The FAA's Center of Excellence for UAS Research

ASSURE

Alliance for System Safety of UAS through Research Excellence

# ASSURE A41 – Investigate and Identify the Key Differences Between Commercial Air Carrier Operations and Unmanned Transport Operations

## Final Report

December 14, 2023

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**16. Abstract**

ASSURE A41 investigated important contrasts between Advanced Air Mobility (AAM) and commercial air carrier operations as we know them today. This research focused on two primary subsets of AAM: air taxi operations (on-demand air-transport services for short duration travel in a high-density environment) and Regional Air Mobility (RAM), scheduled or on-demand medium range, i.e., less than 500 miles, air-transport services operating from existing general aviation facilities). During this research, the team (1) assessed the current state of the industry and identify market trends, (2) developed use cases based on these findings, and (3) conducted experiments and economic assessments that enabled the team to generate forecasts for the AAM industry. This approach provided a means to address questions regarding the growth of AAM, how it will impact existing transportation modes, and its potential social and economic impacts.

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| | |
|---|---|
| AAM | Advanced Air Mobility |
| ADS-B | Automatic Dependent Surveillance - Broadcast |
| ATC | Air Traffic Control |
| ATM | Air Traffic Management |
| IMPLAN | Impact Analysis for Planning |
| MSA | Metropolitan Statistical Area |
| NAS | National Airspace System |
| OEM | Original Equipment Manufacturer |
| RAM | Regional Air Mobility |
| SVO | Simplified Vehicle Operations |
| TC | Type Certificate |
| UAC | Unmanned [Uncrewed] Air Cargo |
| UAM | Urban Air Mobility |
| UAS | Unmanned [Uncrewed] Aircraft System |
| UTM | Unmanned [Uncrewed] Traffic Management |
| VTOL | Vertical Takeoff and Landing |

# EXECUTIVE SUMMARY

ASSURE A41 investigated important contrasts between Advanced Air Mobility (AAM) and commercial air carrier operations as experienced today. This research focused on two primary subsets of AAM: air taxi operations (on-demand air-transport services for short duration travel in a high-density environment) and Regional Air Mobility (RAM), scheduled or on-demand medium range, i.e., less than 500 miles, air-transport services operating from existing general aviation facilities). As a component of this research, the team (1) assessed the current state of the industry and identified market trends, (2) developed use cases based on these findings, and (3) conducted experiments and economic assessments that enabled the team to generate forecasts for the AAM industry. This approach provided a means to address questions regarding the growth of AAM, how it will impact existing transportation modes in the future, and its potential social and economic impacts.

A thorough literature review demonstrated that the viability of AAM passenger transport is highly dependent upon regulatory changes. Title 14 Code of Federal Regulation (CFR): Aeronautics and Space Parts 91, 121, and 135 (in their current version) may require adaptations to reflect operator training and certification reflecting the anticipated shift to Simplified Vehicle Operations (SVO) – technological features intended to make operating the aircraft easier (NASA, 2021b). Streamlined vehicle certification procedures must maintain rigorous testing, especially on developing autonomy components, as well as to allow flexibility to appropriately certify the wide range of vehicle designs, configurations, and mission profiles anticipated. Modified Air Traffic Management (ATM) approaches are necessary to allow the National Airspace System (NAS) to safely handle the projected increase in traffic. The literature implied that incremental implementation of regulatory changes and automation (e.g., starting with an SVO scenario, moving to remotely piloted, and finally to fully autonomous) will help preserve the safety of the NAS.

As an experimental construct, the research team leveraged an online survey to assess the influence of the developed variables on end users' willingness to fly in autonomous vehicles, willingness to pay for such a service, and assess the impact of the pandemic as well as other factors influencing demand for RAM and air taxi services. This survey provided insight into the flying public's perceptions, knowledge, and willingness to use AAM services. Verbal interviews were also employed to gain input from Original Equipment Manufacturers (OEMs) on key issues such as infrastructure requirements, design/airworthiness considerations, and economic/demand factors. These interviews identified three common themes among AAM OEMs and key stakeholders': uncertainty regarding the capability to field highly autonomous systems, the need for interoperability, and a need for regulatory changes and standards to support the growth and development of AAM.

Assumed demand projected by the ASSURE A36 (ASSURE, 2023) site suitability analysis and advanced passenger mobility demand findings Impact Analysis for Planning (IMPLAN) modeling predicts Urban Air Mobility (UAM), and RAM use cases will gross $72.52 billion in ticket sales and result in the manufacture of over 3,480 new Vertical Takeoff and Landing (VTOL) aircraft and the construction of over approximately 8760 new vertiports ground infrastructure investments (including electric grid upgrades, existing airport retrofits, and new vertiport installations appropriate infrastructure, e.g., electric grid upgrades), all by the year 2045. Projections show

AAM Passenger Mobility facilitating 137,430126,385 jobs, $10.9.88 billion in employee earnings, $20.5 18.8 billion million in gross domestic product, $36.632.8 billion in economic output (business sales), and $5.34.7 billion in tax revenue in 2045 when accounting for direct, indirect, and induced economic impacts (appraised in 2022 US dollars). Over the forecast period this equates to 799,795 job-years, $62.3 billion in cumulative earnings, $118.2 billion in cumulative gross domestic product, $207.6 billion in cumulative economic output, and $29.5 billion in cumulative tax revenue. The significant potential economic impact justifies continued effort to develop appropriate policies, procedures, vehicles, etc., necessary for AAM implementation at scale.

# 1 INTRODUCTION & BACKGROUND

This project aimed to identify the key differences between traditional commercial air carrier operations and the future paradigm of unmanned passenger transport. The constructs associated with this project allowed the team to investigate important aspects of Advanced Air Mobility (AAM) as it compares to the traditional views on commercial aviation. More specifically, this research explored some of the greater identified contrasts between AAM and commercial air carrier operations. The ecosystem of AAM represents emerging aviation technologies and concepts geared to offer a new modality in aviation transportation for goods and services including those not traditionally served by current modes of air transportation. This research focused on two primary subsets of AAM, Urban Air Mobility (UAM), also referred to as "air taxi," and Regional Air Mobility (RAM), while assessing the current state of the industry, plausible use cases, and an evaluation of economic impacts and forecasts from the standpoint of users and industry stakeholders. For clarity, UAM is a concept meant to encompass a vision of future flight operations in metropolitan areas with interoperability between traditional aircraft and uncrewed aircraft while RAM will serve rural and urban 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*, as published by the FAA (Federal Aviation Administration, 2020d). Appendix A of this final report presents a thorough literature review and formal definitions captured for this research.

Tasking for this research were as follows:

- Task 1 – Literature Review and Market Analysis
- Task 2 – Use Case Development
- Task 3 – Experiment Plan
- Task 4 – Conduct Designed Experiments
- Task 5 – Economic Assessment and Methodology

These tasks enabled the research team to (1) assess the current state of the industry and identify market trends, (2) develop use cases based upon the state of the industry and market trends, and (3) conduct experiments and economic assessments that enabled the team to generate forecasts for the industry. This approach provided a means to address questions regarding the growth of AAM, how it will impact existing transportation modes, and its potential social and economic impacts. Overall, these tasks provided a means to gather data to show where AAM will distinctly differ from conventional commercial air travel, the potential economic impacts, and public perceptions.

# 2 RESEARCH QUESTIONS

The scope of this work ascertained a full autonomous operating environment as a construct of this research. It is understood that the transition to a fully autonomous environment is gradual transitioning from a conventional pilot on board to a remote pilot finally leading to fully autonomous operations in the future.

The following questions guided this research methodology. The research questions provided an idea of scope and scale for the project in its entirety. Additionally, these questions informed the structure of research tasks such that they addressed the key requirements for this work.

**Research Questions**

1. What is the potential for large Unmanned [Uncrewed] Aircraft Systems (UAS) in carrying passengers in the US? Starting from road transportation and existing air transportation, it is expected that a potential market scope will be laid out.
2. What are the likely locations of large UAS to meet demand and growth of air transportation over a period of 10 years?
3. Will this change significantly following the recovery from COVID-19?
4. What interface characteristics are necessary for UAS passenger (e.g., UAM) to maintain awareness of aircraft system state with automated aircraft system and subsystem control?
5. What are the envisioned characteristics of transition from piloted UAS to fully autonomous UAS in carrying passengers? What are the likely conditions that enable piloted UAS to transition into fully automated UAS and likely timeline?
6. What interface characteristics are necessary for the UAS pilot to manage the aircraft's flight path with automated navigation?
7. How can autonomous systems be evaluated or certified such that safe integration of UAS in the existing ATM environment or emerging Unmanned [Uncrewed] Traffic Management (UTM) is enabled?
8. How will the UTM paradigm integrate with the large UAS environment? Or will a separate paradigm be needed? How will these paradigms be integrated with the NAS ATM that is already in place?
9. How will strategic scheduling of large UAS occur?
10. How will the non-scheduled large UAS be handled?
11. What other resources and NAS investment may be necessary to facilitate growth of UAS in air passengers?
12. What will be the aggregated economic benefits, i.e., direct, indirect, and induced, of integrating large UAS in transporting passengers on the overall economy?

Research tasks described in the following sections addressed the research questions as listed. A more detailed breakdown of findings is discussed in Section 4 – Conclusions. As previously mentioned, this research placed an emphasis on RAM and UAM, focusing on economic impacts and questions related to the public's perception as regards willingness to pay and willingness to fly.

# 3 RESEARCH TASKS

The research tasks depicted below addressed the primary research questions while generating intermediate deliverables that guided the research team's overall efforts. Following is a description of each task, an overview of the findings, and a discussion of conclusions and the significance to the research effort. For the sake of this report, the research team omitted detailed descriptions of research tasks that did not generate relevant deliverables.

## 3.1 Task 1 – Literature Review and Market Analysis

Task 1 consisted of a literature review and market analysis. These tasks allowed the research team to establish the current state of the AAM industry, explore previous research within this domain, and identify key drivers for the AAM market. This section outlines the approach, methodology, and findings for the literature review (Task 1-1) and market analysis (Task 1-2). These tasks informed future tasks while bounding the project's scope. Below is a summary of the literature review findings. Appendix A of this report provides a full review of the literature attained through the duration of this work.

### *3.1.1 Task 1-1: Literature Review – Conclusions*

The following sub-sections offer key points and takeaways from the ASSURE A41/42 joint literature review. The following sections outline a summary of conclusions from the literature review (Appendix A) that framed subsequent tasks for A41. This aided the research team in identifying areas where AAM may have a significant impact and contributed to answering research questions.

#### 3.1.1.1 *Airspace*

The ability to scale ATC services to meet expected demand will become increasingly important with an increase in uncrewed aircraft, and this is especially true with the emergence of UAM and air taxi services (Vascik et al., 2018). With this need for scalability and an increase in traffic density, higher levels of autonomy will likely be required on each end of the system – aircraft and air traffic services (Hill et al., 2020). This implies that investment in new avenues for Air Traffic Management (ATM) and UTM will be essential to compensate for the large influx of aircraft and unconventional operational profiles envisioned for this paradigm of future aviation.

#### 3.1.1.2 *Regulations*

According to the literature review[1], full integration of autonomous AAM will be challenging under the current regulations. This is reflected in challenges associated with the, "see and avoid" requirement under Part 91. Presently, human pilots must perform "see and avoid" functions. As written, amendments to 14 CFR §91.113 are likely required to allow DAA systems to perform "sense and avoid" tasks in lieu of human pilots or operators. Additionally, Parts 121 and 135 do not address or make exemptions for technologies – e.g., autonomy that serves an essential function of flight crew. Phasing in regulatory changes during a transition period marked by crewed operations is the likely path forward.

#### 3.1.1.3 *Automation*

Advancements in technology will drive the progression of AAM. According to the literature review[2] and NASA's vision for convergent autonomy pathways (NASA, 2021b), this progression will have three distinct phases starting with Simplified Vehicle Operations (SVO), a means of simplifying aircraft controls for ease of use and safety, moving to remotely piloted aircraft, and finally resulting in fully autonomous aircraft. During this progression both the skills required of pilots and the certification standards are likely to change. Pilot skillsets will adapt to suit higher levels of autonomy. Thus, pilots will increasingly rely on Artificial Intelligence (AI) and machine learning to supplement their roles (ANSI, p. 342, 2020). However, before large scale adoption of autonomy, smaller scale proof of concepts will have to be successful to establish trust in the technology. This is supported by NASA (2021b) which states the ability to demonstrate that autonomous systems can operate safely will set the pace for adoption (p. 18).

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[1] See Appendix A, pp. A-63 – A-64 for conclusions regarding regulations and autonomy.

[2] See Appendix A, pp. A-9 – A-12

#### 3.1.1.4 *Airman Certification and Training*

The literature review[3] indicated that airman certification requirements and training of pilots will change as the amount of autonomy used in aircraft increases. As crewed aircraft increase the use of autonomy and uncrewed aircraft become larger and more complex, trends are expected to emerge that result in the simplification of controls which will allow pilots to focus on fewer tasks that are more critical to flight (NASA, p. 18, 2021b). Furthermore, pilot skillsets are expected to emphasize a greater reliance on AI and machine learning as they become more prevalent in AAM aircraft over time (ANSI, p. 342, 2020). Pilot certification requirements, including both Part 61 and likely 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.

#### 3.1.1.5 *Design and Airworthiness*

Current airworthiness and type certification processes for AAM vehicles rely heavily on establishing their certification basis via Title 14 CFR Part 21.17(b). While this path to type and airworthiness certification enables novel approaches to aircraft design, it may also be limiting. According to Serrao et al. (2018), there are distinct differences between the certification path for more conventional aircraft designs and those typically used for novel aircraft, such as eVTOLs. Serrao et al. (2018) identifies the following differences between the Title 14 CFR Part 21.17(a) and 21.17(b) processes:

> 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., p. 18, 2018)

These findings imply that the current path to type certification via 21.17(b) does work, but it may not scale to meet the demands of mass production.

Efforts are underway to create standards that support the type certification and airworthiness of AAM vehicles. Certification efforts may be aided by using industry consensus standards to serve as a means of compliance for regulatory requirements, offering a means for new and novel aircraft to meet regulatory requirements. This approach offers greater flexibility, as type certification is not a “one size fits all,” process. However, there are currently gaps in standardization efforts (Serrao et al., p.24, 2020). These gaps are identified within the ANSI *Standardization Roadmap For Unmanned Aircraft Systems, Version 2.0* (2020) and further gaps are are identified in Serrao et al. (2020). While the ANSI Standardization Roadmap provides high-level gaps, such as gaps for operational standards, Serrao et al. (2018) identified more specific gaps relating to certification and airworthiness. These gaps resulted from an ASTM F38 gap analysis which identified standardization gaps for airframes, power plants, and avionics with respect to certification, airworthiness, and crew qualificaitons (Serrao et al., p.24, 2018). These gaps in standardization

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[3] See Appendix A, pp. A-10 – A-11

efforts point to a need for increased involvement by standards bodies to develop standards that support airworthiness and type certificaiton for AAM vehicles.

The result of the reliance on Title 14 CFR Part 21.17(b) and the gaps in industry consensus standards may represent challenges for certifying AAM vehicle. While there are regulatory paths to certification and standards to support them, they may not scale to meet demand. A review of existing regulatory requirements and continued efforts by industry to build consensus standards to support those requirements may aid in streaminging the process for type and airworthiness certificaiton for AAM aircraft.

#### 3.1.1.6 *Unmanned Traffic Management*

UTM systems will need to consider the following five key principles for uncrewed aircraft integration, per ICAO's *Unmanned Aircraft Systems Traffic Management (UTM) – A Common Framework with Core Principles for Global Harmonization:*

> 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, p. 8, 2020).

Bearing this in mind, UTM systems must consider other aircraft in the airspace, including large UAS – i.e., crewed/uncrewed transport aircraft, cargo aircraft, and other AAM vehicles. The implication is that UTM systems will need to coexist with broader ATM systems, and share data. Jiang et al. (2016), states that while UTM will borrow many of the fundamental concepts from convnetional ATC, there will be differences, primarily with methods of control, maneuverability, and other constraints (p. 1). Furthermore, Lascara et al. (2018) highlights that ATC services for UAM vehicles would likely incorporate UTM-like services to higher altitudes than those associated with other UAS (p. 10). Timelines for the implementation of such services are not set in stone. However, (Prevot et al., 2016) anticipates that the increase in UTM operations over time with initial operations in class G airspace, per the FAA's initial UTM CONOPs.

#### 3.1.1.7 *Economic Analysis*

The two major categories of AAM analyzed for market demand were Urban Air Mobility (UAM) and Regional Air Mobility (RAM). Specific areas considered for this analysis were public acceptance (predicated on safety and privacy concerns), willingness to pay more money to save time on transportation, the ability to integrate UAM and RAM with current transportation networks, the need to expand the infrastructure that would support UAM and RAM, regulation barriers, and different market sectors serviced by AAM.

### *3.1.2 Task 1-2: Market Analysis - Conclusions*

This sub-section offers key points and takeaways from the ASSURE A41/42 joint market analysis. The market analysis is built on the literature review, enabling the research team to identify use cases operationalized in Tasks 2, 3, and 4, and formulate key determinants of AAM economic impact used in Task 5.

#### 3.1.2.1 *Passenger Market Characteristics and Viability*

AAM passenger flight services will undergo several stages of transition within the next few decades. According to a Deloitte Insights market study (Hussain and Silver, 2021), there is an expectation that AAM adoption will transition from initial deployment to operations in multiple cities with full automation over the next two decades. Forecasts indicate this transition occurring in six distinct phases.

First, the industry will undergo a certification, testing, and evaluation phase followed shortly thereafter with over a dozen OEMs vying for Entry into Service (EIS) dates as early as 2025 (SMG Consulting, 2022). Second, the AAM industry will witness initial deployment of commercial operations in a few cities around the world. In the US, data indicates these cities to be New York with the transition of Blade flight services to those with AAM capabilities, Los Angeles with the initiation of Archer, Orlando with Lilium taking flight from the Lake Nona Aerotropolis, Chicago with Archer’s first electric air taxi route planned at O’Hare International Airport and Vertiport Chicago, and Miami with Archer services in the planning stages (Archer, 2023; SMG Consulting, 2022). Joby also plans to launch within the next few years in California, among other global and domestic markets (Joby, 2022). Third, new infrastructure investments and lessons learned from phases one and two will create a pathway for less complex commercial operations to occur in a few cities by 2028 (Hussain and Silver, 2021). Fourth, passenger operations with moderate complexity will emerge. The market analysis anticipates that new AAM passenger service launch sites will come online, while other sites will enter their final stages of market readiness. Probable locations for additional AAM passenger service launch sites include the locations evaluated as part of NASA’s set of Community Annex Teams, such as Minneapolis, Dallas, Columbus, and Boston (NASA, 2021a). The fifth phase should consist of commercial deployment with advanced automation in multiple urban, suburban, and rural areas (Hussain and Silver, 2021). By this phase, the industry and regulatory agencies are likely to have found solutions to some fundamental issues (e.g., collision avoidance systems, on-board sensors, and cognitive systems). Finally, the analysis anticipates that the commercial deployment of AAM passenger services will be widespread and will have achieved full automation. The analysis by Hussain and Silver (2021) indicates that AAM passenger service providers will expand into new locations with favorable market conditions. These assumptions were a fundamental component of the economic assessment that the research team has undertaken, which is documented in “Task 5 – Economic Assessment and Methodology.”

#### 3.1.2.2 *Market Segments / Use Cases*

AAM will revolutionize the way people travel to work, hospitals, and other key destinations. AAM passenger services could have far-reaching economic consequences, including altering housing and business locations due to newly available and fast transportation (Rothfeld et al., 2020). The emergence of new AAM technologies, will also bring about a variety of new passenger services in five distinct market segments, including airport shuttles, regional air mobility, on demand air taxi, corporate campus shuttles, and emergency services (UAM Geomatics, 2022).

#### 3.1.2.3 *Competition for AAM Passenger Services*

Emerging AAM technologies have the potential to disrupt several sectors, but these sectors also have strong existing competitors. Research anticipates that AAM services will enter the markets for short journeys (as air taxis), trips to and from airports, regional travel, and ambulance services, but, in all of these, the new entrants will face entrenched incumbents, some of which have significant advantages. There is a small but substantial subset of passengers that is resistant to any of the emerging technologies and that will continue to prefer to take traditional modes (Garrow et al., 2019). These travelers will be among the last to adopt AAM travel if they do so at all.

Air taxi service is one of the most promising use cases for emerging AAM technologies, especially in congested urban areas. Although a potentially large market, it is also a market with many competitors that are already used to making trips of similar distance and frequency. Widespread alternatives to air taxis already exist in the forms of personal automobiles, public transportation systems, and ridesharing/taxis/TNC services. In addition to these traditional competitors, an AAM air taxi service could face notable competition from other emerging technologies such as ground-based autonomous vehicles, which would offer a service with many of the same benefits at a lower cost.

#### 3.1.2.4 *Target Markets and Suitable Market Conditions*

As AAM takes off in the US, there will be multiple characteristics that elevate specific domestic markets for AAM passenger growth. To fully understand the most suitable locations for AAM passenger services within the US, the research team reviewed more than 100 journal articles, market reports, industry papers, regulatory briefings, and leveraged a market analysis conducted by the ASSURE A36 project team (Olivares et al., 2022). The literature review, market analysis, and ongoing discussions with subject matter experts from the Federal Aviation Administration led to the determination of 13 variables that affect AAM passenger market growth as shown in

Table 1.More information about the site suitability analysis and the determination of its variables can be found in within the ASSURE A36 project’s final report (for access: see Olivares et al., 2022 in the References section).

Table 1. Site Suitability Analysis Variables.

| Category | Variable | Variable Description |
|---|---|---|
| Urban Structure | Population Density | The more people there are within a specified area, the greater likelihood that AAM passenger services will be able to connect target customers with their desired business or leisure destinations. |

| Category | Variable | Variable Description |
|---|---|---|
|  | Polycentrism | Polycentrism is a measure of fully formed city centers within a region. The more city centers there are within a specified area, the greater likelihood that AAM services will be needed in the region. |
| Economic Scale | Fortune 1,000 Presence | The presence of Fortune 1,000 companies within a region catalyzes the need for CEO or executive leadership travel, which is somewhat price inelastic, and a target market for AAM service providers. |
|  | Gross Regional Product | The higher an area's gross regional product, the greater the likelihood that there will be a lot of business activity in the region. This may allow AAM services to capture or address business travelers' needs. |
| Congestion and Travel Time | Average Time to Work | The longer an individual's commute time to work, the greater the potential for an AAM trip to save time for that individual, relative to their existing travel method. |
|  | Travel Time Index | A travel time index is a measure of average travel conditions that demonstrates how much longer, on average, travel times are during congestion compared to light traffic. The higher the travel time index, the greater the likelihood for AAM services to be competitive in the region. |
|  | Airport to Central Business District Drive Time | Trips that connect city centers to airports will be a fundamental market segment for AAM. This segment, referred to as the airport shuttle, will be most competitive with vehicular modes of transport when longer drive times from the airport to a region's central business district exist. |
| Market Readiness | Heliports Per Capita | The greater the number of heliports or airports per capita, the more opportunities for existing infrastructure to support AAM services. |
|  | Airports per Capita |  |
|  | Class B Airspace | Presence (or not) of Class B Airspace in MSA (binary). |
|  | Class G Airspace Congestion | AAM services are anticipated to primarily occupy Class G airspace. If this airspace is highly congested within a region, it will limit the amount of AAM trips that can be undertaken. |
| Market Readiness | Existing Investment | Public or private sector investment in AAM infrastructure and policies can serve as a catalyst for AAM activities. The greater the investment, the more likely AAM services are to take hold in a region. |
| Existing Short Haul Market | Airport Short Haul Market Stability<br>(<150 miles) | Short haul airport trips carrying passengers less than 150 miles demonstrate markets that are conducive to air travel and are within the maximum range of AAM passenger service. These markets offer growth opportunities for AAM passenger trips. |

### 3.1.2.4.1 Ground Infrastructure Requirements

Like the hub and spoke model used by the airline industry, it is likely that AAM will rely on core and feeder vertiports (Rimjha et al., 2021). Core vertiports will exist in dense employment areas, or household locations with a higher-than-average income level, while feeder vertiports will provide service in lower demand areas (Rimjha et al., 2021). The efficacy of AAM passenger networks will depend on a minimum level of vertiport infrastructure to support basic needs of those commuting in the urban core or surrounding exurbs.

In large, dense, high income urban cities, approximately 10-18 vertiports (40-60 landing pads) would be required to facilitate an AAM passenger network (EASA, 2021). This equates to approximately one landing pad for every 46,000 individuals living in these large, dense, urban areas. Meanwhile, medium, less dense, moderate income, urban/suburban cities would require 7-21 vertiports (20-45 landing pads; EASA, 2021), which equates to one landing pad for every 21,500 individuals living in medium, less dense urban areas.

In near alignment with EASA vertiport estimates, UAM Geomatics (2022) developed ground infrastructure investment scenarios required to support a mature AAM network throughout international and domestic markets. Within the United States, estimates show a total of 869 vertiports needed to support a mature AAM network in the year 2045 (UAM Geomatics, 2022).

#### 3.1.2.5 *Potential Size and Growth of AAM Passenger Mobility*

Based on AAM market milestones and development criteria established by Hussain and Silver (2021) and the ASSURE A36 site suitability analysis results, this research assumed that 30 Metropolitan Statistical Areas (MSAs) would launch AAM passenger mobility services from the present day through 2045. These 30 MSAs were the highest scoring from a list of 100 suitable metropolitan statistical areas produced during the site suitability analysis. Figure 1 shows a visual depiction of the 100-most suitable MSAs.

