next highest state (i.e., Idaho at 1.8 enplanements per year) and more than 30 times higher than the lowest comparison group (i.e., Montana at 0.5 enplanements per person per year). The difference in freight pounds per capita is even more startling for Alaska as compared to the western U.S. The per capita freight loads in Alaska are 39 times higher than the freight loads for rural communities in the next highest surveyed state. Alaska communities in the study averaged 1,096 pounds of air freight per capita in 2007, while rural communities in Oregon averaged 28 pounds. Rural communities in Montana averaged just 2 pounds of air freight per person in 2007 (Northern Economics Inc., 2009).

### *2.12.3 Comparison to Conventional Air Cargo Services*

In the beginning, UAC should be very similar to conventional air cargo. In the beginning, the industry should expect to see the automatization of existing aircraft, such as autonomizing the Cessna Grand Caravan initially. The Cessna Grand Caravan is representative of the most common regional air cargo carrier. The versatility of this aircraft is seen in its operational diversity, such as the cargo routes to the remote road-less villages in Alaska, to the urban congestion areas like routes FedEx possesses between Oakland International Airport to Monterey Bay regional airport.

One of the major comparison points with conventional operations will be the human ground support. Drone operations, whether they be autonomized or remotely operated, will need expanded ground operations in comparison to those of conventional operations. A second major comparison is the need for more advanced telecommunications support as a portion of the expanded ground operations.

Many of these less urban to remote areas will need expansive infrastructure build-up to support UAC operations as well as a new workforce development program for training and job placement. This will act, for many communities, especially in rural Alaska, as a new job opportunity and new economic growth to the region. Much of this ground infrastructure support will be expanded hanger and warehousing space. As technology advances, expanded airport operations will need to include vertiports to support VTOL operations.

The main contrast between traditional and unmanned air cargo will be the expanded human ground support required for UAC, from Operations and Maintenance of the aircraft to the handling (loading/unloading) of the cargo. There will need to be new technological support and a cyber-security element to help support safe operations. A Part 135 Certificate will still be a requirement for the foreseeable future, but the nature of the requirements of the certificate are going to need to be structured so that the application is appropriate for the technology presented, i.e., no seatbelts needed. Scheduling and an expanded logistical support role will be needed as the demand for just-in-time deliveries becomes more prevalent and the supply chain is sped up. This will increase fleet sizes and ground support. As the supply chain becomes more automated, the need for data transfer and storage will also be greatly expanded.

UAC operations will become more efficient in the long run but will take much more human and infrastructure support in the initial stages than conventional operations, especially in remote areas. Once the operation is in place, it will create a safer, more reliable operation for the end-user, increasing frequency and consistency with the deliveries.

### 2.13 Advanced Air Mobility (AAM)

AAM moves people and cargo between places not conventionally served by surface transportation or underserved by aviation, using revolutionary new aircraft (Cohen et al., 2021). AAM builds upon the UAM concept by incorporating use cases not specific to operations within urban environments, such as:

- Commercial Inter-city (Longer Range/Thin Haul)
- Last mile delivery
- Long haul delivery (150 nautical mile radius)
- Public Services
- Private / Recreational Vehicles

An example of such an application would be using AAM as a feeder from another city to existing public transportation lines, or as a connection between existing public transportation networks in two cities (Straubinger & Fu, 2019).

Another example of a strong AAM use case is the delivery of goods across rural regions using a hub and spoke model for air cargo. The hub and spoke model transports goods from a well-serviced, major cargo port (e.g., airport, shipping port, railroad terminal) to a smaller, hub community surrounded by even smaller communities that cannot support traditional air cargo or routine passenger/cargo combined services. In this UAS use case, cargo carrying UAS can service the smaller communities on a more regular basis by transporting smaller quantities of goods more frequently instead of having to stockpile the deliveries until a large enough quantity is amassed to warrant a traditional aircraft delivery or the goods can be brought in on a passenger flight. This operations model decreases the warehousing needed in the hub or port facilities, allows for perishable goods to reach the community more frequently, increases the turn-around time for mail and other time-sensitive items, increases aviation safety by decreasing the number of flights of traditional aircraft into the communities, and provides a host of other benefits to the communities involved.