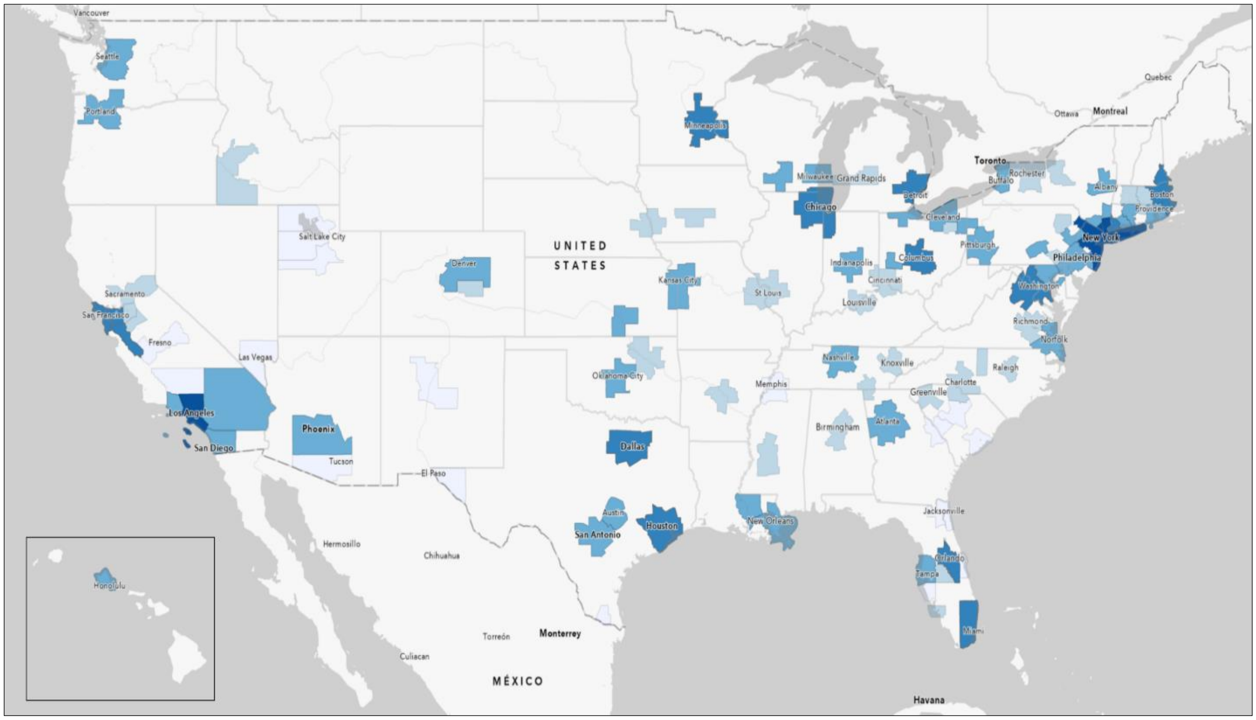
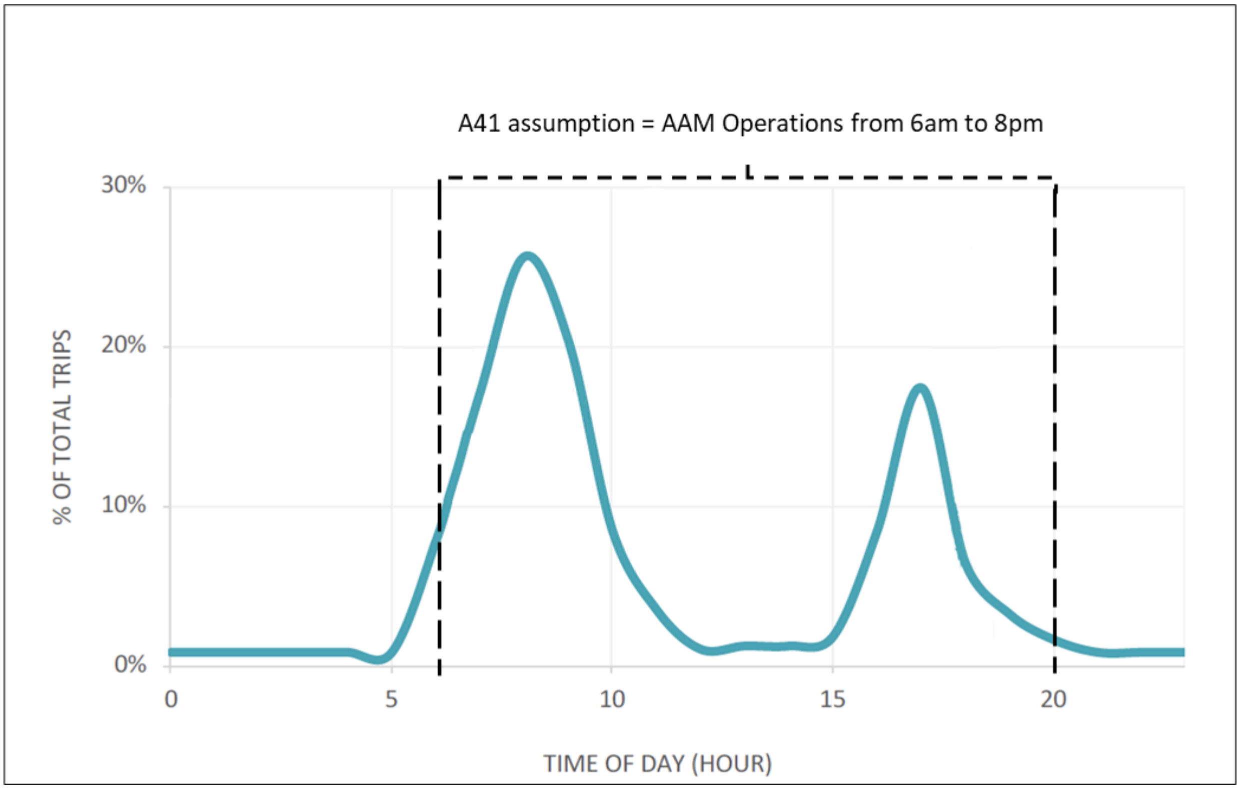


Figure 1. Site Suitability Analysis Results (ASSURE A36, 2022).

Since the completion of the A41 market analysis, the team used new guideposts from the literature to estimate domestic potential market size. These guideposts include hours of operation for AAM passenger mobility operators (assumption is 14 hours of daily service from 6am to 8pm see Figure

XX), an occupancy of 2.5 paying customers per mission, approximately 2.33 missions per hour, and 360 operating days per year. Altogether estimates show that a VTOL fleet of approximately 3,486 aircraft will support 516 million AAM passenger mobility trips that generate approximately $72.5 billion in ticket revenue.



### 3.1.2.6 *Key Drivers of Economic Impact*

It is likely that Advanced Air Mobility will generate substantial economic impact within the United States and around the globe. To better understand the economic impact of the US AAM passenger market, this research focused on the economic impacts generated domestically from VTOL missions. Anticipated use cases consisted of airport shuttle, air ambulance, air taxi, and corporate shuttle use cases making trips with flight distances up to 200 miles.[4]

The research team conducted a comprehensive economic impact assessment based on an extensive literature review (Task 1.1), market analysis (Task 1.2), and previous research conducted by the ASSURE A36 project team. The literature review and market analysis helped identify key drivers of economic impact for the AAM passenger market.

Evaluating the economic impact of AAM passenger markets from the present day through 2045 requires understanding (1) what are primary drivers of AAM economic activities, (2) what is the current demand for those activities, and (3) what will demand look like in the future. There are

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[4] The determination of use cases and flight distance was made during the ASSURE A36 project (Olivares et al., 2022) based on the feasible use cases and flight distances found in the literature and discussed with the project sponsor. These determinations were upheld to maintain consistency between the A36 and A41 projects.

three primary drivers for AAM passenger market economic impact on the US economy, which include: AAM passenger market flight activities (how many passenger flight services will be sold), VTOL fleet activities (how many VTOL aircraft will be purchased to meet AAM passenger market demand and what expenditures will be required to maintain them), and ground infrastructure activities (how many vertiports [i.e., vertipads, vertibases, vertihubs, and megaports] will be required to meet AAM passenger flight demand, how many will be needed to operate them, how many staff will be needed to pilot VTOL aircraft [first onboard and then remotely], and what expenditures will be required to maintain vertiport infrastructure).

To understand AAM passenger demand through 2045, the A41 project leveraged the research conducted by the ASSURE A36 (ASSURE, 2023) project team. The A36 team conducted a site suitability analysis coupled with market penetration modeling to assess AAM passenger demand within the US from the present day through 2045. The A36 team's research provided a basis for the A41 project team. The team used AAM passenger demand estimates to derive AAM passenger revenue, VTOL aircraft needs and associated capital and operations expenditures, vertiport infrastructure needs and the associated capital, operations, and maintenance expenditures. The team then used this information as key input into an economic model. IMPLAN, an input-output model, derived indirect and induced impacts, which include the business-to-business transactions (indirect effects) and household spending transactions (induced effects) that result from AAM passenger market activities. For more information about the methodology used to evaluate the economic impact of AAM passenger mobility from the present day through 2045 see "Task 5 – Economic Assessment and Methodology" on page 51.

## 3.2 Task 2 – Use Case Development

Use case development for Task 2 built upon the literature review and market analysis for Task 1. For this task, the research team used data from the literature and initial market analysis to generate considerations for use cases. The research team would then refine considerations for use cases and scope future tasks based upon the use cases chosen for further investigation. A key consideration at this stage of the project was to determine a use case, or use cases, such that they were representative of likely industry trends. This consideration helped to ensure the research remains relevant and reflects realistic industry development.

### *3.2.1 Use Case Considerations*

Based on the market analysis, the research team considered several potential AAM use cases including corporate campus, airport shuttle, regional air mobility, emergency services, and air taxi. Regional air mobility and air taxi cumulatively made up nearly two thirds of the projected market shares with air taxi garnering 37.8% and RAM following with 27%. The research team chose these use cases because they made up the most significant of the market share (Figure 2).

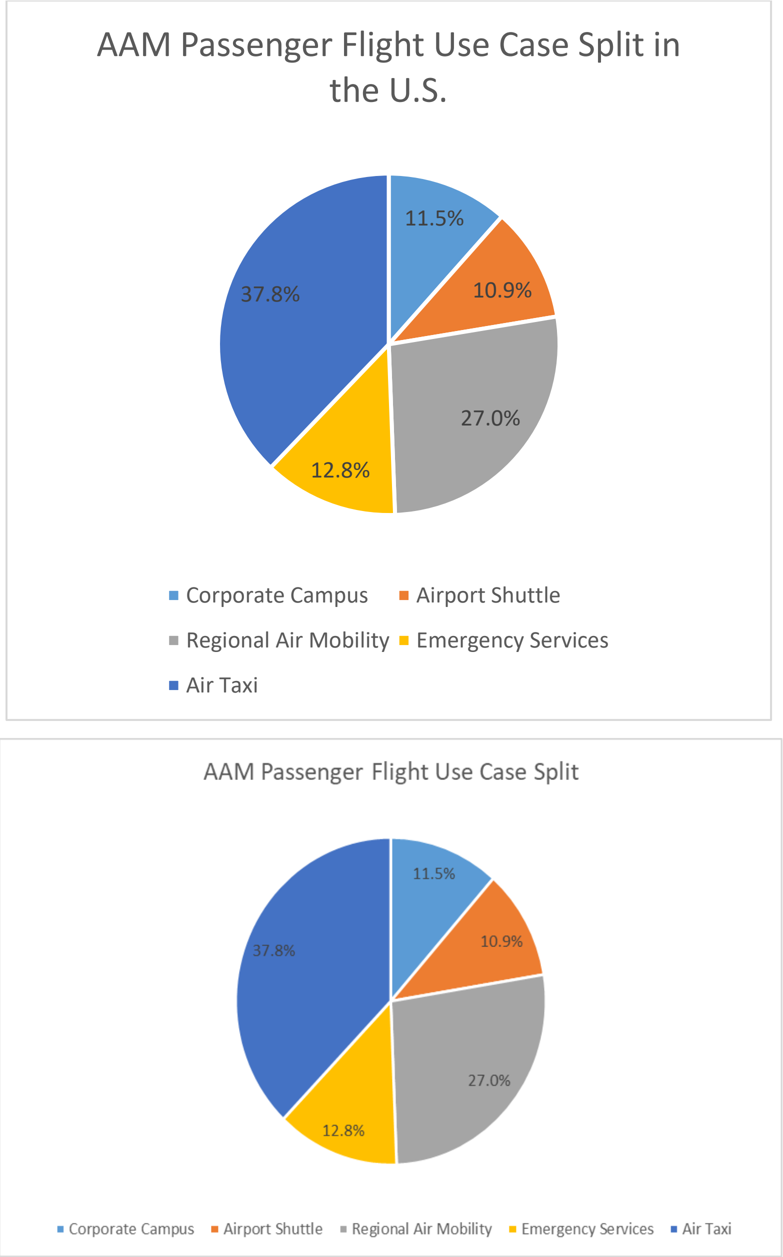

Figure 2. Unmanned Passenger Flights by Market Share (UAM Geomatics, 2021).

While the team initially considered investigating additional use cases, the emphasis on air taxi and RAM was commensurate with their anticipated market shares. As such, the research team did not consider other use cases, such as airport shuttle, corporate campus travel, and emergency services for future tasks. Due to the large share of passengers within the air taxi and RAM use cases, the research team focused on these use cases for the experimental plan, design, and execution, carried out in Tasks 3 and 4. The Economic Impact Assessment (Task 5), however, accounts for economic impacts stemming from multiple AAM use cases including air taxi, short haul RAM operations (under 200-mile trip distance), airport shuttle, and corporate campus use cases shown in Figure 2.[5]

### *3.2.2 Use Case 1 – Air Taxi*

The research team identified defining characteristics of an autonomous air taxi use case based on a review of literature and distilled those characteristics into a general use case. The use case drove the research methodology and addressed larger research questions. For example, *UAM Vision Concept of Operations (ConOps) UAM Maturity Level (UML) 4 Version 1.0*, defined UAM as, "the concept of expanding transportation networks to include short flights that transport people and goods around metropolitan areas (Hill et al., 2020, p. 6). More specifically, UAM,

> … enables thousands of people to use autonomous/semiautonomous air mobility services every day in major cities. Many in the UAM community anticipate that future UAM services are delivered primarily by electric and hybrid-electric Vertical Take-off and Landing (eVTOL/hVTOL) aircraft that are quieter, incur lower operating costs, and employ technologies that significantly increase operational performance (e.g., autonomous systems). (Hill et al., 2020, p.6)

Additionally, NASA's *Urban Air Mobility (UAM) Market Study* specified a complimentary definition of UAM, offering a use case defined by,

> a near-ubiquitous (or door-to-door) ridesharing operation that allows consumers to call vertical takeoff and landing aircraft (VTOLs) to their desired pickup locations and specify drop-off destinations at rooftops throughout a given city. Rides are unscheduled and on-demand, like ridesharing applications today. Like the air metro case, vehicles are autonomously operated and can accommodate 2 to 5 passengers at a time, with an average load of 1 passenger per trip. (Crown Consulting Inc. et al., 2018).

Finally, NASA's *Regional Air Mobility: Leveraging Our National Investments to Energize the American Travel Experience* (NASA, p. 4, 2021b), identified RAM trips as being between 50 and 500 miles. The implication is that air taxi trips will be distinctly different from RAM operations, covering smaller distances. This implies that air taxi trips are likely to cover distances up to by not necessarily including ranges of 50 miles.

The example definitions shown above, in conjunction with supporting literature, provided a starting point to derive basic characteristics of a UAM use case. This use case informed the experiment plan, experiments, and economic assessment.

#### 3.2.2.1 *Summary of Air Taxi Use Case Characteristics*

From these definitions and an extensive review of literature, the research team was able to summarize typical characteristics of a UAM use case. These characteristics informed the research team's approach to developing a model use case and scenario.

1. Operations generally take place within a metropolitan area,
2. The aircraft may employ novel propulsion, consisting of –

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[5] The economic impact assessment did not account for the emergency services use case. The primary focus of this research was passenger mobility, which contains distinctly different market characteristics than emergency services.

        a. Electric propulsion, or

        b. Hybrid electric propulsion,

3. Trips will carry between 2 and 5 passengers,

4. Aircraft with VTOL capability are likely to be common,

5. Aircraft designs reflect operations near populated areas, emphasizing the need for quiet systems that are able to integrate into communities,

6. Operations will largely be on-demand,

7. Operations will rely on a mixture of piloted and unpiloted aircraft with some level of autonomy inherent to the aircraft, infrastructure, and air traffic services,

8. Operations are likely to occur in defined areas at defined altitudes with some form of traffic management, and

9. UAM aircraft may transit controlled airspace classes where more conventional flight operations take place.

10. Air taxi trips will cover distances below the threshold for RAM trips, covering distances of less than 50 miles.

#### 3.2.2.2 *Air Taxi – Model Use Case Assumptions*

From the characteristics derived above, the research team used the following assumptions to drive the UAM model use case and scenario. These assumptions helped tie use case characteristics together to create a feasible use case, and they kept the use case within the scope of this research. The model use case and scenario based upon the driving characteristics and assumptions defined key variables and framed the team's approach to developing an experiment plan and methodology.

> *Assumption 1:* Flight operations occur within a metropolitan area and connect to controlled airspace via an established Urban Air Mobility Operational Environment corridor.
>
> *Assumption 2:* UAM aircraft is VTOL and part of a fleet that employs both electric and hybrid propulsion.
>
> *Assumption 3:* UAM aircraft designs facilitate operations within metropolitan environments with minimal impact on their surroundings – e.g., low noise.
>
> *Assumption 4:* A single flight will carry up to five passengers.
>
> *Assumption 5:* Flights will arrive and depart from a dedicated vertiport specifically for UAM flight operations.
>
> *Assumption 6:* The use case and scenario assume that the infrastructure and traffic control protocols are in place to enable a larger UAM ecosystem to function.

#### 3.2.2.3 *Air Taxi – Model Use Case*

Using the characteristics and assumptions above, the research team arrived at the following model use case and scenario. The scenario that follows is an excerpt from the experiment plan derived as part of Task 3.

> The UAM use case assumes on-demand operations from a vertiport located in a metropolitan area. The UAM service operates a mixture of electric and hybrid fuel aircraft designed for short trips between established destinations over distances that are typically less than 50 miles. The fleet consists of mostly autonomous aircraft, with a small number of aircraft being remotely piloted and optionally piloted. Flights arrive and depart the vertiport as needed (on-demand), with wait times dependent upon volume.

#### 3.2.2.4 *Air Taxi – Scenario*

Breaking down the model use case, the research team derived a scenario from which to define variables. The following scenario offered a typical application of the use case, and it helped the research team identify variables that informed experimental methodology.

> You [initial commute] to a nearby vertiport [initial commute time] away from your home for the purpose of catching a flight on an air taxi to [destination] [travel distance] away for [reason]. The cost of this trip is anticipated to be [price]. You scheduled the departure ahead of time, with an approximate wait of [wait time] upon arrival at the vertiport. The flight is expected to take [flight time] on a(n) [propulsion type] aircraft that is [control scheme]. On average, you can expect to share your commute with [PAX] of passengers.

*Variables*

1. Initial commute: Mode of transportation – e.g., drive, take public transportation, etc.
2. Initial commute time: Time to commute to the vertiport measured in minutes.
3. Travel distance: 10 to 49 miles.
4. Reason: Purpose for travel – e.g., work, recreation, etc.
5. Price: Price range for UAM flight.
6. Wait: Wait time – e.g., the time between arrival at the vertiport and boarding.
7. Flight time: Flight time, as defined by the time between takeoff and landing.
8. Propulsion type: Electric or hybrid.
9. Control scheme: Remotely piloted or automated.
10. PAX: Number of other passengers ranging from 2 to 5.

### ***3.2.3 Use Case 2 – Regional Air Mobility (RAM)***

The second use case considered for this research was RAM. The development of this use case relied heavily on NASA documentation and reports, to include *Regional Air Mobility – Leveraging Our National Investments to Energize the American Travel Experience*. This report, which NASA released in April of 2021, highlights how RAM will emerge and evolve within the NAS. The anticipation is that RAM will leverage existing infrastructure and aviation paradigms, slowly phasing in novel aircraft and business models that will increase the efficiency of air transportation. According to NASA's *Regional Air Mobility – Leveraging Our National Investments to Energize the American Travel Experience*, RAM allows communities to capitalize on existing investments in aviation infrastructure and maximize accessibility to air travel.

> If an affordable, efficient, robust, and environmentally friendly aircraft network were implemented across these thousands of airports, more people would be able to choose convenient air travel over cars for mid-distance trips around 50-500 miles. RAM's vision is to make these local airports the community hubs they were always meant to be, and innovative

> aircraft, operational models, and infrastructure are the keys to making that happen. (NASA, 2021b, p.4)

Moreover, the existing literature indicated that RAM would represent an affordable middle-ground in air transportation, taking advantage of more frequent trips between smaller local and/or regional airports.

> RAM focuses on building upon existing airport infrastructure to transport people and goods using innovative aircraft that offer a huge improvement in efficiency, affordability, and community-friendly integration over existing regional transportation options. These aircraft, that typically carry less than 20 passengers or an equivalent weight in cargo, are flexible in terms of where they can take off and land, even using existing runways and infrastructure to maximize compatibility with today's airports. In short, RAM provides air accessibility that is dependable, efficient, and affordable. (NASA, 2021b, p. 5)

Aircraft characteristics were another consideration when identifying a set of baseline characteristics for a RAM use case. Like UAM, RAM shows great potential to capitalize on novel aircraft and electric propulsion. These aircraft will be "community compatible," operating with minimal disruption to the communities they serve while fulfilling community needs. According to NASA's *Regional Air Mobility – Leveraging Our National Investments to Energize the American Travel Experience*, the definition of a community compatible aircraft consists of two primary characteristics:

> […] First, they are able to operate physically close to communities. This is due to characteristics like their low emissions, low noise, and steep climb/descent profiles reducing nuisance factors. Their ability to operate from short runways that can be located closer to the populations they serve is also a factor. Second, community compatibility provides overall value such that the communities served, despite some drawbacks, on average they reap a net benefit. This benefit comes primarily from increased access to air mobility for individuals and communities, so it is essential to keep operations safe and costs affordable whenever possible. (NASA, 2021, p. 5)

The research team used these concepts in addition to information from other sources to derive baseline characteristics of RAM. These characteristics defined a use case that the research team used to draft the experiment plan (Task 3) and carry out designed experiments (Task 4).

#### 3.2.3.1 *Summary of RAM Use Case Characteristics*

Based upon the literature and supporting documentation by NASA, the research team arrived at the following characteristics for a RAM use case. The characteristics shown below helped to drive the research team in developing a research plan to address a realistic use case for RAM. They also aided in steering follow-on tasks, such as Task 5 – Economic Assessment and Methodology.

1. Operation from a small airport located within a suburb of a large metropolitan area within 16 minutes of a major population center, and

2. Typical RAM trips may carry passengers between 50 and 500 miles.

3. The aircraft can operate in a manner that is compatible with the operation area – e.g., low noise, steep climb gradient, and low/no pollution.

4. The aircraft may be

    a. piloted,
    b. Remotely operated by a pilot on the ground, or
    c. Fully autonomous.
5. The aircraft may employ propulsion, consisting of –
    a. Electric propulsion, or
    b. Hybrid electric propulsion
    c. Conventional internal combustion engines

#### 3.2.3.2 *RAM – Model Use Case Assumptions*

Like the use case for UAM, the research team developed a series of rational assumptions based upon RAM characteristics and a literature review. Like the use case and scenario for UAM, these assumptions drove the development of a baseline scenario that informed the experiment plan and methodology. The following assumptions bounded the research team's RAM use case:

> *Assumption 1*: RAM may offer both (1) on demand, and/or (2) scheduled air services.
>
> *Assumption 2*: RAM fleets may consist of a mixture of internal combustion, hybrid, and electric aircraft. This assumption is based upon the notion that not every airfield from which they may operate will offer the same type of services and/or facilities. This also accounts for a "near-term" scenario that enables a RAM service provider to use existing aircraft – e.g., Tecnam P. (2012).
>
> *Assumption 3*: Aircraft may be a mixture of piloted, remotely piloted, and/or autonomous.
>
> *Assumption 4*: The use case and scenario assume that all necessary ATC services and protocols are in place to enable a larger RAM ecosystem to function – to include considerations for autonomy.

#### 3.2.3.3 *RAM – Model Use Case*

Using the general RAM characteristics and assumptions listed above, researchers developed a model use case for RAM. As with UAM, the model use case for RAM helped bound the research while providing context for the examination of key variables. This enabled a proper exploration of RAM concepts while maintaining a reasonable scope. The RAM use case is as follows:

> The RAM use case assumes both scheduled and on-demand operations from a small airport in the suburb of a larger metropolitan area. This RAM service operates a mixture of internal combustion, hybrid fuel, and electric aircraft that are designed to operate from a smaller paved runway at the local airport. The fleet consists of a series of different types of aircraft, ranging from piloted to remotely piloted and autonomous. Scheduled flights depart at regular intervals, with on-demand flights arriving and departing as needed.

#### 3.2.3.4 *RAM – Scenario*

With the model use case established, the research team developed the following scenario. Within this scenario, the team identified 12 variables for use in developing a research methodology.

> You [initial commute] to your local airport [initial commute time] away for the purpose of catching a [RAM type] flight to a nearby city [travel distance] for [reason]. The cost of this trip is anticipated to be [price], and the average departure interval is [interval] with a wait of [wait]. The flight is expected to take [flight time] on a(n) [propulsion type] aircraft that is [control scheme]. On average, you can expect to share your commute with [PAX] number of passengers.