### *2.13.1 Demand for Advanced Air Mobility*

As of September 2020, more than 200 companies worldwide have been developing eVTOL aircraft and have garnered private investment in AAM, totaling over $2 billion (Lineberger et al., 2021). Kloss and Riedel (2021) observed that 80% of all AAM funding was currently in transport applications rather than cargo. In the context of this literature review, AAM encompasses the movement of people and goods with new aircraft in new airspace.

### *2.13.2 Assumptions, Guideposts, and Modeling Techniques*

Modeling demand for AAM requires a comprehensive accounting of air passenger and air cargo use cases. Many of the techniques and modeling parameters discussed within the context of UAM (see *2.11.1 Demand for* ) also pertain to the passenger movement component of AAM. This includes accounting for variables that influence passenger demand, such as:

- Public acceptance
- Relative attractiveness of UAM compared to other modes of transportation
- Direct and indirect UAM cost structures
- Availability of UAM enabling infrastructure
- Legal or regulatory frameworks that need to be implemented or revised

This also involves accounting for variables that influence UAC demand (see *2.12.1 Demand for Unmanned Air Cargo*), which include:

- Product inventories relative to sales volumes (historically, low inventory to sales ratios has meant that businesses have had to quickly refill their stocks, for which they also used UAC.)
- The relative attractiveness of UAC relative to other modes of transport (i.e., supply chain disruptions or delivery delays via ocean transport cause manufacturers to use air transportation to recover lost time)
- Regulatory barriers to entry
- Domestic and international economic variables including trends in the UAC industry, trade flows, economic output, supply chain efficiencies, and projected growth, among others

Several research efforts have been undertaken to assess the market potential of AAM. UAM Geomatics Inc. (formerly NEXA Advisors) has developed an economic framework for estimating the impact of AAM in metropolitan areas. This framework was implemented to evaluate the economic impact of AAM in Vancouver (Canadian Advanced Air Mobility Consortium et al., 2020) and Ohio (Cohen et al., 2021). The framework shown in Figure 15**Error! Reference source not found.Error! Reference source not found. Error! Reference source not found.Error! Reference source not found.Error! Reference source not found.Error! Reference source not found.Error! Reference source not found.**demonstrates the key primary cases, assumptions, enabling infrastructure, modeling techniques, and model outputs that can be expected within an AAM market analysis. Estimating AAM demand is one of the key parameters within the framework.