*Variables*

1. Initial commute: Mode of transportation – e.g., drive, take public transportation, etc.
2. Initial commute time: Time to commute to the airport measured in minutes.
3. RAM type: Scheduled or on-demand.
4. Travel distance: 50 to 500 miles.
5. Reason: Purpose for travel – e.g., work, recreation, etc.
6. Price: Price range for RAM flight.
7. Interval: Arrival and departure intervals in minutes.
8. Wait: Wait time – e.g., the time between arrival at terminal and boarding.
9. Flight time: Flight time, as defined by the time between takeoff and landing.
10. Propulsion type: internal combustion, hybrid, or electric.
11. Control Scheme: Piloted, remotely piloted, or automated.
12. PAX: Number of other passengers ranging from 0 to 19.

## 3.3 Task 3 – Experiment Plan

With clear definitions, model use cases, scenarios, and variables identified, the research team developed a research plan to inform future tasks. The research plan developed for this task informed experiments carried out in Task 4. The following sections summarize key elements of the experiment plan that led to the experiments and results discussed in following sections.

### *3.3.1 Methodology*

Given the variables and use cases identified in Task 2, the research team devised a research methodology that employs a two-pronged approach to answer research questions. This approach (Figure 3), offered insight into the use cases from two perspectives, seeking insight from AAM OEMs and those who would use the systems – i.e., the “flying public.”

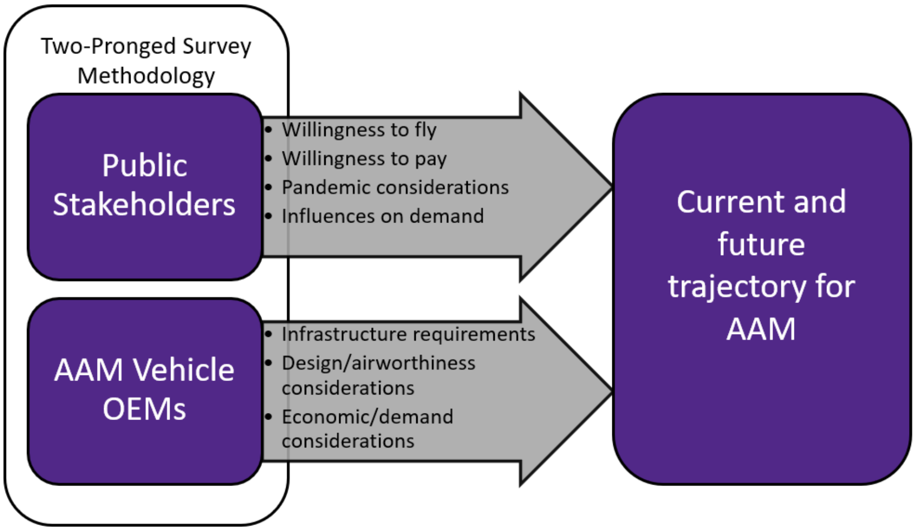


Figure 3. Two-pronged approach to exploring key variables for AAM.

More specifically, the research methodology consisted of:

1. A targeted interview for OEMs to identify important design and operational considerations for their systems and a detail, and
2. A survey aimed at addressing perceptions the public may hold regarding AAM, to include economic considerations.

The combination of a survey and interview approach offered the following capabilities when addressing the research questions:

1. It enabled the research team to address the most significant stakeholders, offering the ability to address questions regarding the growth and development of the industry.
2. This approach offered a broad reach, providing a means to gather input from different populations, people with diverse backgrounds, and those who may have different ideas concerning the development, growth, and overall viability of AAM.
3. Using a two-pronged approach also offered the ability to be thorough while building upon past research.

More importantly, this approach afforded researchers an avenue to identify factors that shape the AAM industry as well as the opinions and dispositions of those who will market and use the technology. The survey methodology addressed questions of willingness to pay/fly and other economic considerations from the standpoint of users whereas the interviews with OEMs offered insight into system design, development, target market, and challenges associated with the development of their system.

### *3.3.2 Experiment Design Overview*

The experiment, consisting of a two-pronged approach using interviews and a survey instrument, enabled the exploration of variables identified in previous tasks while simultaneously addressing guiding research questions. More importantly, the researchers designed the experiments such that they would shed light on areas of potential growth in AAM and highlight areas of future research.

The following sections offer an overview of the experiment design and provide a summary of the experimental methods used for this research.

#### 3.3.2.1 *Purpose*

The research team settled on two distinct data collection methodologies due to the need to gather data from two distinct groups – AAM OEMs and the flying public, henceforth referred to as public stakeholders, respectively. This approach allowed the research team to address focus areas regarding the current state of AAM, the direction of the industry, identify trends, and explore how the industry may evolve over time. Most importantly, this approach provided an opportunity for researchers to gather data from two perspectives. It aided in identifying areas of overlap and disconnects between the priorities of the AAM industry and public stakeholders. To that end, the study addressed the following key focus areas:

1. Willingness to fly – i.e., the likelihood that people will use AAM,
2. Willingness to pay – i.e., consumer perceptions of the value added when travelling via AAM,
3. Economic demand considerations – i.e., overall perceptions of the growth of AAM, including demand models and investments, and
4. Infrastructure requirements, to include investments.

Specific lines of questioning within the survey and/or interview instruments emphasized various aspects of AAM that were dependent upon the respondent.

#### 3.3.2.2 *Data Collection Tools*

For data collection, the research team utilized (1) a standardized interview prompt sheet, and (2) Qualtrics, a digital survey system designed for broad online distribution. The research team relied on face-to-face interviews with AAM OEMs where possible and subcontracted a distribution service, Lucid, to distribute the survey to representative survey panels. This method allowed the team to tailor data collection tools to their specific purpose while still reaching the desired populations.

#### 3.3.2.3 *Sample Populations*

The following sections provide an overview of sampling, classification criteria, and variables for each respondent group. Criteria within this section aided the research team in defining characteristics of respondent groups to ensure the collection of meaningful data.

##### 3.3.2.3.1 Public Stakeholders

For the sake of categorization, public stakeholders consist of survey respondents that make up various subsets of the “general public.” Public stakeholders represent those who might use AAM services, spending their time and money on a commute. As such, their input and overall disposition toward AAM helped shed light on how the AAM industry may evolve and to what extent potential passengers may use certain services. Of particular interest was their interest in willingness to fly/pay, opinions on noise, infrastructure, and other considerations for economic demand.

The team categorized public stakeholders as adults between the ages of 18 and 65 years of age. This broad subset provided a starting point for gathering information on overall dispositions toward AAM. The team used other variables to analyze the sample of public stakeholders by considering basic demographic information. Appendix C highlights this information within the survey questions. Lucid received survey feedback from 5,000 respondents. These respondents were part of curated respondent panels, assembled to represent a cross section of the United States.

For this study, the research team focused on collecting information regarding the following variables:

- Willingness to pay,
- Willingness to fly,
- Perceptions regarding AAM's impact on the surrounding environment – e.g., noise, pollution, traffic, "Not in My Backyard" (NIMBY), etc.,
- Willingness to use an autonomous aircraft, and
- Disposition towards public air transportation that may result from COVID-19 – e.g., willingness to use public air transport on a regular basis.

#### 3.3.2.3.2 AAM System Manufacturers (OEMs)

Input from AAM system manufacturers enabled the research team to explore questions regarding the development, use, and market considerations of AAM systems. This information, when coupled with survey data from public stakeholders, provided perspective on the direction of the industry, identified disconnects between public perceptions and industry directives, and assisted to provide context to other research questions. For this study, the team categorized system manufacturers by the following characteristics:

1. They must have been actively involved in the design, manufacture, and/or sale of AAM aircraft or associated systems,
2. Pursuing a type certificate for an AAM aircraft, and/or
3. Involved in the development of AAM infrastructure to support routine AAM operations.

These simple constraints allowed the research team to develop a series of interview questions for AAM system manufacturers. These interview questions addressed numerous variables, which include:

1. Considerations for passengers – e.g., cost, willingness to pay, service model, etc.,
2. Infrastructure needs/considerations,
3. Overall system use case – e.g., air taxi/UAM, and/or RAM,
4. Target market(s) and/or operating environments,
5. Considerations/concerns for design and airworthiness, and
6. Considerations and concerns regarding technological gaps, to include Detect and Avoid, reliability of autonomy, and noise pollution.

### 3.3.2.4 *Limitations of Methodology*

While the two-pronged approach to addressing public stakeholders and AAM system manufacturers allowed the research team to address many critical variables associated with AAM system development, use cases, and economic considerations, the selected methodologies had some limitations. These limitations stem from such things as the availability of samples within given populations and the time in which the research team was able to collect data. However, the team mitigated these limitations by using a survey distribution service to obtain a census grade sample, communication with AAM OEMs, and the construction of the interview and survey questions themselves.

Limitations of the chosen methodologies were as follows:

1. Survey answers are dependent upon the participants' knowledge and understanding of the topics presented.
2. There may be biases from certain survey participants that could skew results – e.g., RAM/UAM OEMs or those with a vested interest in the technology.
3. The short time available for this task may serve to limit the reach of the survey.
4. The number of OEMs solicited for interviews is comparatively small. This was due to time constraints.

## 3.4 Task 4 – Conduct Designed Experiments

Following the development of the experiment plan within Task 3, the research team carried out designed experiments in Task 4. At the conclusion of this task, the research team consolidated data from the survey and interviews to draw conclusions from the data. This section offers an overview of the data and results.

### *3.4.1 Overview – Survey*

The following sections provide an overview of the survey instrument used to identify aspects of public perception, willingness to pay, willingness to fly, and capture general dispositions toward various aspects of AAM. The research team chose a survey instrument as it allowed a more direct approach to answering aspects of the research questions that went beyond the baseline literature review, connecting literature findings to real-world attitudes, perceptions, and economic analysis deliverables. What follows is an overview of the survey description, data collection and sampling, data preparation, basic demographic information, and a brief discussion of the limitations of the survey instrument.

#### 3.4.1.1 *Survey Description*

The survey also targeted the top 30 potential AAM site locations (Table 2) described in the ASSURE A36 Site Suitability Analysis. The ASSURE A36 research team found the locations listed in Table 2 to be particularly suitable for the growth and development of AAM over time. The team chose these sites based upon extensive research and an economic analysis as part of the ASSURE A36 research effort. While the survey did not target these areas exclusively, they allowed the exploration of connections between ASSURE A41 and complimentary ASSURE research.

Table 2. ASSURE A36 AAM Site Suitability – Top 30 Locations for AAM Growth.

| Rank | Metropolitan Statistical Area |
|---|---|
| 1 | New York-Newark-Jersey City, NY-NJ-PA Metro Area |
| 2 | Los Angeles-Long Beach-Anaheim, CA Metro Area |
| 3 | Dallas-Fort Worth-Arlington, TX Metro Area |
| 4 | Boston-Cambridge-Newton, MA-NH Metro Area |
| 5 | San Jose-Sunnyvale-Santa Clara, CA Metro Area |
| 6 | Orlando-Kissimmee-Sanford, FL Metro Area |

| | |
|---|---|
| 7 | Detroit-Warren-Dearborn, MI Metro Area |
| 8 | Miami-Fort Lauderdale-Pompano Beach, FL Metro Area |
| 9 | San Francisco-Oakland-Berkeley, CA Metro Area |
| 10 | Columbus, OH Metro Area |
| 11 | Minneapolis-St. Paul-Bloomington, MN-WI Metro Area |
| 12 | Chicago-Naperville-Elgin, IL-IN-WI Metro Area |
| 13 | Bridgeport-Stamford-Norwalk, CT Metro Area |
| 14 | Washington-Arlington-Alexandria, DC-VA-MD-WV Metro Area |
| 15 | Houston-The Woodlands-Sugar Land, TX Metro Area |
| 16 | Riverside-San Bernardino-Ontario, CA Metro Area |
| 17 | Philadelphia-Camden-Wilmington, PA-NJ-DE-MD Metro Area |
| 18 | Indianapolis-Carmel-Anderson, IN Metro Area |
| 19 | Seattle-Tacoma-Bellevue, WA Metro Area |
| 20 | Allentown-Bethlehem-Easton, PA-NJ Metro Area |
| 21 | Atlanta-Sandy Springs-Alpharetta, GA Metro Area |
| 22 | Madison, WI Metro Area |
| 23 | Providence-Warwick, RI-MA Metro Area |
| 24 | Poughkeepsie-Newburgh-Middletown, NY Metro Area |
| 25 | Hartford-East Hartford-Middletown, CT Metro Area |
| 26 | Pittsburgh, PA Metro Area |
| 27 | Wichita, KS Metro Area |
| 28 | Portland-Vancouver-Hillsboro, OR-WA Metro Area |
| 29 | Cleveland-Elyria, OH Metro Area |
| 30 | Milwaukee-Waukesha, WI Metro Area |

Figure 4 offers a snapshot of the survey distribution. As shown in **Error! Reference source not found.**, the distribution of the survey correlates with the top 30 AAM sites in addition to surrounding areas, covering both coasts, southern regions of the country, and the Midwest.

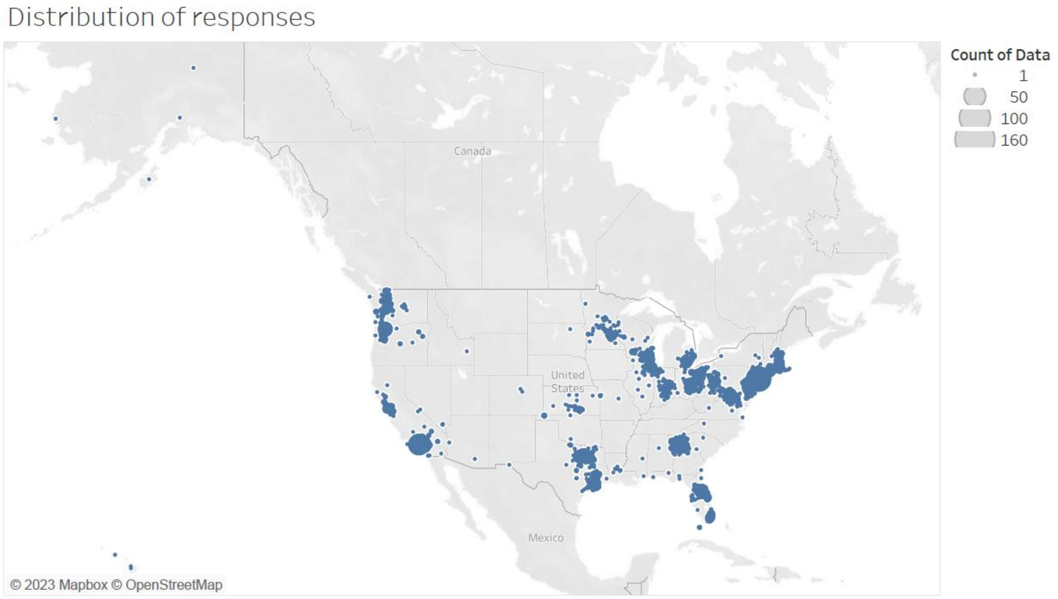


Figure 4. Survey Respondent Locations.

This segment of the experiment captured the viewpoint of prospective passengers to determine their perceptions of AAM, with an emphasis on RAM and UAM (air taxi) modalities. The Qualtrics survey was "live" via Lucid's distribution platform for approximately two weeks, capturing responses from 5,220 respondents, exceeding the team's initial goal of 5,000 responses. In addition to capturing responses from the top 30 AAM site locations identified in ASSURE A36, the team ensured survey distribution such that it captured a representative sample of the US population. Lucid's services structures the survey distribution such that it covered key demographics throughout a variety of populations, to include US census income brackets, ethnic groups, respondent ages, gender, education level, employment status, pilot certifications, employment locations, and marital status.

### 3.4.1.2 *Overview of Lucid – Data Collection and Sampling*

The research team distributed a survey to gather data regarding views, opinions, and willingness to fly/pay for AAM. As indicated in Section 3.3.2.2, the team subcontracted Lucid to distribute the survey. Lucid provided by Cint, offered a reliable method for distributing the survey across the United States, ensuring broad coverage and representative sampling.

Lucid offered a comprehensive suite of tools and resources for data collection (CINT, 2023). and The A41 research team utilized Lucid services to distribute customized research questions in scope for this work. The team worked with Lucid project managers to communicate the scope of the project and provided necessary data to inform sampling and data collection methods.

Lucid offered advanced targeting and sampling capabilities to reach specific audiences, and offered services designed specifically for academic research (CINT, 2023). Lucid services offered a large consumer panel network (CINT, 2023) and assisted the A41 research team to target the appropriate audience for this online survey through defined demographics based on various criteria such as age, gender, location, and income.

Once the research team created the survey using Qualtrics, Lucid distributed the survey via their panels. This flexible approach allowed the A41 research team to reach their target audience of over 5,000 respondents through various channels.

In reference to data collection, the research team used Qualtrics tools to obtain real-time monitoring of data collection, tracking response rates and view results in via dashboards. Additionally, the research team was able to extract the data from Qualtrics dashboard for data analytics. The research team used these tools and coordinated with Lucid to ensure that sample quotas were met by the required deadlines.

#### 3.4.1.3 *Data Preparation*

Raw data received from Qualtrics and Lucid was cleaned and filtered. For this process, data was first imported into STATA 17. Sundry variables related to data recording such as Progress, IP Address, and Q_Recapctascore were dropped from the analyses. Qualtrics related variables were also removed. The raw data was collected with column names as question numbers. To aid contextualization, these questions numbers were renamed into variables such as age, gender, race, and education. A data dictionary was generated to map these new variable names to the respective questions. If respondents chose "Prefer not to answer" in any of the questions, the responses were re-coded as missing to make the analysis process smoother.

#### 3.4.1.4 *Survey Demographics*

The following section provides a demographic summary of the participants who responded to the survey. The team cleaned and sorted this data to draw conclusions from respondents. All demographic data shown is within its respective category, and all categories correspond to survey questions within Appendix C.

##### 3.4.1.4.1 Age

Survey respondents included categories for five age ranges, which included the following distribution: 18-24 (12.7%), 25-34 (25.3%), 35-44 (21.6%), 45-54 (26.8%), 55-64 (8.9%) and an additional 4.7% with no recorded response. Although the exact mean age cannot be determined, an approximate mean age based on the response categories and counts would yield an approximate mean age of 39.1 years. Figure 5 highlights the age distribution of survey respondents.

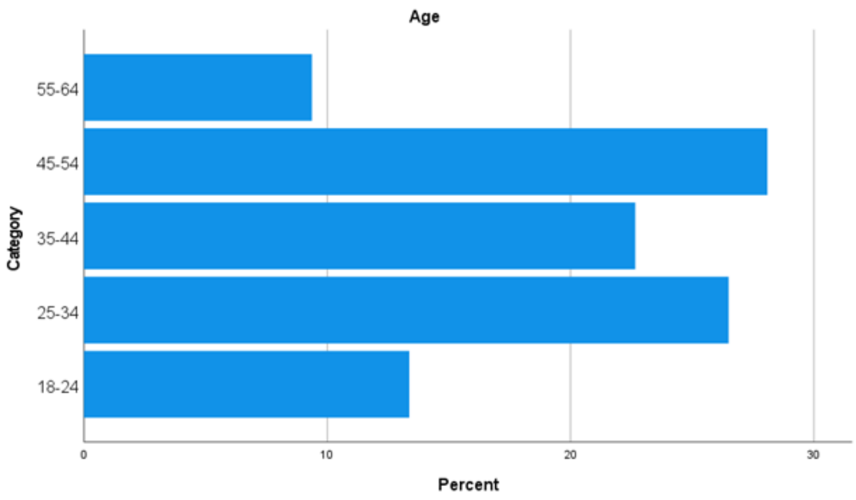


Figure 5. Respondent Age Distribution.

### 3.4.1.4.2 Gender

The survey included a question on gender. Out of the 5208 respondents who chose to answer this question, 43.2% responded Male, 55.9% responded Female, and 0.7% reported that they identified with 'non-binary/third gender'. The option for 'prefer not to answer,' was filtered during data cleaning. These were grouped under "other," as they constituted a very small segment of the data set. Figure 6 shows the gender distribution following the sorting/cleaning of the dataset.

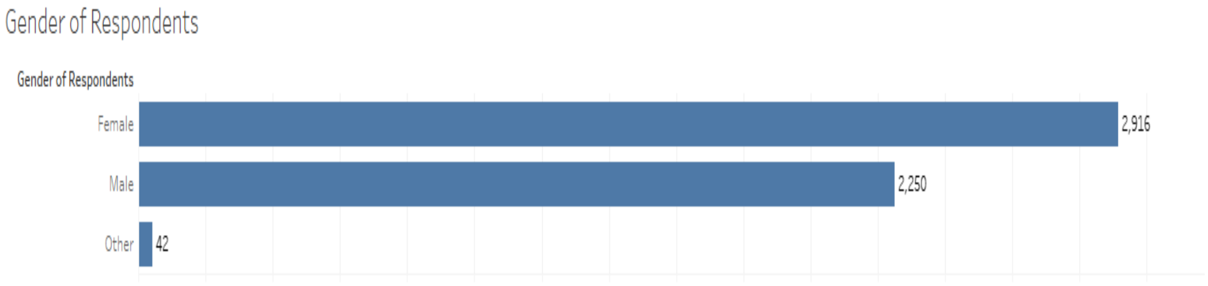


Figure 6. Respondent Gender Distribution.

### 3.4.1.4.3 Race

The survey data included responses on race and the following distribution: American Indian or Alaska Native (1.1%), Asian (5.2%), Black or African American (16.2%), Hispanic/Latinx (8.6%), Native Hawaiian or Other Pacific Islander (0.3%), White (67.1%), Other (1.2%), and Prefer Not to Answer (0.4%). Figure 7 shows a breakdown of this distribution.

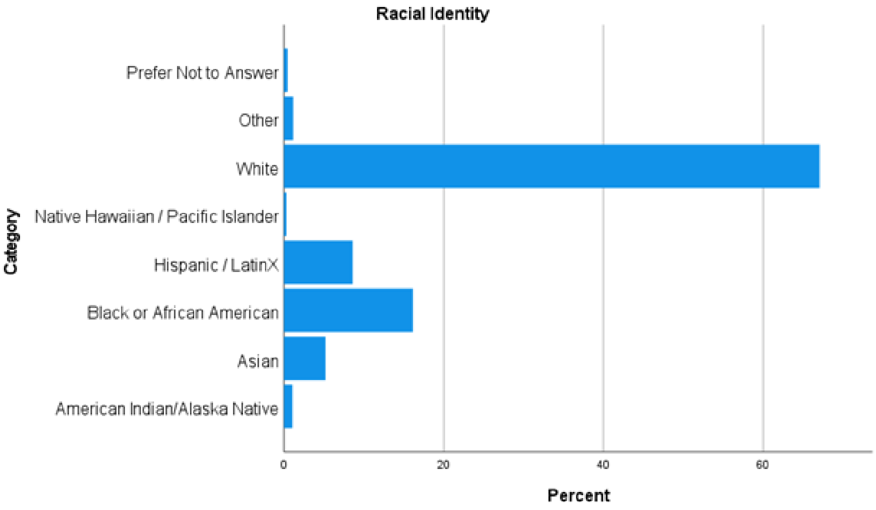


Figure 7. Respondent Race Distribution.

### 3.4.1.4.4 Education

The distribution of education level among survey participants are as follows; Less than high school diploma (3.7%), High school degree or equivalent (24.1%), Vocational/Trade Certification (3.8%), Some college/no degree (17.7%), Associate's degree (9.6%), Bachelor's degree (25.3%), Master's degree (11.2%), Professional Degree (MD/DDS/DVM, 1.9%), Doctorate (2.1%), and missing response (0.6%). Figure 8 shows a breakdown of the distribution of the highest level of education of the respondents.

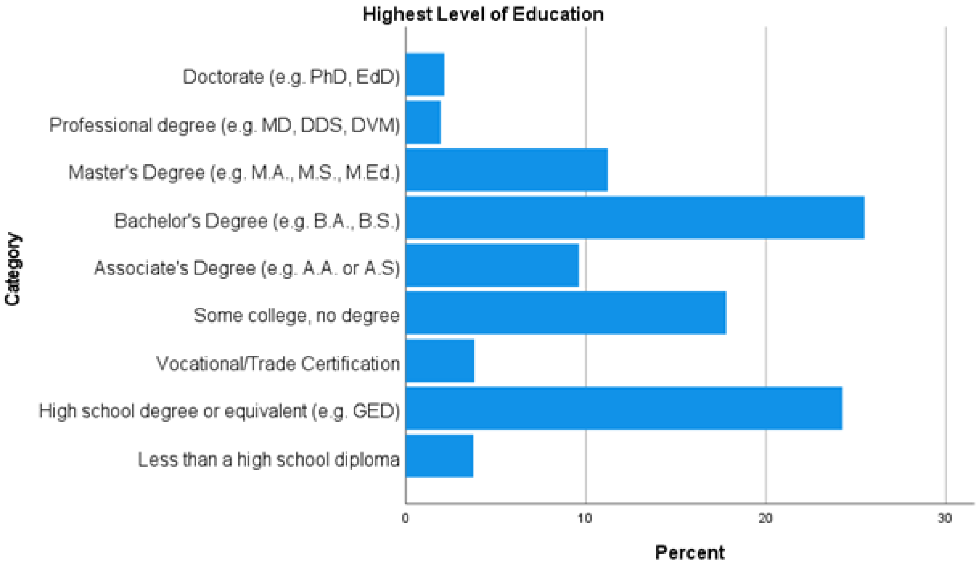


Figure 8. Respondent Level of Education.

### 3.4.1.4.5 Pilot Ratings

The survey included one binary question on whether the participants held pilot ratings. The distribution included 6.8% of those who held some type of pilot rating (helicopter, fixed-wing, UAS), 92.3% who non-pilots were, and 0.9% missing responses. Figure 9 shows respondents with Pilot Certificates.