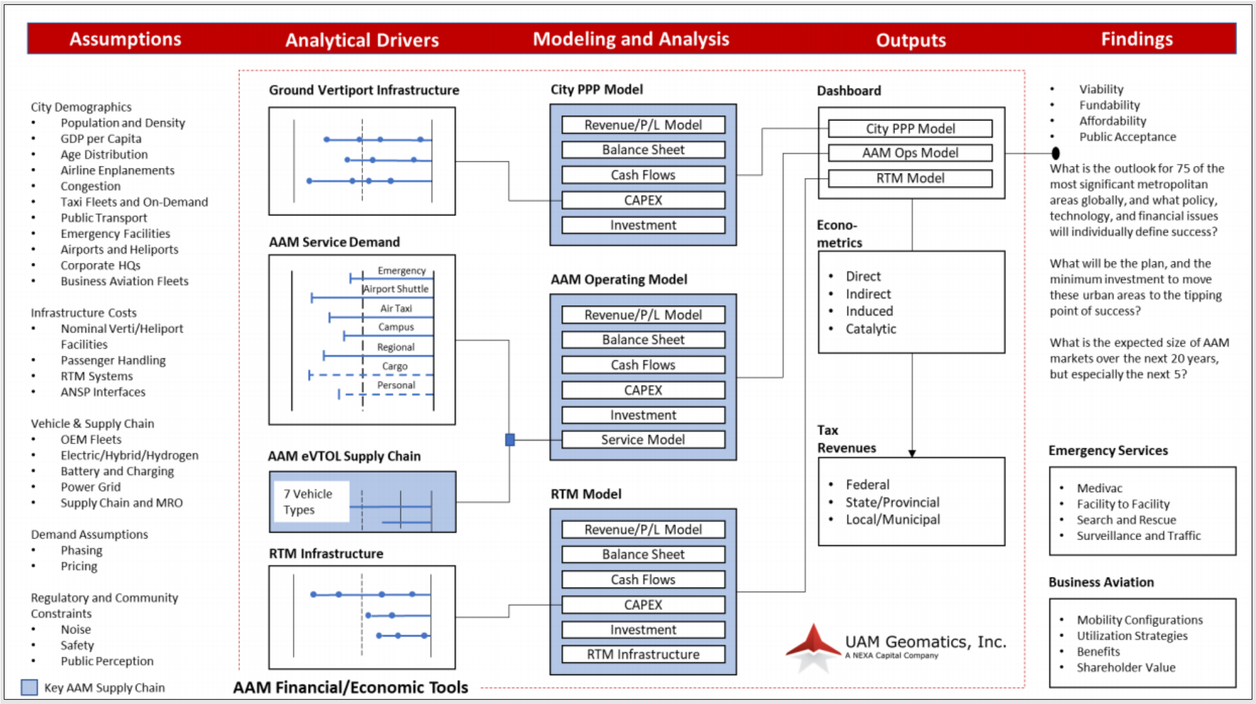


Figure 15: Framework to Estimate the Market Potential of AAM in Metropolitan Areas (Cohen et al., 2021)

Within the next few decades, Advanced Air Mobility is anticipated to become a common mode of transportation, providing applications for passenger and cargo mobility. According to a Deloitte Insights study (Lineberger et al., 2021), the advanced air mobility market is poised to grow sevenfold between 2025 and 2035, with a market value of $17 billion in 2025 and $115 billion in 2035. As a frame of reference, $115 billion is equivalent to 30 percent of the US commercial aerospace market and 0.5 percent of the country’s GDP in 2019 (Lineberger et al., 2021). AAM applications are projected to begin initial deployment in 2025 and reach widespread deployment with full automation by 2042 as shown in Figure 16 (Lineberger et al., 2021).

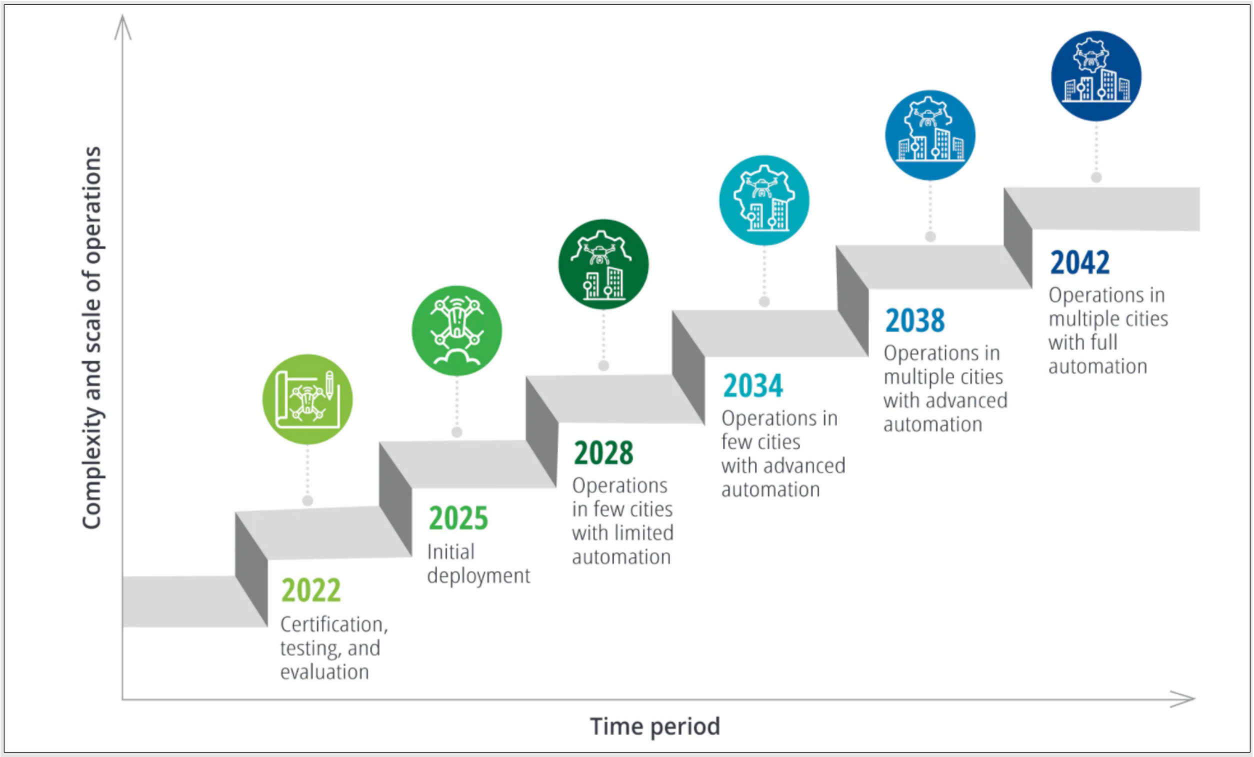


Figure 16. AAM Market Growth Paradigm (Lineberger et al., 2021)

Several assumptions, guideposts, and modeling techniques can be used to estimate AAM demand. For a discussion of passenger-related demand modeling, see *2.12.1 Demand for Unmanned Air Cargo*. For a discussion cargo-related demand modeling, see *Demand for Unmanned Air Cargo.*

# 3 CONCLUSIONS

This literature review explored key aspects of AAM to identify important areas of interest for research efforts associated with ASSURE A41 and 42, identifying considerations for unmanned automated air transport and air cargo, respectively. As part of this literature review, the research team identified the following subject areas that are particularly relevant when discussing both the evolution and integration of AAM in terms of air transportation and cargo delivery:

- Airspace,
- Regulations,
- Automation,
- Airman Certification and Training,
- Design and Airworthiness,
- Unmanned Traffic Management (UTM), and
- Economic Analysis.

In addition, there are some unique considerations for UAC that were identified by the research team. In the case of UAC, trends towards adoption and the impact of integration, particularly in the state of Alaska, offer insight into the current state of the industry and hints of where areas of growth may occur.

What follows are conclusions drawn from literature sources consulted as part of this literature review. Conclusions align with the subject areas identified above, and they shed light on the current state of AAM while framing pathways for future research into unique aspects of RAM, UAM and UAC.

### Airspace

While NextGen efforts to modernize communication, navigation, and surveillance systems/infrastructure is a step in the right direction, the potential addition of large volumes of unmanned air traffic may create challenges to the introduction of AAM. These challenges may be beyond the scope of conventional aviation infrastructure, hinting at the broader need for robust UTM infrastructure to handle new types of traffic in varying classes of airspace.

### Regulations

In addition to changes to the airspace structure, management, and function, there are numerous regulatory challenges that affect the advancement and integration of AAM, particularly RAM, UAM and UAC. Of particular interest are Parts 91, 121, and 135. While there are undoubtedly numerous other regulatory tie-ins, these Parts were considered significant as they govern operating rules, schedule, and on-demand operations respectively.

Presently, the “see and avoid” requirements listed in §91.113 are insufficient to enable AAM operations. As currently written, they do not address the evolutionary phases for AAM, transitioning from piloted, to remotely piloted, and eventually to fully autonomous systems. Regulatory changes are likely required to enable the full gamut of operations that comprise AAM.