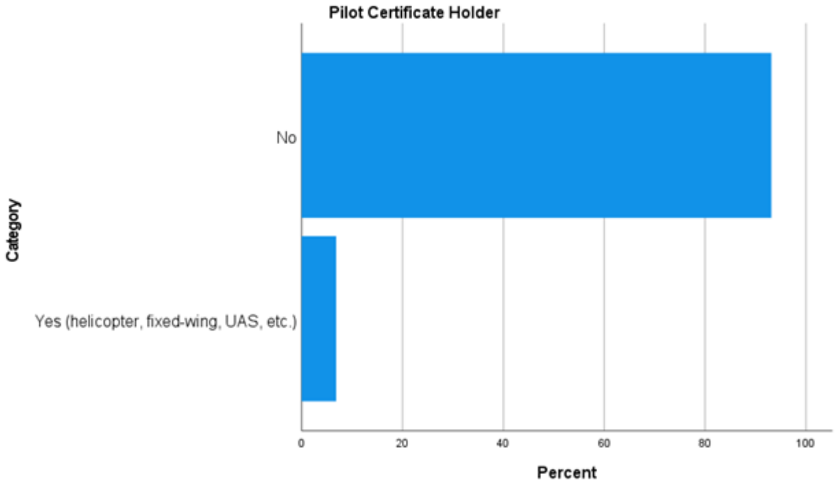


Figure 9. Respondents with Pilot Certificates.

### 3.4.1.4.6 Income

The survey included one question including twelve annual income ranges, commensurate with US census brackets. The responses are as follows; Less than $20,000 a year (15.8%), $20,000 to $34,999 (13.6%), $35,000 to $49,999 (11.9%), $50,000 to $74,999 (16.7%), $75,000 to $99,999 (12.5%), $100,000 to $124,999 (8.2%), $125,000 to $149,999 (7.4%), $150,000 to $174,999 (3.5%), $175,000 to $199,999 (1.9%), $200,000 to $224,999 (1.3%), $225,000 to $249,999 (1.2%), greater than $250,000 (3.0%), and 3.1% missing responses. Figure 10 shows the distributions for respondent income.

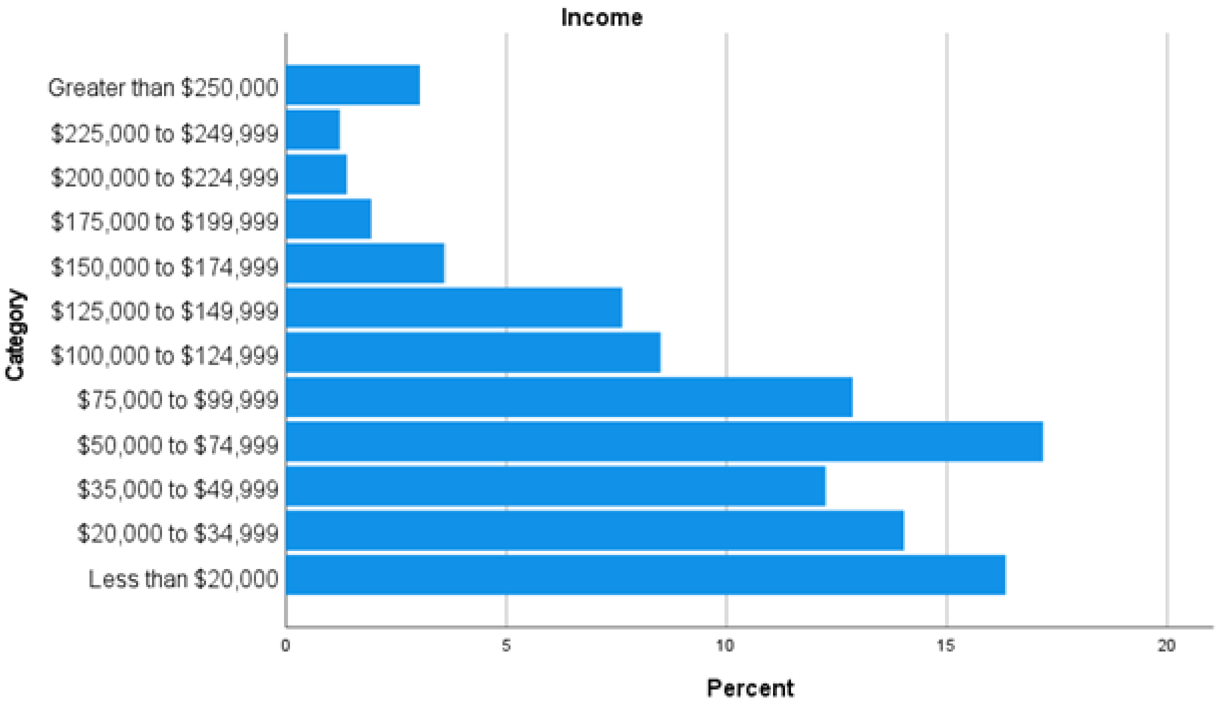


Figure 10. Respondent Income Distribution.

### 3.4.1.4.7 Employment

Participants reported the following information for employment status; Full-time (40 or more hours per week, 48.9%), Part-time (Less than 30 hours per week, 11.8%), Unemployed and looking for work (6.6%), Unemployed and not looking for work (2.0%), Student (4.2%), Retired (9.6%), Homemaker (5.7%), Self-employed (5.7%), Unable to work (5.0%), Prefer not to answer (0.7%). Figure 11 shows the distribution of respondents' employment status.

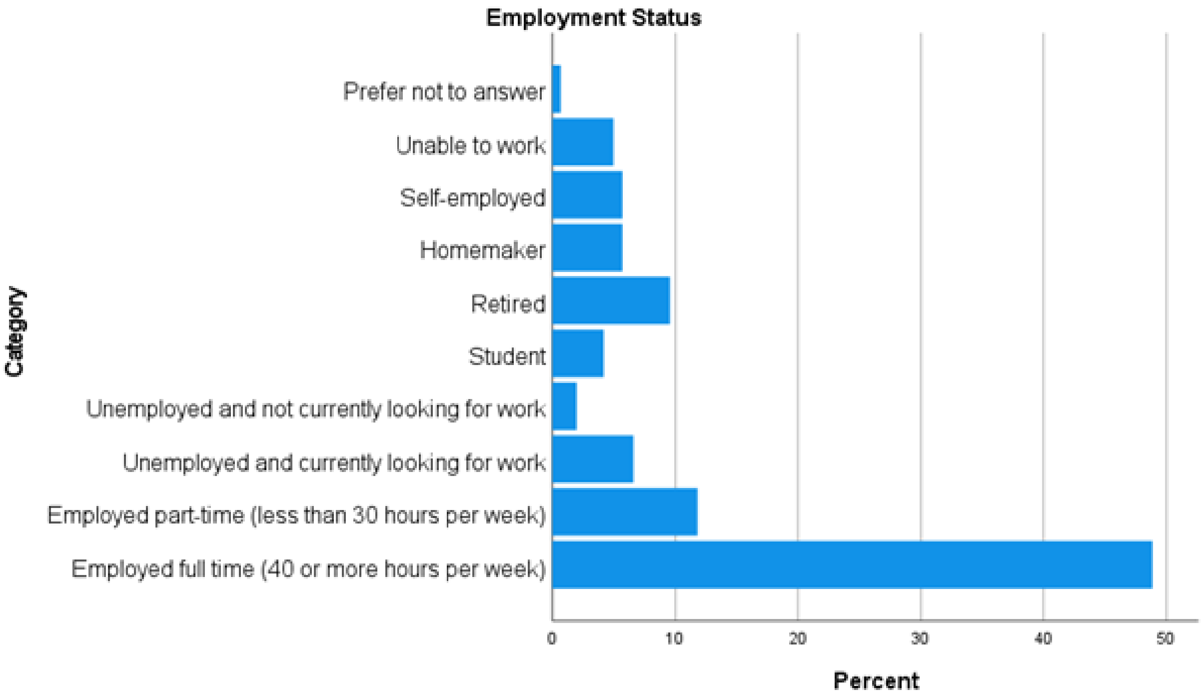


Figure 11. Respondent Employment Status.

### 3.4.1.4.8 Employment Location

Considering the work location of the participants, they responded as follows; Work from home (18.0%) Work in an office (28.6%), Hybrid (combination of office and remote work, 12.2%), Other (outside of traditional home or office, 10.6%), Not applicable (28.8%), and prefer not to answer (1.8%). Figure 12 shows respondents' responses regarding their employment location. These responses provide context for drawing conclusions regarding daily commutes.

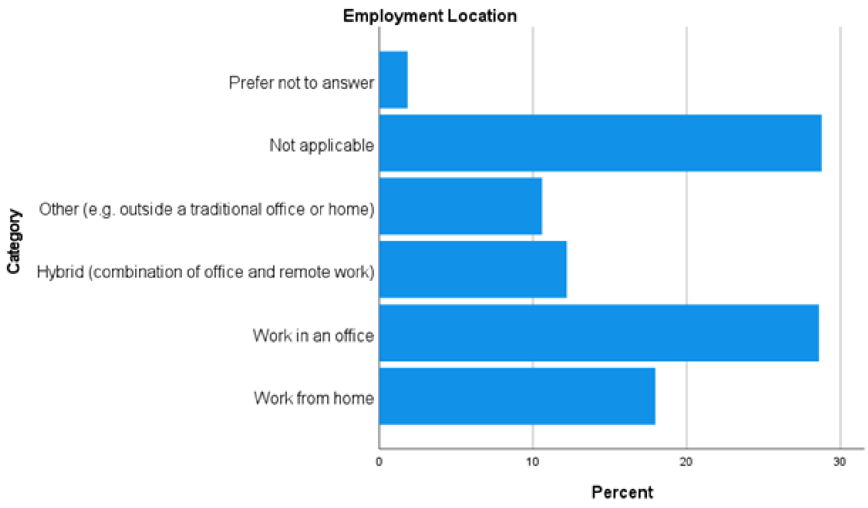


Figure 12. Respondent Employment Locations.

### 3.4.1.4.9 Marital Status

The participants responded in the following with respect to their marital status; Single (never married, 34.1%), Married on in a domestic partnership (51.0%), Widowed (3.3%), Divorced or separated (10.6%), Prefer not to answer (1.0%). Figure 13 shows the distribution of respondents' answers to questions regarding marital status. This question helped to provide a more detailed understanding of respondents and their needs regarding transportation and travel. Figure 13 shows the distribution of respondents' marital status.

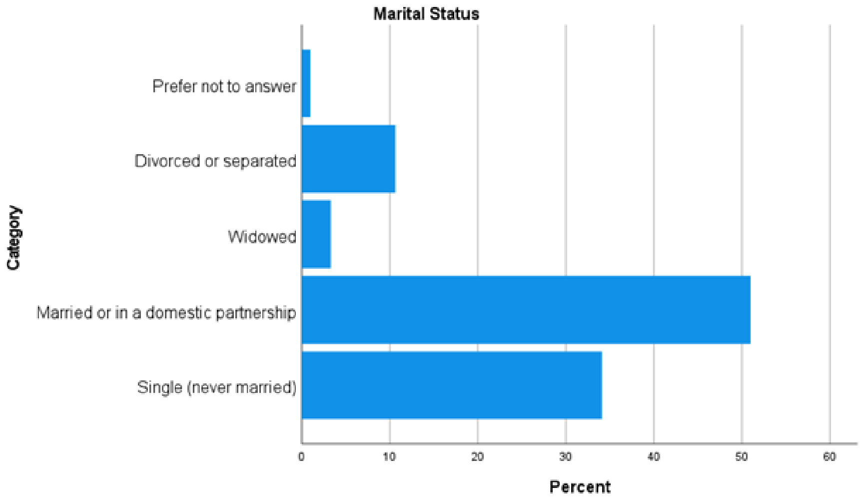


Figure 13. Respondent Marital Status.

#### 3.4.1.5 *Limitations*

The research team acknowledges several limitations within this study. While every attempt was made to obtain a representative sample, limitations still exist that directly impacted the data. The following is a list of limitations the research team acknowledges within this study:

1. Potential for sample bias.
2. Income categories were restricted to census brackets.
3. Race, gender, education, and income brackets may not be fully represented due to sample size.
4. The sample had to be generalized.

### *3.4.2 Overview – Interviews with OEMs and AAM Stakeholders*

The research team conducted interviews with AAM OEMs in-person at the Association for Uncrewed Systems International XPONENTIAL trade show in April of 2022 with additional interviews conducted in the following weeks. Researchers conducted follow-on interviews online via the Zoom teleconference application. The research team secured a total of seven interviews with seven different AAM stakeholders. Table 3 provides a general classification of interview respondents for this research.

Table 3. AAM OEM Interview Respondent Classifications.

| AAM OEM Classification | Number |
|---|---|
| Representative of State DOT | 1 |
| AAM cargo/logistics | 2 |
| AAM passenger – UAM/RAM | 4 |

Interviews consisted of sixteen questions that targeted various aspects of AAM. The goal of these questions was to identify commonalities and differences between OEMs and AAM stakeholders regarding their systems, approaches to common industry problems, and general disposition toward autonomy and regulations.

All interview respondents requested to remain anonymous. As such, the research team aggregated and anonymized respondent answers to ensure anonymity. The research team then distilled the results of the interviews into general themes that emerged within respondents' answers. These themes make up the primary data set for the interview portion of the experiment.

### *3.4.3 Discussion of Results*

The following sections reflect conclusions drawn from survey data. The summarized findings relate to the impact of COVID-19 on respondents' attitudes toward flying and general disposition toward other aspects of AAM. These findings include an exploration of the effect of current commute and transportation modes on attitudes toward AAM. These results also highlighted potential areas of further exploration, including a need for a more granular exploration of differences between metropolitan areas and general perception/understanding of AAM overall. The following discussion references questions and responses used for this analysis by question number. Appendix A provides a reference for the exact wording of the questions and responses as posed in the survey. Throughout the analysis of survey results, the dependence (in an observational, not a causal sense) of various variables on one another is assessed through the use of $\chi^2$ testing to reject the null hypothesis (i.e., the hypothesis that categorical variables are independent). For presented figures making such an assessment, the p value and ratio of $\chi^2$ value to the critical $\chi^2$ value for $p = 0.05$ (denoted $\chi_c^2$) are reported. Note that in many cases, the null hypothesis can be rejected so strongly that the calculated p value is smaller than the machine precision of MATLAB (the tool used to perform the computations). In this case, the p value is reported as 0 and the $\chi^2$ ratio gives an indication of the statistical degree of certainty with which the variables can be said to depend on one another.

#### 3.4.3.1 *Effect of COVID-19 on End-User Attitudes Toward AAM*

One of the primary research questions was "Will [the potential for large UAS in carrying passengers in the US and the likely locations of large UAS to meet demand and growth of air transportation over a period of 10 years] change significantly following the recovery from COVID-19?" Several questions from the survey provided information which helped develop a response to this research question. The team accomplished this by correlating the willingness of potential passengers to use and pay for air taxi and RAM services with their comfort level with COVID-19 associated risks.

Researchers developed a metric to assess the effect of COVID on respondents' attitudes toward flying using the responses from questions 25 and 27 which assess pre-COVID and post-COVID comfort flying commercially respectively. The developed metric indicates whether respondents' comfort level flying commercially increased, decreased, or remained constant (neutral toward COVID) with the onset of the COVID-19 pandemic. Note the survey captured responses in January of 2023 and the question specifically asks about current concerns relative to COVID. This discussion references this as the "COVID effect" throughout this report. Figure 14 displays the distribution of the COVID effect of all the respondents who indicated (by their answer to question 26) that COVID had affected their willingness to fly commercially. This includes approximately 44% of the total survey respondents. Despite indicating (by their answer to question 26) that COVID had affected their willingness to fly, approximately 45% (of the group that stated COVID had affected their willingness to fly) indicated (by their responses to questions 25 and 27) that their comfort level flying was currently (i.e., as of January 2023) the same as prior to the pandemic. This could indicate that the comfort levels of those respondents, while initially affected by the pandemic, had already recovered to pre-COVID levels prior to the survey distribution. Most of the remainder (~43%) had a decreased comfort level flying due to COVID. On the surface, this appears to suggest that the recovery from the COVID-19 pandemic could have a significant impact on the willingness of potential passengers to use AAM transport services. Further discussion below explores this hypothesis.

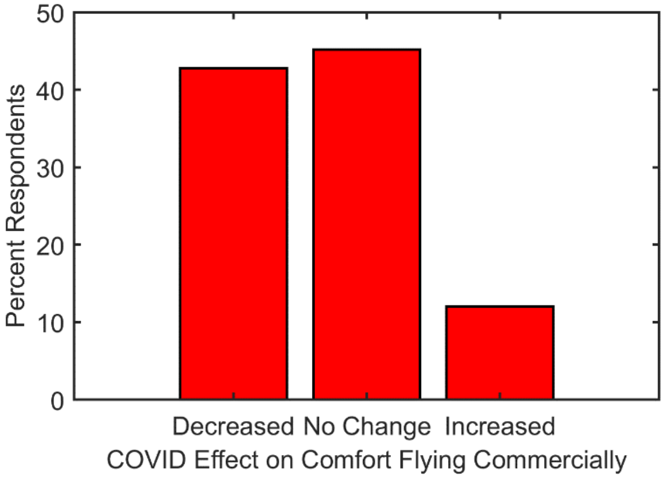


Figure 14: Distribution of effect of COVID on respondents' comfort flying commercially (2285 responses, those of respondents who indicated COVID-19 had affected their willingness to fly commercially, included).).

The observant reader will note that questions 25 and 27 specifically ask about willingness to fly on a commercial airline. One must give some justification to apply the developed COVID effect metric to air-taxi and RAM services. This justification exists in the strong relationship between the answers of individual respondents to question 27, which asks about post-COVID comfort flying commercially and question 28, which asks about post-COVID comfort flying on a small (4-6 passenger) aircraft. Figure 15 illustrates the relationship of respondents' answers to these two questions. While attitudes are not identical, the match is very strong.: $p = 0$, $\chi^2/\chi_c^2 = 77.1$ This relationship justifies the use of the COVID effect metric to inform research questions regarding air-taxi and RAM services.

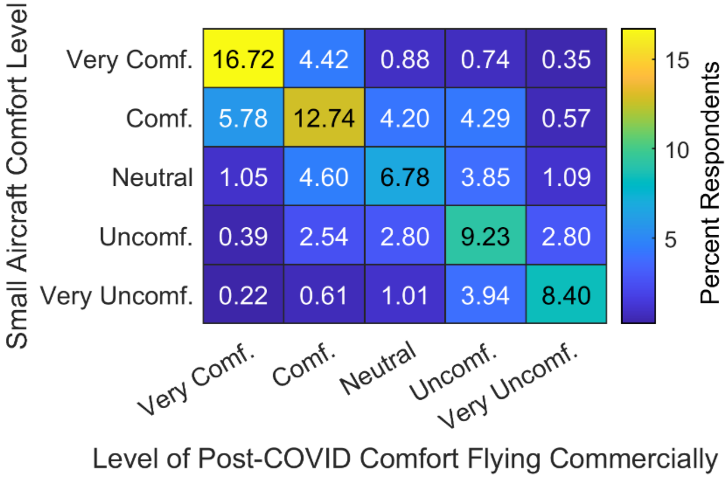
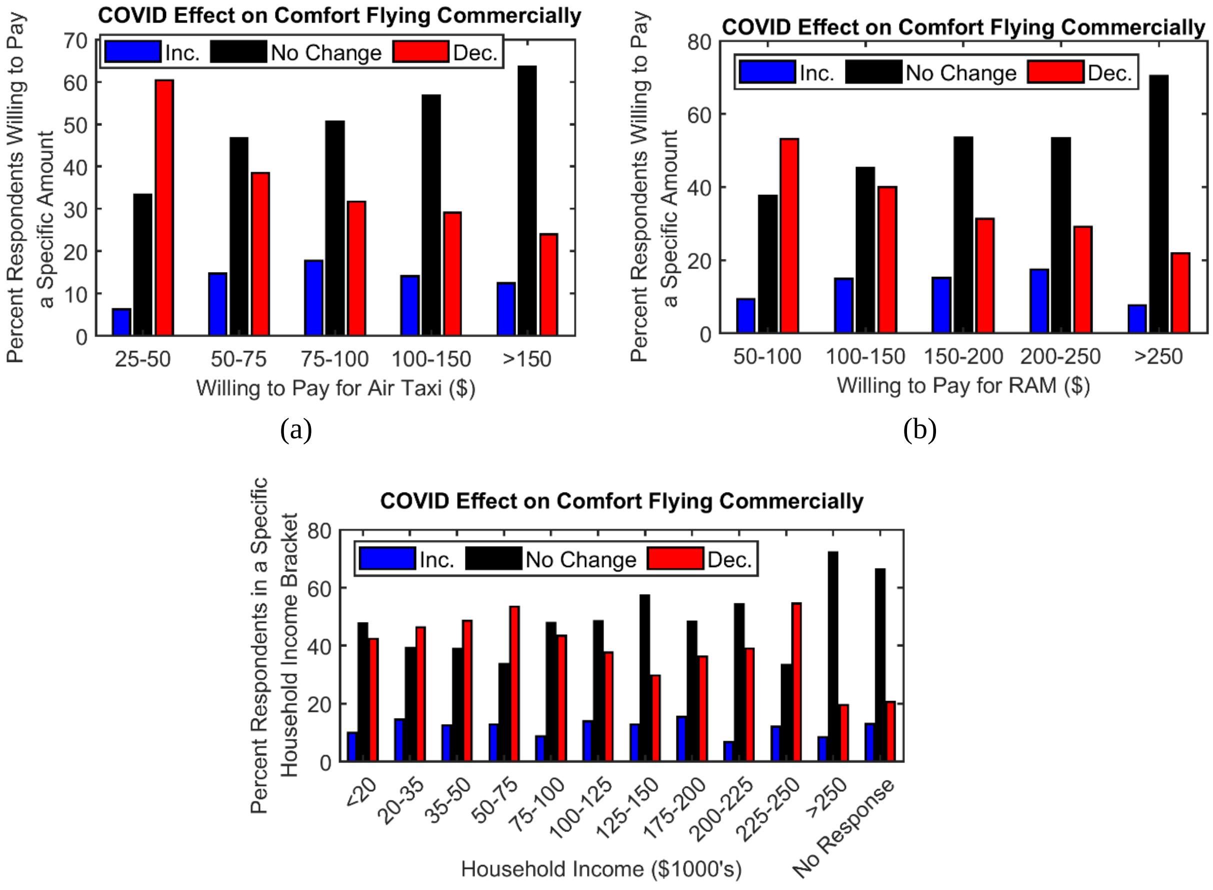


Figure 15: Relationship between individual respondents' indicated level of comfort flying commercially and in a small (4-6 passenger) aircraft post-COVID (2285 responses, those of respondents who indicated COVID-19 had affected their willingness to fly commercially, included).

The foregoing discussion and presented results suggest there could be a strong impact of recovery from the pandemic on potential end-user willingness to use AAM transport services. However, the likely initially high cost and limited-service options and volume suggest that the general population will not be first adopters. This assumption was also documented in research comparing AAM service to that of Uber Black, which offers fares ranging from \$120-\$180 for 70–150-minute trips (KPMG, 2019). Figure 16 displays relationships between COVID effect and categories of respondents who are likely to be first adopters, namely, those who are from high-income households (as per their response to question 6) and those who expressed a willingness to pay more (per trip) for air-taxi and RAM services to save time (as per their response to questions 47 and 39 respectively). The statistics describing the variable dependence for parts a, b, and c, are $p = 0$, $\chi^2/\chi_c^2 = 9.36$, $p = 0$, $\chi^2/\chi_c^2 = 6.03$, and $p = 3.45e\text{-}10$, $\chi^2/\chi_c^2 = 2.65$, respectively. It should be noted that when asking questions about non-existent services (e.g., air taxi) it can be difficult to separate respondents' willingness to pay (or anticipated willingness to pay) from ability to pay. As this is a fine distinction which may often come down to respondents' interpretation of the questions, the reader is referred to Appendix C which contains the exact text of the questions as presented to the respondents. Figure 16c shows that all income brackets above the \$50k-\$75k bracket (except for the \$225k-\$250k bracket) reported higher percentage of respondents with no change in their level of comfort flying commercially due to COVID than the lower income brackets. The maximum percentage of respondents reporting "no change" (72%) coincides with the highest income bracket. As the initially high cost of AAM transport services is likely to make them inaccessible to lower income brackets for a time, the likely first adopters will be those from households with higher income. Thus, the observed trend suggests that whatever the overall effect of COVID on potential passengers' willingness to use AAM transport services, it did not appear to have a strong effect on first adopters' attitudes. Figure 16a and b further support this assessment of likely first adopters' attitudes. There is a strong trend of the COVID effect metric with willingness to pay more for air-taxi and RAM services if they save time. Over 60% and 70% of respondents (for air-taxi and RAM respectively) who expressed willingness to pay the most for AAM services had a COVID effect metric of "no change."



(a) (b)

(c)

Figure 16: Relationship of COVID effect to variables likely related to being a first-adopter of AAM transport services: (a) Amount willing to pay per trip for air-taxi services if they save time, (b) amount willing to pay per trip for RAM services if they save time, (c) household income.