In addition to the limitations imposed by Part 91, Part 121, which governs scheduled air carrier services, will also affect the advancement and implementation of AAM. A Part 121 Certificate is generally provided to large U.S. based airlines, regional air carriers, and cargo operators to operate a scheduled air service after demonstrating that they comply with requirements for the certificate. At present, Part 121 covers only manned aircraft operations by virtue of not addressing some of the novel aspects of remotely piloted and/or fully autonomous aircraft. Revisions may be required to address the more novel aspects of AAM, to include autonomy, infrastructure, design, airworthiness, and more.

Like Part 121, Part 135 provides guidance in the process and requirements for obtaining an operating certificate for on-demand commuter flights – i.e., air taxis. While there is room for AAM to fill this role, particularly in the realm of UAM and UAC, the heavy dependence on novel technologies and type certification currently creates hurdles to the adoption of autonomous aircraft for Part 135 operations. This is due in large part to novel designs, electric propulsion, and technology inherent to current AAM concepts that have yet to be fully explored. As such, unmanned air transport, to include UAM and UAC are not currently practical under existing rules.

Despite the current challenges associated with obtaining operating certificates for Part 121 and 135 operations using novel, highly automated aircraft, there are still near-term benefits offered by a subset of AAM. RAM provides a near-term solution to connect smaller airports to larger hubs using lighter, more conventional piloted aircraft. Since, the number of major capacity-constrained airports in the U.S. is increasing at a faster pace, the introduction of RAM can help in slowing this trend by utilizing existing airport infrastructure at less congested airports to reduce traffic congestion as passengers travel to larger hubs.

UAC faces its own unique barriers to integration. A great deal of the information that exists for the integration and logistical implementation of cargo-capable aircraft operating at an airport is in large part, conceptual. The primary focus of the research material being discovered speaks mainly on the "how" to get cargo delivered and best vehicle to do that and exists almost exclusively as operational test subjects. Based on the material available, and with the limitations imposed on flying organizations, the areas being tested have not produced information significant or relevant enough to adequately determine best practices for integration and logistics certification of cargo UAS at a functional multi-role airport.

### Automation

Automation is foundational to the full realization of AAM, to include UAM and UAC. The goal is to achieve a lesser reliance on human pilots with a steady focus in system automation. It is believed greater levels of automation will initially be seen in unmanned cargo aircraft and transition to unmanned passenger aircraft after sufficient validation and trust has been achieved. This process will begin with SVO which greatly simplifies aircraft operation, reducing the pilot's required skillset and knowledge level. From there, it is anticipated that AAM will progress to remotely piloted aircraft. Once sufficient trust in automation is achieved, there will be a shift towards greater autonomy, eventually removing the human pilot/operator altogether.

Naturally, the shift from piloted, to remotely piloted, and eventually to full automation will influence the way airman training and certification is provided. There is specific emphasis on simplifying cockpit controls and reducing pilot workload while still maintaining an equivalent level of safety. Such a transition is also characterized by the trend of the decreasing pilot skill required for the operation of AAM.

With the shifts toward automation, there is a need to develop trust in automation prior to embarking upon flight operations that may carry increased risk, such as those that transport people or large cargo. This being the case, the literature pointed to a need to establish trust in automation as it is gradually phased in to both automated transport and cargo paradigms. This transition will see a gradual shift towards autonomy as trust is established over time.

### Airman Certification and Training

A stated previously, airman certification and training will be intrinsically linked to the introduction of greater levels of autonomy as manned pilots are gradually phased out. Presently, there are stark differences between remote pilot certifications for UAS and manned aircraft, with no specific practical skillsets required for sUAS. As larger, more complex UAS become more prevalent, this is expected to change.

### Design and Airworthiness

AAM concepts, to include RAM and UAM and UAC often incorporate novel design elements, to include electric propulsion, VTOL/STOL capabilities, and unconventional vehicle configurations – e.g., multirotor, tilt rotor, etc. With the high degree of variation in design, there is a need for standardization across the industry to enable consistent approaches to common design challenges while offering potential means of compliance for demonstrating airworthiness as part of the type certification process.