Further insight into the effect of the COVID-19 pandemic on the attitudes of potential passengers toward AAM transport services can be gained by examining the relationship of post-COVID comfort level flying commercially (question 27), and on a small (4-6 passenger) aircraft (question 28) with level of comfort with piloted (question 29), remotely-piloted (question 30), and autonomous (question 31) aircraft (see Figure 17). The statistics describing the variable dependence for parts a through e are $p = 0$, $\chi^2/\chi_c^2 = 63.0$, $p = 0$, $\chi^2/\chi_c^2 = 163$, $p = 0$, $\chi^2/\chi_c^2 = 76.5$, $p = 0$, $\chi^2/\chi_c^2 = 106$, $p = 0$, $\chi^2/\chi_c^2 = 64.4$, and $p = 0$, $\chi^2/\chi_c^2 = 97.6$, respectively. The results indicated that a significant majority of respondents who are very comfortable flying commercially, with respect to COVID, are also comfortable with flying in remotely piloted and autonomous vehicles (though this effect is tempered somewhat for small aircraft). This trend is even clearer for those who are very uncomfortable, with large percentages also being uncomfortable with remotely piloted, autonomous, and surprisingly, even piloted aircraft. These results, especially the last, may suggest that respondents do not clearly distinguish between different perceived risks (i.e., from automation and/or from COVID) when flying. This conclusion further supports the results shown in Figure 18 ($p = 0$, $\chi^2/\chi_c^2 = 48.8$). This figure correlates respondents' comfort level flying commercially prior to the COVID-19 pandemic (question 25) with their comfort level flying in an autonomously piloted aircraft (question 31). In contrast to Figure 17a, respondents who indicated a high-level of comfort flying commercially, were divided on their comfort level with autonomously piloted flights. On the other hand, those who are very uncomfortable with commercial flying (i.e., they perceived a risk, even prior to the pandemic) broadly indicate commensurate levels of comfort with autonomous flights (i.e., another perceived risk). If this hypothesis is accurate, it suggests that those with significant concerns about COVID as it relates to aviation safety are also those with concerns about increased autonomy. It would follow that COVID would not have as strong an effect on the attitudes of likely users of air-taxi/RAM services as those of the general population. This further supports the results above in indicating there may not be a significant effect on AAM demand (at least from first adopters) due to recovery from the COVID-19 pandemic.

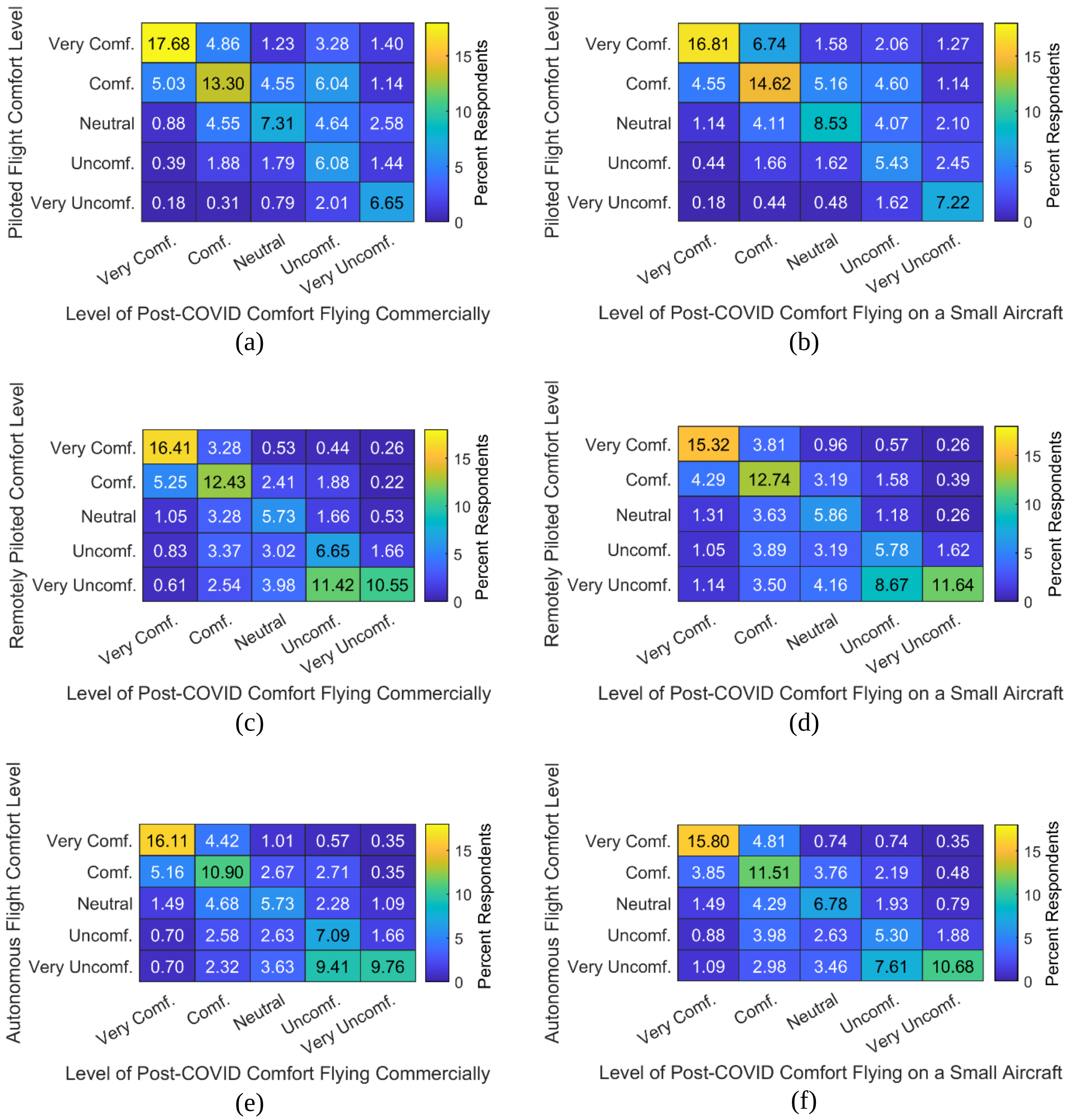


Figure 17: Relationship between level of post-COVID comfort flying both commercially (a, c, and e) and in a small (4-6 passenger) aircraft (b, d, and f) and comfort flying in a piloted (a and b), remotely piloted (c and d), and autonomous (e and f) aircraft.

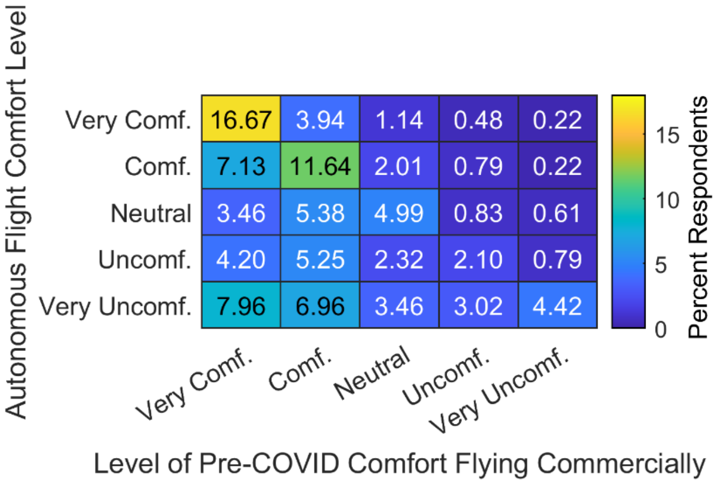
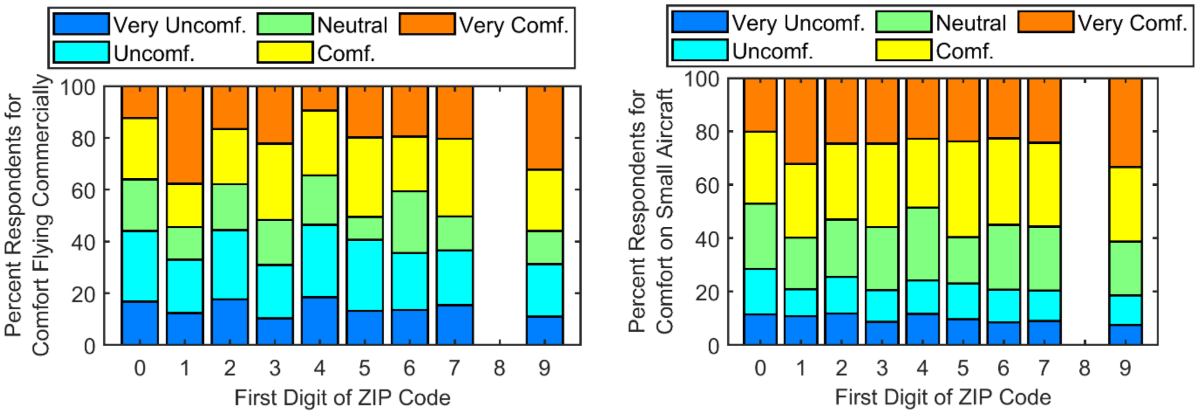


Figure 18: Relationship between level of pre-COVID comfort flying commercially and comfort flying in an autonomous aircraft.

#### 3.4.3.2 *Effect of Respondent Location on COVID-19*

Given the highly coupled nature of the overall AAM problem (technically, logistically, UTM-perspective, and demand), implementation in (and between) each metropolitan area will likely be unique. Thus, it is of interest to examine the effect of location on the attitudes of potential AAM end users regarding the COVID-19 pandemic, as it relates to flying and a general analysis of nationwide trends was undertaken as part of this study. A site-specific analysis should certainly be conducted for each MSA prior to rolling out AAM services in the area. Figure 19 displays the post-COVID comfort level of respondents flying (both commercially, Figure 19a, p = 2.99e-13, $\chi^2/\chi_c^2 = 2.75$, and in a small aircraft, Figure 19b, p = 5.13e-8, $\chi^2/\chi_c^2 = 2.04$) sorted by the first digit of the ZIP code they provided on the survey (question 10). The United States Post Office website clearly defines these regions in a map which can be found at the US Postal Service's website (US Postal Service, n.d.). Note that the survey recorded very few responses from ZIP codes beginning with "8". Since there was insufficient data for a statistically significant sample, the team omitted these results from this analysis. Overall, when classified in this fashion, there was not a significant variation in comfort levels with location. There were slightly higher percentages of respondents from ZIP codes beginning with 1 and 9 which are very comfortable flying (both commercially and in a small aircraft). These ZIP code regions include New York city and Los Angeles MSAs, both considered strong candidate locations for early roll-out. While these population centers make up a small geographical portion of the large ZIP code regions in this analysis, the high population of these areas resulted in significant responses from these MSAs (as defined by ZIP code lists found in New York City Zip Codes, n.d.; Communities by Zip Code Los Angeles County, 2023a; Communities by Zip Code Los Angeles County, 2023b). Specifically, 38.6% of all respondents with a ZIP code beginning with "1" were located in the New York city area and 39.4% of all respondents with a ZIP code beginning with "9" were located in the Los Angeles area. This could indicate that populations in these MSAs would be more receptive and willing to use air taxi and RAM services than the general American public in the post-COVID-19 pandemic world. That said, the trend is not strong, especially for small aircraft.



(a) (b)

Figure 19: Relationship between post-COVID comfort level and location (grouped by first ZIP code digit) for (a) commercial flights, and (b) small aircraft flights.

While the survey captures the above trend accurately, the results shown in Figure 20 suggest that the increased comfort with flying post-COVID for respondents with ZIP codes beginning with 1 or 9 may not actually be related to COVID at all. Specifically, Figure 20 plots the COVID effect metric (previously defined, see Figure 14 discussion) of respondents from each ZIP code group. The statistics describing the variable dependence are $p = 0.0659$, $\chi^2/\chi_c^2 = 0.959$. Briefly, this indicates whether respondents' comfort level flying commercially increased, decreased, or remained the same relative to their pre-COVID comfort level. An examination of this metric shows that the differences between ZIP code areas are minimal. This is demonstrated by the lack of ability to reject the null hypothesis (i.e., that variables are independent) at a $p = 0.05$ level. Figure 21 displays the relationship between responses to Question 25 (i.e., pre-COVID comfort flying commercially) and respondent ZIP code. Both ZIP code areas 1 and 9 have higher than average levels of pre-COVID comfort flying commercially, especially at the "very comfortable" level. This trend is statistically significant, as indicated by $p = 1.37\text{e-}5$ and $\chi^2/\chi_c^2 = 1.67$. However, it is also somewhat obscured by the fact that ZIP code area 5 also shows higher than average comfort. Although statistically significant, the trends are not strong. Together, these results (both the higher pre-COVID comfort as well as the lack of locational dependence of the COVID effect metric) may suggest that the observed higher post-COVID comfort recorded in Figure 19 for ZIP code areas 1 and 9 is a result of a generally higher comfort with flying, rather than a smaller impact of the COVID-19 pandemic on respondent attitudes.

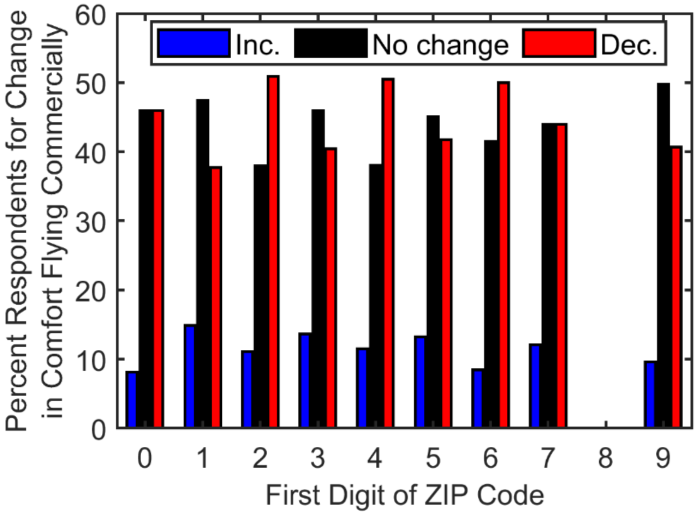


Figure 20: Relationship of COVID effect metric to respondent location (grouped by first ZIP code digit).

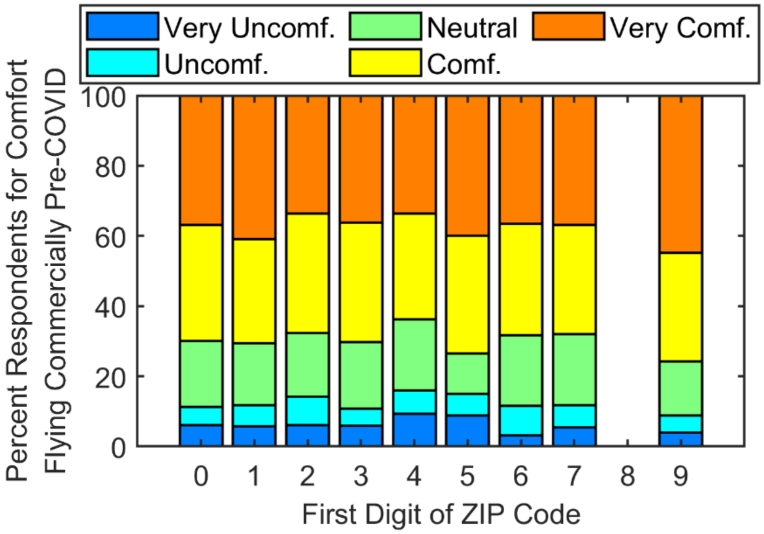


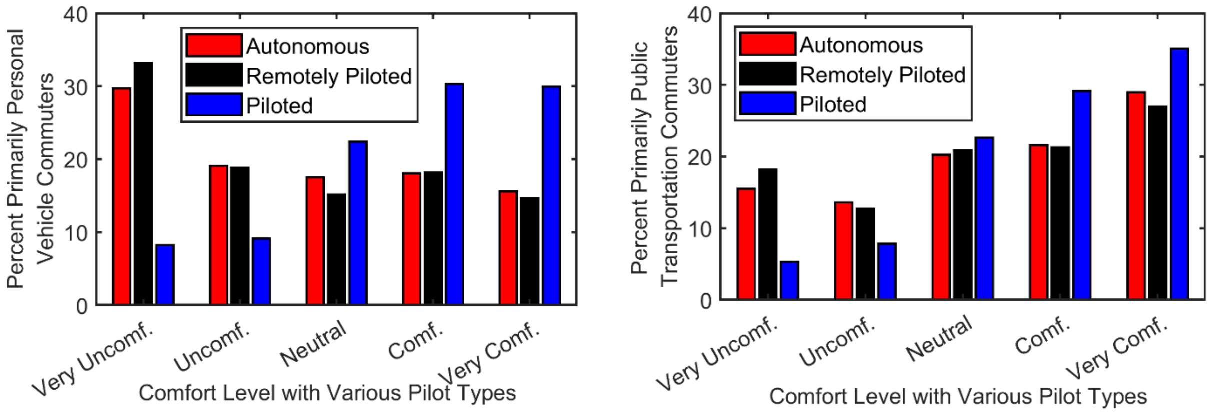
Figure 21: Relationship of pre-COVID comfort flying commercially to respondent location (grouped by first ZIP code digit).

There is significantly more information presented in the resulting data, and future work should include a more granular analysis of the trends, not only in attitude with specific site locations, but also of willingness to pay, anticipated times for peak demand, trip purposes, motivations, etc. Furthermore, the type of residence area (urban, suburban, rural) as well as work location may also play a significant role on attitudes and inform the necessary range/recharge time/logistics and a myriad of other factors involved in the highly coupled AAM problem. This type of information will be crucial to understand for the successful commercial implementation of AAM services at each potential site/service area.

#### 3.4.3.3 *Correlation of Public Transportation Use with End-User Attitudes Toward AAM*

Some existing AAM related literature places significant emphasis on ensuring the fundamental integration of newly developed AAM systems with current public transportation systems (Straubinger, 2019, 2020). This will facilitate access to the AAM services as well as enhancing their overall usefulness. Having said this, Al Haddad et al. (2020) noted that in stated-preference surveys, those who are currently public transportation users tend to self-report later anticipated adoption of AAM services. The anticipated initial demand for AAM services could significantly affect the locations in which it is available, the system capacity, and the way operators integrate with existing public transportation. Therefore, the findings of Al Haddad et al. (2020) are quite important to consider. This is especially true given that their research explicitly focused on the region around Munich, Germany. Additionally, they found distinct differences in attitudes toward AAM between those who took the German and English versions of their survey, indicating culture could have a significant impact on public receptivity. The survey implemented as part of the present work obtained responses from a diverse (both demographically and geographically) US-representative population sample. Thus, the team investigated the relationship between primary commute mode of transportation and attitudes toward AAM to determine if the findings of Al Haddad et al. (2020) for the Munich region are representative of US attitudes as well.

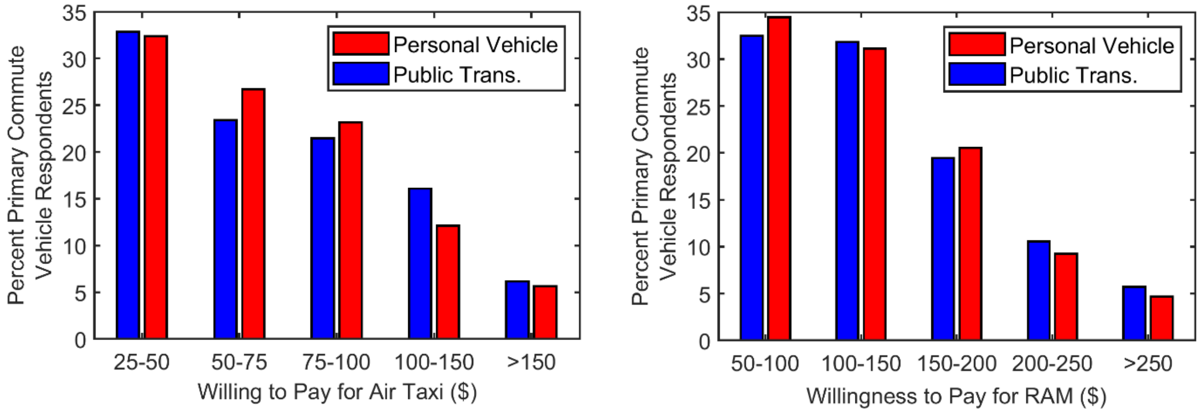
Figure 22 displays results correlating the primary mode of transportation employed for commuting (specifically a personal vehicle or public transportation, though the survey provided other options, see question 13) with stated comfort level flying in piloted (question 29), remotely piloted (question 30), and autonomously piloted (question 31) aircraft. The statistics describing the variable dependence for parts a and b are $p = 0$, $\chi^2/\chi_c^2 = 71.0$ and $p = 6.15\text{e-}14$, $\chi^2/\chi_c^2 = 5.13$, respectively. Note that in all previous figures showing relationships between survey responses, the percentages recorded have been for the variable on the horizontal axis. Thus, all the percentages at a single horizontal location sum to 100%. In this and subsequent figures (specifically, Figures 22, 23, 24, and 25) the percentages denoted on the vertical axis indicate percent respondents for a particular primary commute method, i.e., the percentages in each line/series/legend entry sum to 100%. This change in format displays the results more clearly. The comfort level of respondents who use public transportation as their primary commute method with piloted flights is quite comparable to those who use a personal vehicle. Conversely, there is a significant distinction between public transportation and personal vehicle respondents regarding remotely and autonomously piloted flights. Specifically, respondents who primarily use public transportation for their commute show a significantly higher comfort level with remotely and autonomously piloted flights than those who primarily employ a personal vehicle for their commute. While Al Haddad et al. (2020) specifically examined adoption time scale, rather than comfort level, these conclusions seem to be exactly opposite to what they discovered, namely that public transportation users are more likely to be late adopters of AAM services. It is worth noting that Al Haddad found that those who took their survey in English were more likely to trust automation more, perceive a greater usefulness of UAM, and enjoy automation more, than respondents who took their survey in German. Thus, there are significant differences based (presumably) on the culture of potential AAM users. There is some intuitive sense to the trends shown in Figure 22, as public transportation users have already surrendered control of their commute vehicle to another, whereas personal vehicle users have retained that control for themselves. One hypothesis is that the surrender of control is a key factor in potential AAM users’ comfort level.



(a) (b)

Figure 22: Relationship of primary commute mode of transportation to comfort level for piloted, remotely piloted, and autonomous flights.

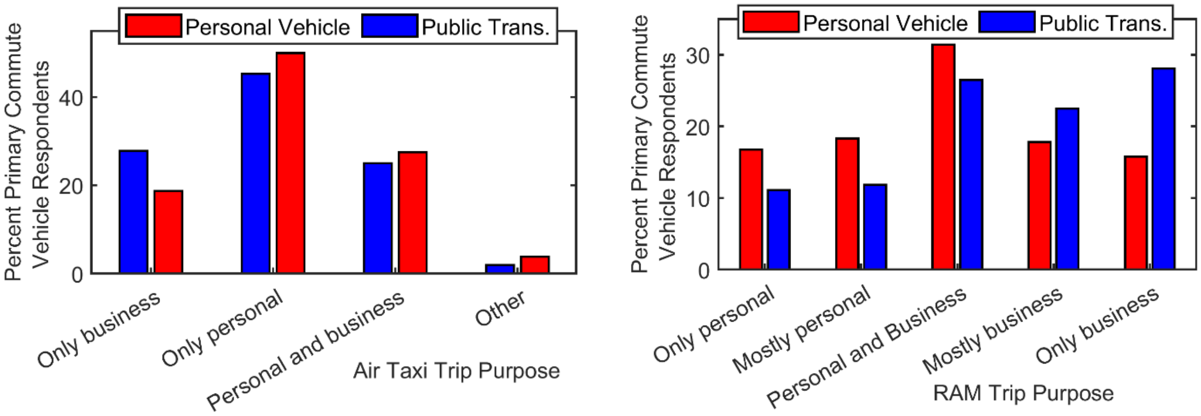
As with AAM in general, there are a variety of factors which play into the actual adoption of air taxi or RAM services by prospective end users. Comfort with technology is certainly key, but willingness to pay is also a crucial component. Figure 23 displays data correlating survey respondents' willingness to pay (questions 39 and 47 for Figure 23a and b respectively) for both air taxi and RAM services with their primary commute method. The statistics describing the dependence of the variables displayed in parts a and b are $p = 0.0516$, $\chi^2/\chi_c^2 = 0.992$ and $p = 0.575$, $\chi^2/\chi_c^2 = 0.306$, respectively. As is clear both from the figures and the statistics, no significant differences in the acceptable cost limits between public transportation users and personal vehicle users are observed. While there are other complicating factors (such as correlation between income level and commuting mode) which will influence actual behaviors, the fact that those currently using public transportation to commute are equally willing to pay for AAM and more comfortable with it (compared to those using personal vehicles), this suggests that they would be earlier adopters. 43his contrasts with Al Haddad et al.'s (2020) results; however, one should remember that the surveyed populations between their work and the present work are completely different and of a different culture. Al Haddad et al. (2020) specifically noted that those who completed their survey in English (as opposed to German) were more likely to be early adopters of AAM. These results support the hypothesis that culture can play a significant role in determining potential users' attitudes toward AAM. Furthermore, it is significant that Al Haddad et al. (2020) specifically examined the time of adoption (in years after introduction) of AAM services, while the present work is addressing willingness to pay and comfort level.



(a) (b)

Figure 23: Relationship of primary commute mode of transportation to amount respondents are willing to pay for (a) air taxi and (b) RAM services.