The ANSI *Standardization Roadmap for Unmanned Aircraft Systems* outlines current standardization efforts for unmanned aircraft systems and lists critical gaps that must be addressed in future standardization efforts. Although, the Roadmap does not exclusively target UAM or UAC, it addresses some key points that offer insight into the direction of AAM in general, emphasizing the need for standards regarding automation, interiors, and equipment for unmanned air taxis and UAC aircraft.

Regarding design, a specific "Part" certification for UAS structures or avionics does not yet exist. The FAA in §21.17(b) have provided guidance to the applicant for UAS Type Certification to tailor the applicable existing manned aircraft requirements. However, there are currently no UAS with a full, standard type certificate. This emphasizes the need for standardization and regulatory requirements that guide design constraints.

### Unmanned Traffic Management (UTM)

The implementation of UTM systems will likely adopt a phased approach. Initial UTM concepts will likely begin on a small scale, capturing AAM operations that may occur in low-risk – e.g., less dense airspace. Following that, UTM operations may scale to suit larger aircraft, higher traffic volumes, and higher risk operations, such as routing for aircraft that carry passengers.

### Economic Analysis

Determinants of AAM market demand are found within UAM and UAC contexts. Variables that influence unmanned passenger demand include:

- Public acceptance
- Relative attractiveness of UAM compared to other modes of transportation
- Direct and indirect UAM cost structures
- Availability of UAM enabling infrastructure
- Legal or regulatory frameworks that need to be implemented or revised

More specifically, the following economic conclusions were identified for UAM constructs:

- UAM demand is a highly coupled problem with public acceptance, user cost and time savings, transportation mode competition, and UAM enabling infrastructure being key factors.
- Public acceptance will require high levels of safety and be affected by privacy concerns.
- Due to expectations, UAM can likely be more expensive than alternative transportation modes, but must also provide overall time savings (access and process times included).
- Congestion may give UAM an edge over ground transportation, especially in certain markets. It will likely be critical (to achieve widespread adoption of UAM) to integrate UAM access with existing public transportation networks. Note that UAM has the potential to adversely affect existing public transportation networks.
- To achieve large scale usage, UAM infrastructure will need a significant expansion: more access points (vertiports) and electric grid upgrades to handle charging the vehicles. Access

point operational efficiency will be important to maintaining low costs and significant time savings for the users.

- Regulations will also play a key role as well (e.g., affecting infrastructure or minimum clearances affecting climb rates and hence vehicle recharge (and client wait) times.
- The relative influence (or even existence) of these factors may vary significantly across various locations and demographics, making careful planning essential to successfully targeting and serving a market.
- With such an untested technology, many of these conclusions are tentative, and in places there is still disagreement in the literature.

Meanwhile variables that influence UAC demand include:

- Product inventories relative to sales volumes (historically, low inventory to sales ratios has meant that businesses have had to quickly refill their stocks, for which they also used UAC).
- The relative attractiveness of UAC relative to other modes of transport (i.e., supply chain disruptions or delivery delays via ocean transport cause manufacturers to use air transportation to recover lost time)
- Regulatory barriers to entry.

Domestic and international economic variables including trends in the air cargo industry, trade flows, economic output, supply chain efficiencies, and projected growth, among others.

While air cargo accounts for a relatively small portion of global trade volumes, but COVID-19 has increased demand for air cargo services. This demand has been influenced by delays and shutdowns from ocean shipping, which caused customers to emphasize the need for expedited deliveries via air cargo.

Globalization and its associated supply chain efficiencies is another factor contributing to the increase in air cargo demand. Air freight's more responsive service justifies higher costs for many commodities. It enables efficient supply-chain strategies—such as JIT and postponement—by reducing carrying costs through lower inventory requirements.

Looking to the future, growth trends should be considered by evaluating domestic and international economic variables, including trends in the air cargo industry, trade flows, domestic and international economic output, supply chain efficiencies, and projected growth.

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