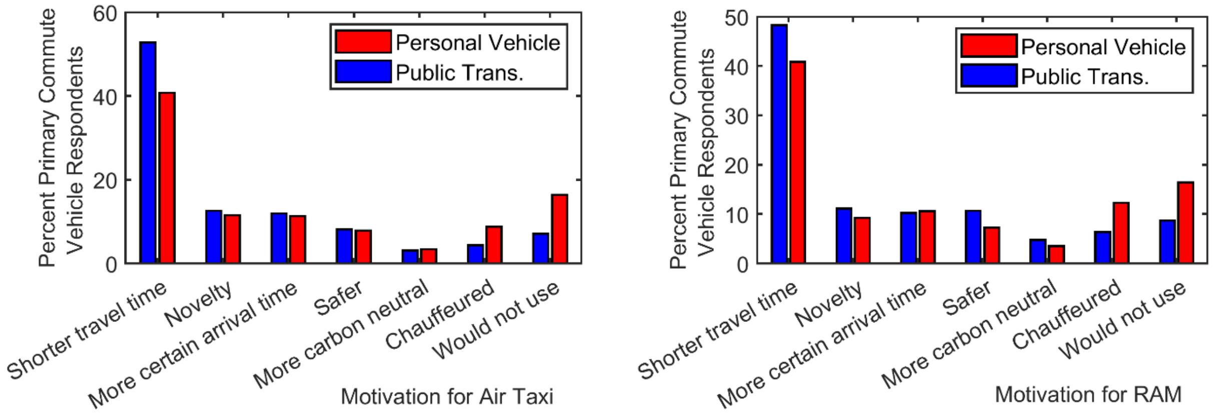
Logistics and appropriate service capacity, accessibility and location are key factors in successful implementation of AAM. Indeed, in general for public transportation systems, increased demand leads to increased desirability, due to more frequent departures (flexibility to the user). Thus, it is not only crucial to understand what the majority of likely clientele will be, but also for what purpose and at what time the demand will typically occur. Significantly more analysis of the results of this survey could help answer these questions. Additionally, given the unique nature of each metropolitan area and transportation service demands and challenges, this analysis should be location specific. However, this report includes a preliminary analysis. Figure 24 shows the percentages of respondents who primarily use either public transportation or a personal vehicle for their commute who indicated the purposes for which they anticipate using air taxi and RAM services (questions 45 and 37, respectively). The statistics that describe the variable dependence in parts a and b are p = 2.74e-7, $\chi^2/\chi_c^2$ = 4.27 and p = 0, $\chi^2/\chi_c^2$ = 8.77, respectively. Note the difference in responses due to the different wording between the two questions. However, some general trends appear consistent between the two, while others are quite distinct. It appears that a greater percentage of public transportation users (as compared to personal vehicle users) anticipate using AAM services for business only. While approximately 45% of public transportation users anticipated using air taxi services for only personal travel, less than 25% said they would use RAM services for only personal or mostly personal travel. This trend in reduced anticipated usage for personal travel is also reflected, though to a lesser degree, among those who primarily commute in a personal vehicle. This may indicate a broader perception of demand for different types of transportation services, rather than a difference of attitudes between users of different commute types. This also suggests that there may be increased demand during “rush hour” for AAM services.



(a) (b)

Figure 24: Relationship of primary commute mode of transportation anticipated travel purpose for (a) air taxi and (b) RAM services.

One final aspect which could significantly impact the necessary form of successful AAM implementation is the motivation of potential users for employing AAM services. Figure 25 correlates the motivation of users for adopting air taxi and RAM services (questions 43 and 33 respectively) with their primary mode of transportation for their commute. The statistics that described the dependence of variables in parts a and b are p = 2.46e-12, $\chi^2/\chi_c^2$ = 5.26 and p = 6.69e-11, $\chi^2/\chi_c^2$ = 4.70, respectively. It is clear from the figure that respondents perceive saving time as their dominant anticipated motivation for using AAM services. This strongly suggests that, to operate at scale, AAM services will have to provide time savings relative to ground transportation. The trends in those using public transportation vs. a personal vehicle for their current commute are primarily similar, with two important exceptions. First those currently driving a personal vehicle are understandably more interested in the aspect of not having to drive themselves (as public transportation users already do not have to drive themselves). Secondly, in agreement with the trends observed in Figure 22, those driving personal vehicles are more likely to anticipate not using AAM services at all, than those using public transportation.



(a) (b)

Figure 25: Relationship of primary commute mode of transportation to motivation to use (a) air taxi and (b) RAM services.

In summary, these results suggest that respondents (recall the surveyed population all reside within the United States) who currently use public transportation for their commute (as compared with those who currently use a personal vehicle for their commute) are more comfortable flying on a remotely or autonomously piloted aircraft as well as comparably willing to pay for AAM (air taxi and RAM) services. Additionally, the dominant motivation behind the anticipated use of AAM in both groups is saving time.

#### 3.4.3.4 *Other Observed Correlations of Future Interest*

The survey deployed as part of this effort focused on assessing the attitudes of potential AAM service end-users to give a broad overview of the market landscape and identify barriers to public acceptance of such technology. As such, it was broad in scope. This resulted in the identification of many inter-variable relationships of interest which warrant further investigation and, potentially, follow-up with additional investigation methods. Results highlight a few areas of interest which were not within the scope of the current project but would be valuable areas for further investigation. The team suggests that another project sponsoring this team to continue these works could significantly elucidate some of the questions posed below.

A more granular location analysis of the results aids in understanding the potential variability in implementations of AAM across different metropolitan areas. The literature review clearly revealed the highly coupled nature of many factors influencing the implementation of AAM services. The result is that implementations in, around, and between specific metropolitan areas may vary quite significantly. Therefore, future work should conduct the overview analyses of potential end-users' attitudes toward, willingness to pay for, etc. AAM services on a granular locational level. This will allow a better understanding of more specific demand time, amount, patterns, etc. for specific markets/implementations. Additionally, locational classification analyses (e.g., rural vs. urban residents) may shed further light on where AAM access points should be located.

There were also many unanticipated relationships between variables which deserve further attention. For example, respondents' self-reported comfort level with autonomously piloted vehicles strongly correlated with their comfort related to COVID-19 (explored in this report), preference for vehicle fuel type, stated purpose for which they would use AAM services, and concerns regarding noise pollution. Another example is that respondents' stated familiarity with "AAM" was correlated to their reported comfort level with autonomously piloted vehicles, comfort level related to COVID-19, concerns about noise pollution, stated preference for vehicle fuel type, stated motivation for using RAM services, residence, and commute location, whether they were a pilot, and other factors. While the importance of some of these relationships is apparent, the cause of others is unclear and bears further investigation. In addition to these examples, there are other observed trends which also bear further investigation. A more in-depth analysis of the survey results already obtained may answer some of these questions; however, obtaining reliable answers to many of these questions may require further data. The team recommends an additional research project to pursue these topics and others which have come up throughout the discussion of results throughout the report.

#### 3.4.3.5 *Interview Findings*

The research team conducted a survey of AAM OEMs to identify trends that could not be identified in a survey of potential AAM users – e.g., design considerations, specific use cases for aircraft, and other aspects of AAM vehicles. The goal was to answer research questions that were best suited to input from those directly involved in AAM aircraft development and service applications. This information is intended to complement market analysis, economic assessment, and survey to identify common trends, themes, and other commonalities between data sets.

The research team analyzed answers to these questions and identified common themes among interview respondents associated with each question. Questions and associated themes are listed below. Themes identified throughout the interviews are further consolidated into three primary points which summarize important conclusions from the interviews. It is important to note that while interviews yielded useful insight into AAM OEM and other stakeholder positions, the sample size was small, consisting of six interview respondents (Table 3; p. 30). Representatives of OEMs that did agree to interviews desired anonymity, and answers to questions were often limited by a desire to protect proprietary information.

*Question 1:* What is your primary focus (line of business) for unmanned passenger travel – e.g., system manufacturer/integrator, avionics, or other?

*Theme(s):* Most AAM OEMs focused on manufacturing and integrating systems, and most interviewed did not specify that they would be operators as well. The DOT entity interviewed emphasized a balance between government and commercial needs/priorities. None of the interview subjects identified themselves as operators only. Most are involved in more than one focus area.

*Question 2:* What are the primary target markets for your system?

*Theme(s):* The DOT entity focused on enabling OEMs to enter the market while AAM OEMs generally emphasized scaling and/or covering use case(s) to get their aircraft in service. Service providers that fall outside the scope of air taxi catered to a large cross section of use cases/customers while the air taxi service providers were narrowly focused on their use case.

*Question 3:* Which best describes the use case for your system – Regional Air Mobility (RAM), Urban Air Mobility (Air Taxi), or other?

*Theme(s):* Two OEMs focused on air cargo. However, most OEMs did not constrain their use cases explicitly to UAM, with one OEM targeting Regional Air Mobility (RAM). However, many OEMs did not identify RAM as a use case for their systems. All OEMs focused on the development of eVTOL aircraft.

*Question 4:* Do you anticipate your design will include in-flight maps and/or trip data for the passenger during the flight?

*Theme(s)*: There was no consensus among OEMs interviewed for this study regarding passenger comforts and availability of in-flight maps or trip data. No standard practice or pattern emerged on this topic. The purpose of this question was to determine what kind of data, if any, would be available to passengers regarding aircraft routing, status, trip information, or other vital data regarding the aircraft. OEMs gave no specific indications one way or the other that aircraft flight or routing data would be available to passengers.

*Question 5:* What additional design considerations for passengers stand out as being unique?

*Theme(s):* Air taxi service providers are focusing on passenger experience/comfort as a design feature/selling point. This question was not applicable to other OEMs. Regardless of their stance on passengers, all OEMs emphasized safety.

*Question 6:* What is your approach to the transition from conventional piloted aircraft to uncrewed, autonomous aircraft?

*Theme(s):* The common approach from OEMs is a transition from piloted to unpiloted aircraft. OEMs view the initial push for full autonomy to come from air cargo. However, different OEMs had differing opinions on how this transition might take place, with attitudes toward that transition aligning with their chosen market niche(s).

*Question 7:* Based on your company's vision for AAM systems design, what control modality do you plan to employ for command and control?

*Theme(s):* The research team identified a mix of approaches to AAM. Consideration for robust command and control links is commensurate with the planned level of system autonomy. Robust command and control did not seem to play a significant role in pilot-centric designs.

*Question 8:* What is your approximate timeline for implementing full autonomy in your system(s), if at all?

*Theme(s):* Estimated timelines for greater levels of autonomy varied among interview respondents. While some OEMs project greater reliance on autonomy within a few years, others see autonomy as being a decade or more away. At least one OEM highlighted that higher levels of autonomy are entirely dependent upon regulations and societal acceptance. Furthermore, most respondents representing air taxi cannot put a definitive timeline on autonomous implementation other than, "about a decade." Other use cases can provide much more fine-tuned estimates that fall between 1.5 – 3 years.

*Question 9:* Does your system require input from a human pilot? If so, to what extent?

*Theme(s):* OEM approaches to controls requiring human input varied, covering a spectrum from conventional human control to higher levels of automation. Specific differences were captured in OEM approaches to their respective markets and business cases.

*Question 10:* To what extent would your system interface with Unmanned Traffic Management (UTM) systems and/or ATC?

*Theme(s):* The inclusion of some form of Air Traffic Control (ATC) interface, network functionality, and/or data exchange with some form of traffic management system was common across most OEMs. Air cargo OEMs emphasized this functionality to a lesser extent. This is likely because air cargo OEMs interviewed for this study anticipated operating in austere environments and away from complex airspace.

*Question 11:* How does your system/design approach the problem of interoperability – e.g., equipage, ATC considerations, detect and avoid, cooperative/non-cooperative systems, etc.?

*Theme(s):* The majority of AAM OEMs considered multiple aspects of interoperability. OEMs seemed to understand that operations in the NAS require an aircraft/system to be compatible with infrastructure, communication, and data exchange systems used by other aircraft/systems. All OEMs were familiar with concepts surrounding NextGen, Automatic Dependent Surveillance - Broadcast (ADS-B), reliance on consensus standards, and other avenues for ensuring interoperability/interfaces between other aircraft/systems in the NAS.

*Question 12:* Do you anticipate a shared UTM environment between your system and existing small uncrewed aircraft systems – for example, established corridors, protocols, and/or unique traffic management systems?

*Theme(s):* All OEMs/stakeholders interviewed anticipated a need for interoperability and connectivity across the broader aviation ecosystem. Two OEMs mentioned dedicated corridors. The common theme is that communication/coordination with ATC and/or a USS is a broad assumption.

*Question 13:* In your opinion, what are the most crucial changes – e.g., investment and/or regulatory changes, needed to facilitate the growth of AAM in the National Airspace System (NAS)?

*Theme(s):* OEMs saw regulatory changes as the most significant need. There were indications that while airworthiness certification was clear for some, other OEMs felt that there needed to be more investigation into emerging technologies. Specifically, one OEM mentioned a need for regulators to define a consistent roadmap. Additionally, one OEM highlighted a need to free the industry of its high reliance on private funding to grow, citing applications in defense.

*Question 14:* What are some of the more novel operational benefits of your system's design when compared to conventional aircraft?

*Theme(s):* OEMs emphasized efficiency in their designs. OEMs commonly referenced electric and/or some other form of novel propulsion. All OEM designs were a departure from conventional aircraft planforms/designs.

*Question 15:* To what extent have federal aviation regulations affected your system design considerations?

*Theme(s):* OEMs indicated a need for standards and highlighted how regulations have driven design decisions. One OEM highlighted an area of interest in software certification and safety, which framed a significant portion of the discussion. Interview responses highlighted a general need to understand nuances in regulations and how they affect design decisions. One OEM mentioned the Part 23 re-write as being particularly good for enabling emerging technologies such as eVTOL and electric propulsion.

*Question 16:* What are the most significant challenges regarding airworthiness and type certification that you have faced thus far?

*Theme(s):* OEM experiences with the Type Certificate (TC) process ranged from not too challenging to challenging. There was a noted lack of standards, and at least one OEM described the process as a, "moving target." One OEM indicated a need for general process improvement and greater efficiency on the part of the FAA to manage timelines.

The consensus was that, at the time of this interview [Spring 2022], the TC process was difficult but manageable. There was an identified need to standardize processes and address new/novel technologies such as batteries/or other novel aspects of AAM vehicles, such as electric propulsion. Additional clarity was desirable for multiple processes [unspecified] and the novelty of AAM systems posed some unique challenges, as designs varied between OEMs.

#### 3.4.3.6 *Summary of Interview Findings*

To summarize themes captured from stakeholder responses, the OEMs and stakeholders interviewed for this research focused mostly on manufacturing, and in the case of the state DOT entity, enabling the growth of AAM. While there were areas where OEMs and stakeholders had differing ideas, such as opinions on passenger features, there were some significant common themes that emerged throughout the interviews. The research team identified the following themes as being particularly significant and consolidated them further to capture the most significant points.

**Transition to Autonomy** – Most OEMs and stakeholders agreed that AAM will transition from piloted operations to greater levels of autonomy over time. While not all OEMs and stakeholders accept this transition to autonomy in the same way, these findings support conventions identified within NASA (2021b). NASA (2021b) implies a gradual shift in which key functions of a pilot, such as “see and avoid” responsibilities, are transitioned to automated systems which have been vetted over time. This gradual shift would enable automated functions to be developed and tested in lower risk scenarios such that sufficient safety data can drive implementation. However, the research notes that the study needs a larger sample size to derive a true correlation.

However, despite OEMs and stakeholders mostly agreeing on the path to autonomy, none of the OEMs and/or stakeholders interviewed were able to point to a timeline for the implementation of high levels of autonomy in their systems – i.e., operations without a pilot in the cockpit. Answers ranged from 18 months to within a decade. The broad range of answers was due to several factors, including proprietary timelines and uncertainty with the regulatory environment. Those in the air taxi realm seemed less certain on the timelines for implementing autonomy. Respondents representing air cargo for this study were more confident in their implementation of autonomy for air cargo operations.

**Interoperability and Data Exchange** – Most OEMs and stakeholders interviewed were in consensus regarding the need for interoperability and data exchange across the entire aviation ecosystem, with a single logistics-focused OEM having no comment on the subject. This extended to the use of ADS-B (In/Out), communication and data exchange with ATC, and connections across UTM networks to maintain awareness of low-altitude traffic. Two OEMs specifically mentioned operations within dedicated corridors in addition to an emphasis on the need for connectivity to available networks and services. There was a broad assumption that connection/coordination with ATC and connections with various data networks would be expected. This highlights the importance of spectrum usage and ensuring capacity for any existing and/or new data exchanges to ensure AAM vehicles can interface with the requisite networks and information systems +to the extent needed to operate safely.

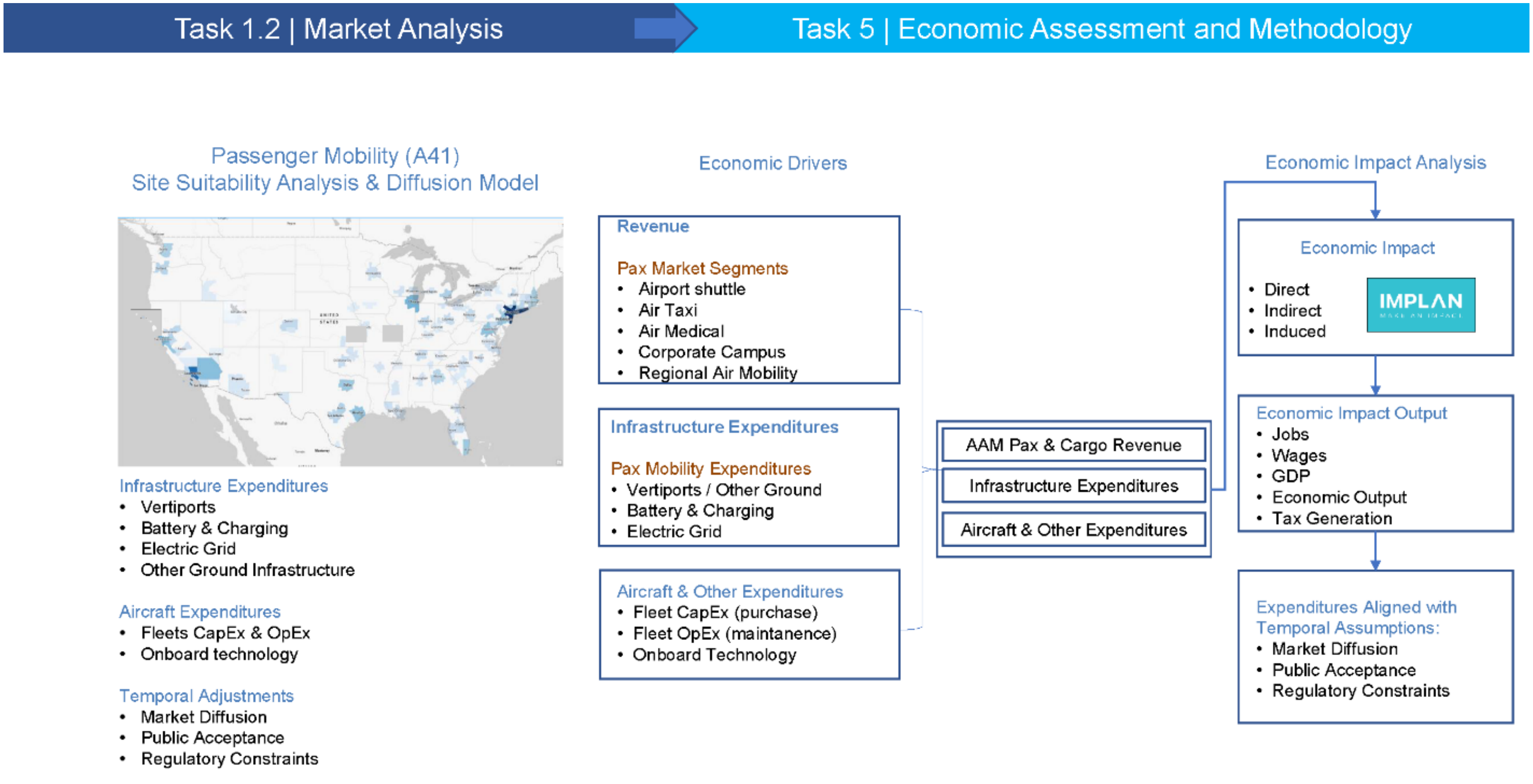
**Need for Consistency and Standardization in the TC Process** – Most OEMs and stakeholders emphasized the importance of regulations and standards and their impact on AAM overall. Concerns and considerations for regulatory limitations and/or lack of guidance in the form of standards was a frequent remark from respondents. This was especially true when addressing novel design features of AAM vehicles such as distributed electric propulsion, autonomous flight functions, and battery technology. OEMs indicated a need for standards and an understanding of regulations. Responses to questions regarding type certification clearly reflected this need. For OEMs who were pursuing a TC, experiences varied, with common responses emphasizing a need for standards and process improvement on the part of the FAA. One stakeholder referenced “moving targets” inherent in the TC process and pointed to a need for process improvement for TC applicants. Two additional respondents corroborated this finding, mentioning that changes to requirements mid-process made design and development more difficult, creating a need to constantly revise their approach to given technical challenges.

While themes identified in OEM interviews regarding AAM aircraft certification and standardization do not necessarily point to shortcomings in established regulations and standards, they do highlight potential areas where changes may be needed. While the sample size for OEM interviews is small, the themes present in their responses were largely consistent among those pursuing a TC and indicate a desire for additional guidance and standardization when navigating the process. Additionally, the notion that the 14 CFR 12.17(b) path to type certification is not meant for mass production (Serrao et al., p. 18, 2018) may point to a need to review certification pathways for new or novel aircraft to ensure that bottlenecks in TC processes do not hinder the process for current or future applicants. However, further research with a larger sample size may be required to determine the true extent of the challenges faced by OEM aircraft manufacturers when navigating the TC process.

## 3.5 Task 5 – Economic Assessment and Methodology

The following sub-sections offer key points and takeaways from the economic impact assessment. They outline the methodological approach taken by the research team and the findings from the economic impact analysis undertaken to estimate the economic impact of advanced air mobility from the present day through 2045.

### 3.5.1 *Methodology*



Task 1.2 | Market Analysis

Task 5 | Economic Assessment and Methodology

Passenger Mobility (A41)
Site Suitability Analysis & Diffusion Model

Infrastructure Expenditures
- Vertiports
- Battery & Charging
- Electric Grid
- Other Ground Infrastructure

Aircraft Expenditures
- Fleets CapEx & OpEx
- Onboard technology

Temporal Adjustments
- Market Diffusion
- Public Acceptance
- Regulatory Constraints

Economic Drivers

Revenue

Pax Market Segments
- Airport shuttle
- Air Taxi
- Air Medical
- Corporate Campus
- Regional Air Mobility

Infrastructure Expenditures

Pax Mobility Expenditures
- Vertiports / Other Ground
- Battery & Charging
- Electric Grid

Aircraft & Other Expenditures
- Fleet CapEx (purchase)
- Fleet OpEx (maintanence)
- Onboard Technology

AAM Pax & Cargo Revenue

Infrastructure Expenditures

Aircraft & Other Expenditures

Economic Impact Analysis

Economic Impact
- Direct
- Indirect
- Induced

IMPLAN

Economic Impact Output
- Jobs
- Wages
- GDP
- Economic Output
- Tax Generation

Expenditures Aligned with Temporal Assumptions:
- Market Diffusion
- Public Acceptance
- Regulatory Constraints

*Economic Impact Analysis Framework Adapted From: Crown Consulting, Nexa Capital Partners, University of Cincinnati, and ASSURE A36 Project Team*

Figure 26. Economic Impact Assessment Methodological Framework.

The team conducted an economic impact assessment to evaluate how AAM passenger mobility will affect the US economy. This required defining the period of analysis (the duration of time for measuring impacts), isolating the determinants of economic impact (the key drivers that cause changes to the economy), developing the process to model economic impacts (building the economic model), and reporting the analysis findings. For this study, the period of analysis was determined to be from the present day through 2045. The team selected this period to provide a meaningful long-term economic impact estimate and to align with the time horizon used in ASSURE project *A36: Evaluation of UAM Market Potential: Demand Feasibility, Potential Size and Growth, Characteristics of Population, and Ground Infrastructure*, so the team could readily compare results among the two studies.

Figure 26 provides a visual depiction of the methodological framework used to estimate AAM passenger mobility impacts (the figure navigates sequentially from left to right). First, an extensive market analysis was undertaken to understand the extent of the AAM passenger mobility marketplace and how it would evolve through 2045 (see “Task 1-2: Market Analysis ” on page 6). The analysis identified information pertaining to AAM enabling infrastructure, AAM aircraft cost structures and growth trajectories, and AAM passenger mobility market diffusion in the market analysis which became integral inputs of the economic impact assessment. Second, the team used AAM passenger mobility demand estimates by market to estimate the direct impacts of AAM passenger mobility revenue, ground infrastructure capital investments and operating expenditures, and AAM aircraft capital and operations expenditures. Third, the economic impacts resulting from AAM passenger mobility ticket revenue, ground infrastructure expenditures, and AAM aircraft expenditures were derived using an input-output model (more information on economic impact analysis using input-output modeling can be found in “Economic Modeling and Terminology” on page 62).

**AAM Passenger Mobility Demand Forecasting –** As an important methodological note, the research team sourced AAM passenger demand by market from the ASSURE A36 research project. For this research, AAM passenger demand has been defined to encompass airport shuttle, air taxi, corporate shuttle, and short-haul regional air mobility markets (flight distances less than 200 miles). To model the locations of prospective domestic AAM passenger mobility markets, the A36 team used a site suitability analysis, which evaluated the metropolitan statistical areas within the United States with the highest prevalence of characteristics suitable for AAM market development. The team then analyzed AAM passenger demand by market using demand projections from UAM Geomatics, adjusted using SMG Consulting’s AAM Reality Index (2022) and market penetration milestones from Hussain and Silver (2021), and reprojected using a Bass Diffusion Modeling framework led by Mississippi State as part of the A36 project work (Olivares et al., 2022).

**AAM Passenger Mobility Ticket Revenue** – The research team modeled passenger ticket revenue using estimated AAM passenger mobility trips from 2023-2045. The team then derived passenger mobility trips by using guideposts from the literature review and market analysis, as shown in Table 4. Researchers used the following equation to arrive at annual estimated passenger trips:

Annual Passenger Trips = (VTOL aircraft) x (Hours of Operation) x (Missions per Hour) x (Customers per Mission) x (Annual Days of Operation)

The number of annual passenger trips was then multiplied by the ticket fare for each flight. Drawing from the literature, ticket price estimates ranged from $50 to $300+ per flight. The team estimated $140 (in $2022) per AAM passenger trip for this analysis.

Table 4. AAM Passenger Trip Asserted Values.

| AAM VTOL Characteristics | Asserted Values |
|---|---|
| Days of Operation | 362 |
| Daily Operational Hours (Business Hours) | 14 |
| Missions per Hour | 2.0 |
| Customers per Mission | 2.90 |

To estimate the number of VTOL aircraft in operation from 2023-2045, researchers used market diffusion rates and ground infrastructure investment forecasts (see “AAM Passenger Mobility Ground Infrastructure Capital and Operations Expenditures” for more information. Table 5 shows total VTOL in operation in year 2045.

Table 5. Estimated STOL & VTOL Aircraft Making AAM Passenger Missions in Year 2045.

| Metropolitan Statistical Area | Suitability Score | Estimated Launch Year | STOL & VTOL Aircraft | | |
|---|---|---|---|---|---|
| | | | Low | Medium | High |
| **New York-Newark-Jersey City, NY-NJ-PA** | **74.13** | **2022-2025** | 405 | 540 | 675 |
| **Los Angeles-Long Beach-Anaheim, CA** | **66.23** | **2022-2025** | 221 | 294 | 368 |
| **Orlando-Kissimmee-Sanford, FL** | **33.92** | **2022-2025** | 50 | 66 | 83 |
| **Miami-Fort Lauderdale-Pompano Beach, FL** | **32.67** | **2022-2025** | 84 | 112 | 140 |
| **Dallas-Fort Worth-Arlington, TX** | **39.27** | **2026-2028** | 69 | 92 | 115 |
| **Boston-Cambridge-Newton, MA-NH** | **36.00** | **2026-2028** | 114 | 152 | 190 |
| **Columbus, OH** | **31.73** | **2026-2028** | 245 | 326 | 408 |
| **Minneapolis-St. Paul-Bloomington, MN-WI** | **31.15** | **2026-2028** | 53 | 70 | 88 |
| San Jose-Sunnyvale-Santa Clara, CA | 34.22 | 2029-2034 | 32 | 42 | 53 |
| Detroit-Warren-Dearborn, MI | 32.73 | 2029-2034 | 48 | 64 | 80 |
| San Francisco-Oakland-Berkeley, CA | 31.81 | 2029-2034 | 128 | 170 | 213 |
| Chicago-Naperville-Elgin, IL-IN-WI | 30.73 | 2029-2034 | 221 | 294 | 368 |
| Bridgeport-Stamford-Norwalk, CT | 28.41 | 2035-2045 | 39 | 52 | 65 |
| Washington-Arlington-Alexandria, DC-VA-MD-WV | 28.29 | 2035-2045 | 194 | 258 | 323 |
| Houston-The Woodlands-Sugar Land, TX | 27.83 | 2035-2045 | 125 | 166 | 208 |
| Riverside-San Bernardino-Ontario, CA | 26.82 | 2035-2045 | 12 | 16 | 20 |
| Philadelphia-Camden-Wilmington, PA-NJ-DE-MD | 25.16 | 2035-2045 | 54 | 72 | 90 |

|  |  |  |  |  |  |
|---|---|---|---|---|---|
| Indianapolis-Carmel-Anderson, IN | 24.96 | 2035-2045 | 53 | 70 | 88 |
| Seattle-Tacoma-Bellevue, WA | 24.82 | 2035-2045 | 111 | 148 | 185 |
| Allentown-Bethlehem-Easton, PA-NJ | 24.45 | 2035-2045 | 36 | 48 | 60 |
| Atlanta-Sandy Springs-Alpharetta, GA | 24.06 | 2035-2045 | 68 | 90 | 113 |
| Madison, WI | 23.73 | 2035-2045 | 12 | 16 | 20 |
| Providence-Warwick, RI-MA | 23.64 | 2035-2045 | 36 | 48 | 60 |
| Poughkeepsie-Newburgh-Middletown, NY | 23.57 | 2035-2045 | 30 | 40 | 50 |
| Hartford-East Hartford-Middletown, CT | 23.10 | 2035-2045 | 30 | 40 | 50 |
| Pittsburgh, PA | 23.05 | 2035-2045 | 23 | 30 | 38 |
| Wichita, KS | 22.81 | 2035-2045 | 23 | 30 | 38 |
| Portland-Vancouver-Hillsboro, OR-WA | 22.73 | 2035-2045 | 26 | 34 | 43 |
| Cleveland-Elyria, OH | 22.72 | 2035-2045 | 44 | 58 | 73 |
| Milwaukee-Waukesha, WI | 22.43 | 2035-2045 | 36 | 48 | 60 |
| **United States** |  | 2022-2045 | 2,615 | 3,486 | 4,358 |

**AAM Passenger Mobility Aircraft Fleet Capital and Operations Expenditures** – To estimate AAM aircraft capital expenditures, the team multiplied the mean vehicle cost for AAM passenger mobility aircraft by the number of aircraft anticipated to operate in a US domestic market during the project period. The mean vehicle cost used for this analysis was $1,950,000 (see Table 6) and sourced from an AAM aircraft database developed by Olivares et al. (2022).

Further analysis estimated the number of AAM vehicles in the domestic aircraft fleet using anticipated ground infrastructure investments in low, medium, and high growth trajectories by domestic market. Table 10 provides ground infrastructure needs by domestic market and for more information on ground infrastructure methods see "AAM Passenger Mobility Ground Infrastructure Capital and Operations Expenditures." Ground infrastructure estimates were then cross walked with ground infrastructure landing pad characteristics from Johnston, Reidel, and Sahdev (2020) to estimate the number of AAM aircraft operating per type of ground infrastructure (see Table 10).

For this analysis, researchers assumed aircraft purchases to coincide with ground infrastructure investments and AAM passenger mobility demand as it evolves within domestic markets from 2023 to 2045 (see "AAM Passenger Mobility Demand Forecasting" for details on demand diffusion). The team assumed that a VTOL aircraft accompanied every VTOL charging and parking space. In year 2045, estimates indicate 2,615 to 4,358 VTOL aircraft to be part of the AAM passenger mobility domestic fleet (see Table 10).

The research team developed AAM aircraft fleet operating costs using study results from Ackert (2011), Moore (n.d.), and literature guideposts on the relationship between an aircraft's value and its maintenance status. Ackert (2011) found that aircraft maintenance costs equate to approximately 19.3 percent of the aircraft's value, Moore (n.d.) found that Airlines spend more than 12 percent of asset replacement value annually on maintenance, and general rule of thumb is that aircraft maintenance costs can range from 10 to 45 percent (Battles, 2003). For this analysis, the research team used a value of 14.45 percent of capital costs, accruing annually, to estimate AAM aircraft operating costs (see Table 6).

Table 6. Operating Expenditures as Percentage of Aircraft Capital Expenditures.

| Source | Cost |
|---|---|
| Ackert (2011) | 19.26% |
| Battles (2003) | 10-45% |
| Moore (n.d.) | 12%+ |
| A41 Analysis Value | 14.45% |

Table 7. Estimated AAM Passenger Mobility Aircraft Cost by OEM (Olivares et al., 2022).

| Original Equipment Manufacturer (OEM) | Vehicle Cost ($2022 millions) | Mission Purpose |
|---|---|---|
| Joby | $1,300,000 | Air Taxi |
| Ehang | $336,000 | Air Taxi |
| Lilium | $4,500,000 | Air Taxi |
| Archer | $5,000,000 | Air Taxi |
| Samad Aerospace | $10,000,000 | Regional |
| XTI | $6,500,000 | Regional |
| ASX | $1,000,000 | Air Taxi |
| Astro Aerospace | $150,000 | Personal Air Vehicle |
| LIFT Aircraft | $500,000 | Personal Air Vehicle |
| Flutr Motors | $200,000 | Air Taxi |
| Daymak Avvenir | $250,000 | Personal Air Vehicle |
| Doroni | $150,000 | Personal Air Vehicle |
| Moog | $200,000 | Air Taxi |
| Vickers Aircraft Company | $180,000 | Personal Air Vehicle |
| EAC (Electric Aircraft Concept) | $200,000 | Air Taxi |
| DeLorean Aerospace | $275,000 | Personal Air Vehicle |
| Horizon Aircraft | $3,500,000 | Air Taxi |
| Transcend Air | $3,500,000 | Regional |
| Scienex | $200,000 | Air Taxi |
| Horizon Helicopters | $1,000,000 | Air Taxi |
| 25th Percentile | $200,000 | AAM Passenger Mobility |
| Mean | $1,950,000 | AAM Passenger Mobility |
| 75th Percentile | $3,500,000 | AAM Passenger Mobility |

**AAM Passenger Mobility Ground Infrastructure Capital and Operations Expenditures** – The team developed infrastructure expenditures using UAM Geomatics (2022) ground infrastructure needs projections for US cities. Researchers then fitted city projections to the 30 domestic metropolitan statistical areas anticipated to become AAM passenger mobility markets by 2045 (as determined by the ASSURE A36 site suitability analysis (Olivares, G. et al., 2022)) and shown in Table 10.

The research team divided AAM ground infrastructure investments into categories, including existing facility retrofits, vertipad, vertibase, vertihub, and megahub as defined by Johnston, Riedel, and Sahdev (2020) and UAM Geomatics (2022). Existing facility retrofits are defined as electrification and other upgrades most likely occurring at general aviation airports that enable AAM operations. Research indicates that general aviation airports have an essential role to play in the transition from traditional to uncrewed aircraft operations within multiple AAM use cases, such as airport shuttle, air taxi, and regional air mobility (UAM Geomatics, 2022; NASA, 2021). Vertipads are defined as being equipped with one takeoff and landing pad and two parking spots with charging capacity (Johnston, Riedl, and Sahdev, 2020). Vertibases are assumed to be equipped with up to five takeoff and landing pads and up to 10 parking spots with charging capability (Johnston, Riedl, and Sahdev, 2020).[6] Vertihubs are anticipated to have 10-15 takeoff and landing pads with up to 20 parking spots equipped with charging capabilities (Johnston, Riedl, and Sahdev, 2020).[7] Megahubs introduced by UAM Geomatics (2022); though not explicitly defined, the research team estimates that a megaport will have an estimated 20-60 parking spaces equipped with charging capabilities.[8] The research team developed a crosswalk between UAM Geomatics (2022) and Johnston, Riedel, and Sahdev (2020) that could define ground infrastructure investment categories, estimate ground infrastructure capital and operating costs, and estimate AAM passenger mobility aircraft capital investment needs from 2023-2045. The team built the crosswalk in three stages. First, the team fitted ground infrastructure investment projections from UAM Geomatics (2022) to the 30 metropolitan statistical areas anticipated to have AAM passenger mobility markets (see Table 10). Second, UAM Geomatics (2022) classifications were aligned with Johnston, Riedel, and Sahdev (2020) ground infrastructure classifications, parking and charging space characteristics, and infrastructure capital and operating costs (see Table 8 and Table 9). Third, researchers used aircraft parking space projections to estimate the number of AAM aircraft purchased over time. For this analysis, researchers assumed ground infrastructure supply was optimized to coincide with AAM passenger mobility demand within a geographic market. In other words, the analysis assumes that ground infrastructure is constructed at a rate to fulfill, but not exceed demand over time. Therefore, each aircraft parking space is assumed to be utilized before new ground infrastructure is constructed.

This analysis also assumes that there is both an operating and reserve AAM fleet within each market occurring at a ratio of 1 reserve AAM aircraft for every 5 aircraft in operation. The reserve fleet allows for system redundancy in the case of uncharacteristically high peak demand periods or instances where aircraft require servicing for maintenance. This equates to approximately one AAM aircraft per every 24,400 annual aircraft operations assuming 362 days of annual flights, 14 hours of daily operation, two flights per hour, 2.9 customers per flight, and one reserve aircraft for every five aircraft in operation.

By 2045, approximately 870 AAM ground infrastructure investments are forecasted (ranging from approximately 650 to 1,090 investments depending on domestic economic growth). These investments would enable approximately 3,890 AAM aircraft parking spaces (ranging from approximately 2,610 to 4,360 parking spaces, depending on U.S. economic growth) to fulfill domestic AAM passenger mobility demand through 2045 (see Table 10).

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[6] Based on values provided by Johnston, Riedel, and Sahdev (2020) vertiports are assumed to have 3 takeoff and landing pads and 6 charging spots on average. These values were used for the economic assessment.

[7] Based on values provided by Johnston, Riedel, and Sahdev (2020) vertihubs are assumed to have 10 takeoff and landing pads and 20 charging spots on average. These values were used for the economic assessment.

[8] Based on context provided by UAM Geomatics (2022) megaports are assumed to have 40 takeoff and landing pads equipped with charging capabilities. These values were used for the economic assessment.

Table 8. AAM Aircraft Spaces by Ground Infrastructure Category.

| Category | Airport Retrofits & Vertipads | Vertibases | Vertihubs | Megaports |
|---|---|---|---|---|
| Spaces | 2 | 6 | 20 | 40 |

*For this analysis it is assumed that most airport retrofits will occur at general aviation airports and will offer aircraft parking characteristics similar to those of typical Vertipad infrastructure.

Table 9. Ground Infrastructure Costs by Type in millions of $2022.

| Category | Airport Retrofits & Vertipads* | Vertibases | Vertihubs | Megaports |
|---|---|---|---|---|
| CapEx | $992,600 | $2,434,700 | $11,822,000 | $64,200,000 |
| OpEx | $750,000 | $4,000,000 | $16,000,000 | $20,000,000 |

*For this analysis it is assumed that most airport retrofits are anticipated to exhibit similar cost structures to Vertipad capital and operations expenditures.

Table 10.Ground Infrastructure Composition and Characteristics by AAM Passenger Mobility Domestic Marketplace Estimated in Year 2045.

| Ground Infrastructure Share by Category | | | | | Ground Infrastructure Investments | | | VTOL Spaces | | |
|---|---|---|---|---|---|---|---|---|---|---|
| **Metropolitan Statistical Area** | **Airport Retrofits & Vertipad** | **Vertibase** | **Vertihub** | **Megaport** | **Low** | **Med** | **High** | **Low** | **Med** | **High** |
| New York-Newark-Jersey City, NY-NJ-PA | 68.0% | 19.4% | 11.7% | 1.0% | 77 | 103 | 129 | 405 | 540 | 675 |
| Los Angeles-Long Beach-Anaheim, CA | 81.8% | 10.4% | 7.8% | 0.0% | 58 | 77 | 96 | 221 | 294 | 368 |
| Orlando-Kissimmee-Sanford, FL | 85.0% | 10.0% | 5.0% | 0.0% | 15 | 20 | 25 | 50 | 66 | 83 |
| Miami-Fort Lauderdale-Pompano Beach, FL | 73.9% | 13.0% | 13.0% | 0.0% | 17 | 23 | 29 | 84 | 112 | 140 |
| Dallas-Fort Worth-Arlington, TX | 83.3% | 8.3% | 8.3% | 0.0% | 18 | 24 | 30 | 69 | 92 | 115 |
| Boston-Cambridge-Newton, MA-NH | 82.9% | 9.8% | 7.3% | 0.0% | 31 | 41 | 51 | 114 | 152 | 190 |
| Columbus, OH | 80.5% | 12.6% | 6.9% | 0.0% | 65 | 87 | 109 | 245 | 326 | 408 |
| Minneapolis-St. Paul-Bloomington, MN-WI | 80.0% | 15.0% | 5.0% | 0.0% | 15 | 20 | 25 | 53 | 70 | 88 |
| San Jose-Sunnyvale-Santa Clara, CA | 80.0% | 10.0% | 10.0% | 0.0% | 8 | 10 | 13 | 32 | 42 | 53 |
| Detroit-Warren-Dearborn, MI | 84.2% | 10.5% | 5.3% | 0.0% | 14 | 19 | 24 | 48 | 64 | 80 |
| San Francisco-Oakland-Berkeley, CA | 80.5% | 9.8% | 9.8% | 0.0% | 31 | 41 | 51 | 128 | 170 | 213 |
| Chicago-Naperville-Elgin, IL-IN-WI | 81.8% | 10.4% | 7.8% | 0.0% | 58 | 77 | 96 | 221 | 294 | 368 |
| Bridgeport-Stamford-Norwalk, CT | 44.4% | 44.4% | 11.1% | 0.0% | 7 | 9 | 11 | 39 | 52 | 65 |
| Washington-Arlington-Alexandria, DC-VA-MD-WV | 82.9% | 10.0% | 7.1% | 0.0% | 53 | 70 | 88 | 194 | 258 | 323 |
| Houston-The Woodlands-Sugar Land, TX | 79.5% | 10.3% | 10.3% | 0.0% | 29 | 39 | 49 | 125 | 166 | 208 |
| Riverside-San Bernardino-Ontario, CA | 83.3% | 16.7% | 0.0% | 0.0% | 5 | 6 | 8 | 12 | 16 | 20 |
| Philadelphia-Camden-Wilmington, PA-NJ-DE-MD | 87.0% | 8.7% | 4.3% | 0.0% | 17 | 23 | 29 | 54 | 72 | 90 |
| Indianapolis-Carmel-Anderson, IN | 80.0% | 15.0% | 5.0% | 0.0% | 15 | 20 | 25 | 53 | 70 | 88 |
| Seattle-Tacoma-Bellevue, WA | 82.1% | 10.3% | 7.7% | 0.0% | 29 | 39 | 49 | 111 | 148 | 185 |
| Allentown-Bethlehem-Easton, PA-NJ | 72.7% | 18.2% | 9.1% | 0.0% | 8 | 11 | 14 | 36 | 48 | 60 |
| Atlanta-Sandy Springs-Alpharetta, GA | 86.7% | 10.0% | 3.3% | 0.0% | 23 | 30 | 38 | 68 | 90 | 113 |
| Madison, WI | 83.3% | 16.7% | 0.0% | 0.0% | 5 | 6 | 8 | 12 | 16 | 20 |
| Providence-Warwick, RI-MA | 72.7% | 18.2% | 9.1% | 0.0% | 8 | 11 | 14 | 36 | 48 | 60 |
| Poughkeepsie-Newburgh-Middletown, NY | 77.8% | 11.1% | 11.1% | 0.0% | 7 | 9 | 11 | 30 | 40 | 50 |
| Hartford-East Hartford-Middletown, CT | 77.8% | 11.1% | 11.1% | 0.0% | 7 | 9 | 11 | 30 | 40 | 50 |
| Pittsburgh, PA | 50.0% | 25.0% | 25.0% | 0.0% | 3 | 4 | 5 | 23 | 30 | 38 |
| Wichita, KS | 50.0% | 25.0% | 25.0% | 0.0% | 3 | 4 | 5 | 23 | 30 | 38 |

| | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| Portland-Vancouver-Hillsboro, OR-WA | 87.5% | 0.0% | 12.5% | 0.0% | 6 | 8 | 10 | 26 | 34 | 43 |
| Cleveland-Elyria, OH | 81.3% | 12.5% | 6.3% | 0.0% | 12 | 16 | 20 | 44 | 58 | 73 |
| Milwaukee-Waukesha, WI | 84.6% | 7.7% | 7.7% | 0.0% | 10 | 13 | 16 | 36 | 48 | 60 |
| **United States Total** | **79.3%** | **12.4%** | **8.2%** | **0.1%** | **652** | **869** | **1,086** | **2,615** | **3,486** | **4,358** |

### *3.5.2 Economic Modeling and Terminology*

To evaluate the effect of AAM passenger mobility on the US economy, the research team leveraged an economic impact analysis using an input-output model. Input-output modeling is a method used in economics to analyze the interdependencies between different sectors of an economy. It provides a systematic framework for understanding how changes in one sector can affect other sectors and the overall economy. The primary concept behind input-output modeling is that each sector of the economy both consumes and produces goods and services. The input-output model represents these relationships using a matrix that shows the flows of inputs and outputs between sectors. This matrix is known as the input-output table (Munroe, 2005).

The input-output table represents the total inputs required by each sector to produce a unit of output and the total outputs produced by each sector. By examining this table, economists can analyze the direct effects of changes in demand or production in one sector as well as the indirect and induced effects on other sectors (van Leeuwen, Nijkamp, and Rietveld, 2005). The following sections provide descriptions of direct, indirect, and induced impacts.

**Direct impacts -** Direct economic impacts refer to the immediate effects resulting from a specific event, project, or policy change on an economy or a particular industry or sector. Typical measures for these impacts are in terms of changes in output, employment, income, or other economic indicators. Direct economic impacts are often the most easily quantifiable and readily observable effects.

**Indirect impacts -** Also known as secondary impacts, indirect impacts refer to the impacts that occur because of interdependencies and linkages between different sectors of the economy. Indirect impacts capture the ripple effects that arise when final demand changes in one sector leads to changes in production in other sectors to help fulfill that demand. Indirect impacts often take form as business-to-business transactions. For example, if an AAM aircraft manufacturer received a purchase order of 20 vertical takeoff and landing aircraft, that order may lead to the purchase of new parts, fabrics, software, or other factors of production sourced from other businesses. An input-output model and make table quantify these supply chain effects.

**Induced impacts -** Also known as tertiary impacts, induced impacts refer to the economic effects that arise from changes in household spending patterns resulting from direct and indirect impacts. Induced impacts capture the feedback loop between changes in economic activity and household consumption. These impacts reflect the effects of changes in income on consumer behavior and subsequent economic activity. An input-output model quantifies these household spending effects.

For this study, the research team used IMPLAN to conduct an economic impact analysis. IMPLAN is a platform that uses databases, economic factors, multipliers, and demographic statistics with a refined, customizable modeling system. The input-output model serves as the foundation for the economic impact analyses.

### *3.5.3 Ticket Revenue Direct Effects*

By 2045, AAM passenger mobility flight offerings will be available in 30 domestic markets (Olivares et. al, 2022) with approximately 85.4 million AAM passenger mobility trips occurring that year. This quantity of AAM passenger trips is equivalent to approximately 5.3 percent of traditional domestic enplanements projected for the year 2045 (derived from FAA [2023]). Though demand projections for AAM passenger mobility services are modest through 2035, AAM services are anticipated to increase markedly thereafter through 2045 (see **Error! Reference source not found.**). Supporting an estimated 525.4 million cumulative trips through 2045 (with a medium growth trajectory), AAM passenger mobility will generate substantial economic impacts on the US economy.

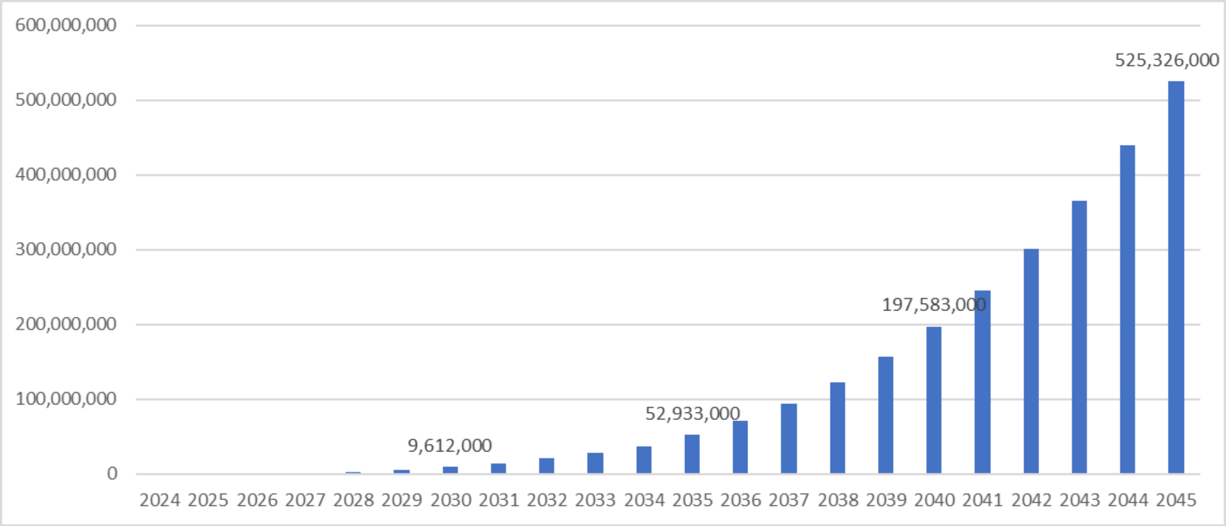

Figure 27. AAM Passenger Mobility Cumulative Enplanements Over Time (Medium Growth Trajectory).

Estimates show AAM ticket revenue to facilitate approximately $72.5 billion in direct economic output in a medium economic growth trajectory. Direct output estimates depend on the overall health of the US economy and would fluctuate if the economy were to experience a sustained downturn (low growth trajectory: $54.4 billion in direct output), or period of high economic productivity (high growth trajectory: $90.6 billion in direct output). Summary of Economic Impacts – Direct, Indirect, and Induced Impacts

### *3.5.4 Fleet Expenditure Direct Effects*

Depending on the US economic growth trajectory, an estimated fleet of 2,615 to 4,358 AAM aircraft (STOL and VTOL) will see use for AAM passenger mobility missions in year 2045. The purchase of these aircraft as well as expenditures made to keep them maintained will have a positive impact on the US economy. The research estimates that from 2023 to 2045, AAM aircraft capital expenditures could total $5.1 billion to $8.5 billion and AAM aircraft operations and maintenance expenditures could reach $4.5 billion to $7.6 billion. Altogether this equates to a direct economic impact of $9.6 to $16.1 billion in fleet expenditures, depending on the economic growth trajectory of the US economy.

### *3.5.5 Infrastructure Expenditure Effects*

Advanced passenger mobility will require enabling infrastructure so that AAM missions can take people to work, school, medical, tourism, and other destinations. The construction of an array of airport retrofits, vertiports, including vertipads, vertibases, vertihubs, and megaports becomes increasingly necessary as AAM activities emerge in launch cities and continue to develop around the United States. The construction and operation of these vertiports will have an impact on the US economy. Projections indicate that an estimated 652-1,086 AAM ground infrastructure investments will be required to meet advanced air mobility demand from the present day through 2045.

The capital investments made for these vertiports and the annual expenditures to keep them maintained and operating have a positive impact on the US economy. Projections show an estimated $1.4 billion to $2.3 billion in spending on vertiport capital projects from 2023 to 2045 and an estimated $1.6 billion to $2.6 billion in anticipated spending on vertiport operations and maintenance expenditures during that same time. The "Summary of Economic Impacts – Direct, Indirect, and Induced Impacts" discusses indirect and induced impacts associated with these expenditures.

### *3.5.6 Summary of Economic Impacts – Direct, Indirect, and Induced Impacts*

From 2023 to 2045, an estimated 30 domestic markets will come online and provide AAM passenger mobility flight services. Estimates indicate approximately 525.4million AAM passenger trips and $72.5 billion in ticket revenue generation over this period. Projections show this level of activity supported by an AAM fleet of approximately 3,490 aircraft. New investments in AAM aircraft and ongoing expenditures to support their operations and maintenance will generate approximately $7.8 billion in direct output for the US economy from the present through 2045 (approximately $6.8 billion in capital expenditures and $1.0 billion in operations and maintenance expenditures). Over the same period, approximately 870 ground infrastructure investments will generate approximately $4 billion in direct output for the US economy ($1.9 billion in capital expenditures and $2.1 billion in operations and maintenance expenditures).

Though difficult to pinpoint the precise locations where ground infrastructure investments will occur, this analysis forecasts varying levels of investment in 30 metropolitan statistical areas (see Table 10). Findings from the literature suggest airport shuttle, regional air mobility, and air taxi use cases will likely rely on airport infrastructure upgrades (UAM Geomatics, 2022; NASA 2021b), including three-phase power and electric charging capabilities for STOL and VTOL aircraft in addition to the utilization of vertiport infrastructure. This analysis assumes that enabling infrastructure investments will be required to fulfill AAM passenger mobility demand modeled over the forecast period.

As described in "Economic Modeling and Terminology" on page 62, direct impacts from AAM passenger mobility activities generate secondary and tertiary benefits from business-to-business transactions and additional spending stemming from increases in household earnings. Altogether, the direct, indirect and induced impacts of AAM passenger mobility on the US economy are shown in **Error! Reference source not found.**, **Error! Reference source not found.**, **Error! Reference source not found.**, AAM Passenger Mobility will support an estimated $18.7 billion in gross domestic product (value added) in the year 2045. AAM Passenger Mobility will generate an estimated total of $118.2 billion from 2023-2045.

, and AAM Passenger Mobility will support an estimated $32.8 billion economic output (business sales) in the year 2045. AAM Passenger Mobility will generate an estimated total of $207.6 billion from 2023-2045.

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### *3.5.7 Workbook Tool Accompanying the Research*

The research team built an excel workbook tool to explore, customize, and calculate the economic impact of AAM passenger mobility accompanies this research. The workbook tool enables users to estimate the economic impact of AAM passenger mobility across the United States and within the 30 projected metropolitan statistical areas where AAM activities are forecasted to emerge from the present through 2045. The workbook tool allows for customized economic impact analyses, in which users can adjust default values and AAM markets by entering user-provided inputs. Figure 28 and Figure 29 show screenshots of the tool.

Table 11. Total US Jobs Supported by AAM Passenger Mobility Through Year 2045.

| Employment | | 2025 | 2030 | 2035 | 2040 | 2045 | Total Job Years |
|---|---|---|---|---|---|---|---|
| **Pax Ticket Revenue** | **Direct** | 90 | 1,180 | 4,660 | 12,315 | 25,925 | 159,495 |
| | **Indirect** | 100 | 1,340 | 5,295 | 13,995 | 29,460 | 181,230 |
| | **Induced** | 140 | 1,875 | 7,415 | 19,595 | 41,245 | 253,735 |
| | **Total** | 330 | 4,395 | 17,370 | 45,905 | 96,630 | 594,460 |
| **Fleet Capital Expenditures** | **Direct** | 15 | 125 | 480 | 495 | 870 | 6,805 |
| | **Indirect** | 35 | 310 | 1,205 | 1,240 | 2,170 | 16,995 |
| | **Induced** | 45 | 385 | 1,490 | 1,535 | 2,690 | 21,080 |
| | **Total** | 95 | 820 | 3,175 | 3,270 | 5,730 | 44,880 |
| **Fleet Operations & Maintenance** | **Direct** | 25 | 280 | 1,095 | 2,895 | 6,090 | 37,470 |
| | **Indirect** | 15 | 195 | 775 | 2,055 | 4,320 | 26,585 |
| | **Induced** | 25 | 280 | 1,095 | 2,895 | 6,090 | 37,470 |
| | **Total** | 65 | 755 | 2,965 | 7,845 | 16,500 | 101,525 |
| **Vertiport Capital Expenditures** | **Direct** | 20 | 185 | 720 | 740 | 1,300 | 10,170 |
| | **Indirect** | 15 | 110 | 430 | 445 | 780 | 6,110 |
| | **Induced** | 25 | 205 | 800 | 825 | 1,440 | 11,290 |
| | **Total** | 60 | 500 | 1,950 | 2,010 | 3,520 | 27,570 |
| **Vertiport Operations & Maintenance** | **Direct** | 25 | 210 | 820 | 845 | 1,480 | 11,585 |
| | **Indirect** | 15 | 125 | 490 | 505 | 885 | 6,940 |
| | **Induced** | 25 | 235 | 910 | 935 | 1,640 | 12,835 |
| | **Total** | 65 | 570 | 2,220 | 2,285 | 4,005 | 31,360 |
| **AAM Pax Mobility Econ Impact** | **Direct** | 175 | 1,980 | 7,775 | 17,290 | 35,665 | 225,525 |
| | **Indirect** | 180 | 2,080 | 8,195 | 18,240 | 37,615 | 237,860 |
| | **Induced** | 260 | 2,980 | 11,710 | 25,785 | 53,105 | 336,410 |
| | **Total** | 615 | 7,040 | 27,680 | 61,315 | 126,385 | 799,795 |

In the year 2045, AAM Passenger Mobility will support an estimated 126,385 jobs. AAM Passenger Mobility will support an estimated 799,795 job-years from 2023-2045.

Table 12. Total US Employee Earnings Supported by AAM Passenger Mobility Through Year 2045 ($2022 USD).

| Labor Income | | 2025 | 2030 | 2035 | 2040 | 2045 | Cumulative |
|---|---|---|---|---|---|---|---|
| **Pax Ticket Revenue** | **Direct** | $10,700,000 | $141,100,000 | $558,000,000 | $1,474,500,000 | $3,103,900,000 | $19,095,400,000 |
| | **Indirect** | $7,400,000 | $96,800,000 | $382,900,000 | $1,011,700,000 | $2,129,600,000 | $13,101,700,000 |
| | **Induced** | $8,400,000 | $110,300,000 | $436,200,000 | $1,152,500,000 | $2,426,000,000 | $14,924,800,000 |
| | **Total** | $26,500,000 | $348,200,000 | $1,377,100,000 | $3,638,700,000 | $7,659,500,000 | $47,121,900,000 |
| **Fleet Capital Expenditures** | **Direct** | $2,100,000 | $18,300,000 | $71,000,000 | $73,200,000 | $128,200,000 | $1,003,800,000 |
| | **Indirect** | $3,500,000 | $29,800,000 | $115,600,000 | $119,100,000 | $208,700,000 | $1,634,000,000 |
| | **Induced** | $2,600,000 | $22,400,000 | $87,100,000 | $89,700,000 | $157,200,000 | $1,230,600,000 |
| | **Total** | $8,200,000 | $70,500,000 | $273,700,000 | $282,000,000 | $494,100,000 | $3,868,400,000 |
| **Fleet Operations & Maintenance** | **Direct** | $1,700,000 | $21,000,000 | $82,700,000 | $218,500,000 | $459,800,000 | $2,829,400,000 |
| | **Indirect** | $1,100,000 | $13,600,000 | $53,600,000 | $141,600,000 | $297,900,000 | $1,833,400,000 |
| | **Induced** | $1,300,000 | $16,200,000 | $64,000,000 | $169,100,000 | $355,800,000 | $2,189,200,000 |
| | **Total** | $4,100,000 | $50,800,000 | $200,300,000 | $529,200,000 | $1,113,500,000 | $6,852,000,000 |
| **Vertiport Capital Expenditures** | **Direct** | $2,100,000 | $18,200,000 | $70,700,000 | $72,800,000 | $127,600,000 | $999,000,000 |
| | **Indirect** | $900,000 | $7,700,000 | $30,000,000 | $30,900,000 | $54,200,000 | $424,300,000 |
| | **Induced** | $1,400,000 | $12,000,000 | $46,700,000 | $48,100,000 | $84,200,000 | $659,600,000 |
| | **Total** | $4,400,000 | $37,900,000 | $147,400,000 | $151,800,000 | $266,000,000 | $2,082,900,000 |
| **Vertiport Operations & Maintenance** | **Direct** | $2,400,000 | $20,700,000 | $80,400,000 | $82,900,000 | $145,200,000 | $1,136,200,000 |
| | **Indirect** | $1,000,000 | $8,800,000 | $34,100,000 | $35,200,000 | $61,700,000 | $482,600,000 |
| | **Induced** | $1,600,000 | $13,700,000 | $53,100,000 | $54,700,000 | $95,900,000 | $750,600,000 |
| | **Total** | $5,000,000 | $43,200,000 | $167,600,000 | $172,800,000 | $302,800,000 | $2,369,400,000 |
| **AAM Pax Mobility Econ Impact** | **Direct** | $19,000,000 | $219,300,000 | $862,800,000 | $1,921,900,000 | $3,964,700,000 | $25,063,800,000 |
| | **Indirect** | $13,900,000 | $156,700,000 | $616,200,000 | $1,338,500,000 | $2,752,100,000 | $17,476,000,000 |
| | **Induced** | $15,300,000 | $174,600,000 | $687,100,000 | $1,514,100,000 | $3,119,100,000 | $19,754,800,000 |
| | **Total** | $48,200,000 | $550,600,000 | $2,166,100,000 | $4,774,500,000 | $9,835,900,000 | $62,294,600,000 |

AAM Passenger Mobility will support an estimated $9.8 billion in employee earnings in the year 2045. AAM Passenger Mobility will have earned an estimated total of $62.3 billion from 2023-2045.

Table 13. Total Gross Domestic Product Supported by AAM Passenger Mobility Through Year 2045.

| Value Added (Gross Domestics Product) | | 2025 | 2030 | 2035 | 2040 | 2045 | Cumulative |
|---|---|---|---|---|---|---|---|
| **Pax Ticket Revenue** | **Direct** | $24,200,000 | $317,800,000 | $1,257,000,000 | $3,321,400,000 | $6,991,700,000 | $43,012,900,000 |
| | **Indirect** | $11,900,000 | $156,700,000 | $620,000,000 | $1,638,200,000 | $3,448,500,000 | $21,215,100,000 |
| | **Induced** | $14,900,000 | $195,700,000 | $774,100,000 | $2,045,500,000 | $4,305,900,000 | $26,489,900,000 |
| | **Total** | $51,000,000 | $670,200,000 | $2,651,100,000 | $7,005,100,000 | $14,746,100,000 | $90,717,900,000 |
| **Fleet Capital Expenditures** | **Direct** | $4,700,000 | $39,700,000 | $154,200,000 | $158,900,000 | $278,300,000 | $2,179,200,000 |
| | **Indirect** | $5,700,000 | $48,400,000 | $188,300,000 | $193,900,000 | $339,800,000 | $2,660,300,000 |
| | **Induced** | $4,700,000 | $39,800,000 | $154,700,000 | $159,300,000 | $279,100,000 | $2,185,400,000 |
| | **Total** | $15,100,000 | $127,900,000 | $497,200,000 | $512,100,000 | $897,200,000 | $7,024,900,000 |
| **Fleet Operations & Maintenance** | **Direct** | $1,900,000 | $22,800,000 | $89,700,000 | $237,100,000 | $498,900,000 | $3,069,900,000 |
| | **Indirect** | $3,700,000 | $44,800,000 | $176,700,000 | $466,800,000 | $982,200,000 | $6,044,200,000 |
| | **Induced** | $3,100,000 | $37,900,000 | $149,400,000 | $394,700,000 | $830,600,000 | $5,110,800,000 |
| | **Total** | $8,700,000 | $105,500,000 | $415,800,000 | $1,098,600,000 | $2,311,700,000 | $14,224,900,000 |
| **Vertiport Capital Expenditures** | **Direct** | $2,400,000 | $20,400,000 | $79,300,000 | $81,700,000 | $143,100,000 | $1,120,500,000 |
| | **Indirect** | $1,300,000 | $11,400,000 | $44,500,000 | $45,800,000 | $80,200,000 | $628,100,000 |
| | **Induced** | $2,500,000 | $21,300,000 | $82,900,000 | $85,300,000 | $149,500,000 | $1,170,600,000 |
| | **Total** | $6,200,000 | $53,100,000 | $206,700,000 | $212,800,000 | $372,800,000 | $2,919,200,000 |
| **Vertiport Operations & Maintenance** | **Direct** | $2,700,000 | $23,200,000 | $90,200,000 | $93,000,000 | $162,900,000 | $1,274,900,000 |
| | **Indirect** | $1,500,000 | $13,000,000 | $50,500,000 | $52,100,000 | $91,300,000 | $714,700,000 |
| | **Induced** | $2,800,000 | $24,200,000 | $94,200,000 | $97,100,000 | $170,100,000 | $1,331,500,000 |
| | **Total** | $7,000,000 | $60,400,000 | $234,900,000 | $242,200,000 | $424,300,000 | $3,321,100,000 |
| **AAM Pax Mobility Econ Impact** | **Direct** | $35,900,000 | $423,900,000 | $1,670,400,000 | $3,892,100,000 | $8,074,900,000 | $50,657,400,000 |
| | **Indirect** | $24,100,000 | $274,300,000 | $1,080,000,000 | $2,396,800,000 | $4,942,000,000 | $31,262,400,000 |
| | **Induced** | $28,000,000 | $318,900,000 | $1,255,300,000 | $2,781,900,000 | $5,735,200,000 | $36,288,200,000 |
| | **Total** | $88,000,000 | $1,017,100,000 | $4,005,700,000 | $9,070,800,000 | $18,752,100,000 | $118,208,000,000 |

AAM Passenger Mobility will support an estimated $18.7 billion in gross domestic product (value added) in the year 2045. AAM Passenger Mobility will generate an estimated total of $118.2 billion from 2023-2045.

Table 14. Total Domestic Output Supported by AAM Passenger Mobility Through Year 2045.

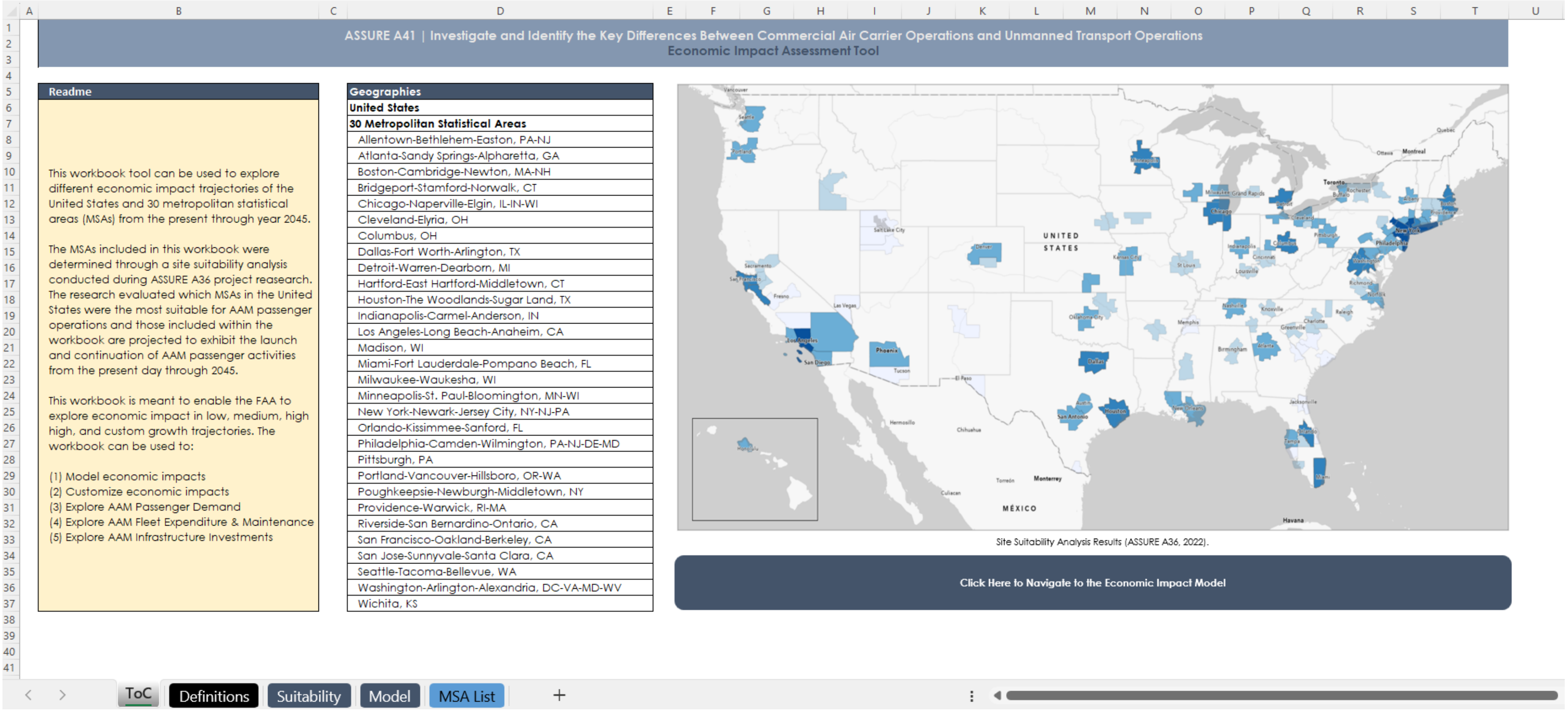
| Output (Business Sales) | | 2025 | 2030 | 2035 | 2040 | 2045 | Total |
|---|---|---|---|---|---|---|---|
| **Pax Ticket Revenue** | **Direct** | $40,710,000 | $535,580,000 | $2,118,580,000 | $5,597,970,000 | $11,783,960,000 | $72,494,980,000 |
| | **Indirect** | $23,647,000 | $311,102,000 | $1,230,618,000 | $3,251,688,000 | $6,844,939,000 | $42,110,101,000 |
| | **Induced** | $26,539,000 | $349,151,000 | $1,381,126,000 | $3,649,380,000 | $7,682,097,000 | $47,260,298,000 |
| | **Total** | $90,896,000 | $1,195,833,000 | $4,730,324,000 | $12,499,038,000 | $26,310,996,000 | $161,865,379,000 |
| **Fleet Capital Expenditures** | **Direct** | $14,510,000 | $123,810,000 | $481,240,000 | $495,690,000 | $868,490,000 | $6,799,670,000 |
| | **Indirect** | $12,995,000 | $110,882,000 | $430,989,000 | $443,930,000 | $777,802,000 | $6,089,647,000 |
| | **Induced** | $8,321,000 | $71,001,000 | $275,974,000 | $284,261,000 | $498,048,000 | $3,899,372,000 |
| | **Total** | $35,826,000 | $305,693,000 | $1,188,203,000 | $1,223,881,000 | $2,144,340,000 | $16,788,689,000 |
| **Fleet Operations & Maintenance** | **Direct** | $3,670,000 | $44,800,000 | $176,690,000 | $466,750,000 | $982,210,000 | $6,043,840,000 |
| | **Indirect** | $3,103,000 | $37,884,000 | $149,414,000 | $394,697,000 | $830,584,000 | $5,110,839,000 |
| | **Induced** | $4,209,000 | $51,375,000 | $202,621,000 | $535,251,000 | $1,126,360,000 | $6,930,839,000 |
| | **Total** | $10,982,000 | $134,059,000 | $528,725,000 | $1,396,698,000 | $2,939,154,000 | $18,085,518,000 |
| **Vertiport Capital Expenditures** | **Direct** | $3,900,000 | $33,700,000 | $131,000,000 | $134,900,000 | $236,300,000 | $1,850,400,000 |
| | **Indirect** | $2,422,000 | $20,931,000 | $81,366,000 | $83,788,000 | $146,769,000 | $1,149,302,000 |
| | **Induced** | $4,402,000 | $38,035,000 | $147,850,000 | $152,251,000 | $266,694,000 | $2,088,406,000 |
| | **Total** | $10,724,000 | $92,666,000 | $360,216,000 | $370,939,000 | $649,763,000 | $5,088,108,000 |
| **Vertiport Operations & Maintenance** | **Direct** | $4,500,000 | $38,300,000 | $148,900,000 | $153,500,000 | $268,900,000 | $2,104,800,000 |
| | **Indirect** | $2,795,000 | $23,789,000 | $92,483,000 | $95,341,000 | $167,017,000 | $1,307,315,000 |
| | **Induced** | $5,079,000 | $43,226,000 | $168,052,000 | $173,244,000 | $303,487,000 | $2,375,527,000 |
| | **Total** | $12,374,000 | $105,315,000 | $409,435,000 | $422,085,000 | $739,404,000 | $5,787,642,000 |
| **AAM Pax Mobility Econ Impact** | **Direct** | $67,290,000 | $776,190,000 | $3,056,410,000 | $6,848,810,000 | $14,139,860,000 | $89,293,690,000 |
| | **Indirect** | $44,962,000 | $504,588,000 | $1,984,870,000 | $4,269,444,000 | $8,767,111,000 | $55,767,204,000 |
| | **Induced** | $48,550,000 | $552,788,000 | $2,175,623,000 | $4,794,387,000 | $9,876,686,000 | $62,554,442,000 |
| | **Total** | $160,802,000 | $1,833,566,000 | $7,216,903,000 | $15,912,641,000 | $32,783,657,000 | $207,615,336,000 |

AAM Passenger Mobility will support an estimated $32.8 billion economic output (business sales) in the year 2045. AAM Passenger Mobility will generate an estimated total of $207.6 billion from 2023-2045.

Table 15. Total Tax Revenue Generated by AAM Passenger Mobility Through Year 2045.

| Total Tax Revenue | | 2025 | 2030 | 2035 | 2040 | 2045 | Total |
|---|---|---|---|---|---|---|---|
| **Pax Ticket Revenue** | **Direct** | $7,245,000 | $95,311,000 | $377,017,000 | $996,201,000 | $2,097,045,000 | $12,901,026,000 |
| | **Indirect** | $2,864,000 | $37,689,000 | $149,086,000 | $393,933,000 | $829,249,000 | $5,101,539,000 |
| | **Induced** | $3,299,000 | $43,412,000 | $171,725,000 | $453,752,000 | $955,168,000 | $5,876,194,000 |
| | **Total** | $13,408,000 | $176,412,000 | $697,828,000 | $1,843,886,000 | $3,881,462,000 | $23,878,759,000 |
| **Fleet Capital Expenditures** | **Direct** | $659,000 | $5,624,000 | $21,859,000 | $22,515,000 | $39,449,000 | $308,855,000 |
| | **Indirect** | $1,088,000 | $9,282,000 | $36,074,000 | $37,157,000 | $65,103,000 | $509,713,000 |
| | **Induced** | $1,035,000 | $8,827,000 | $34,312,000 | $35,342,000 | $61,921,000 | $484,807,000 |
| | **Total** | $2,782,000 | $23,733,000 | $92,245,000 | $95,014,000 | $166,473,000 | $1,303,375,000 |
| **Fleet Operations & Maintenance** | **Direct** | $541,000 | $6,596,000 | $26,013,000 | $68,719,000 | $144,610,000 | $889,827,000 |
| | **Indirect** | $513,000 | $6,258,000 | $24,684,000 | $65,207,000 | $137,217,000 | $844,343,000 |
| | **Induced** | $749,000 | $9,145,000 | $36,067,000 | $95,279,000 | $200,501,000 | $1,233,740,000 |
| | **Total** | $1,803,000 | $21,999,000 | $86,764,000 | $229,205,000 | $482,328,000 | $2,967,910,000 |
| **Vertiport Capital Expenditures** | **Direct** | $507,000 | $4,375,000 | $17,008,000 | $17,514,000 | $30,679,000 | $240,241,000 |
| | **Indirect** | $276,000 | $2,373,000 | $9,224,000 | $9,498,000 | $16,639,000 | $130,293,000 |
| | **Induced** | $547,000 | $4,728,000 | $18,384,000 | $18,931,000 | $33,162,000 | $259,678,000 |
| | **Total** | $1,330,000 | $11,476,000 | $44,616,000 | $45,943,000 | $80,480,000 | $630,212,000 |
| **Vertiport Operations & Maintenance** | **Direct** | $585,000 | $4,973,000 | $19,332,000 | $19,930,000 | $34,912,000 | $273,276,000 |
| | **Indirect** | $318,000 | $2,696,000 | $10,484,000 | $10,808,000 | $18,935,000 | $148,206,000 |
| | **Induced** | $631,000 | $5,375,000 | $20,896,000 | $21,543,000 | $37,736,000 | $295,379,000 |
| | **Total** | $1,534,000 | $13,044,000 | $50,712,000 | $52,281,000 | $91,583,000 | $716,861,000 |
| **AAM Pax Mobility Econ Impact** | **Direct** | $9,537,000 | $116,879,000 | $461,229,000 | $1,124,879,000 | $2,346,695,000 | $14,613,225,000 |
| | **Indirect** | $5,059,000 | $58,298,000 | $229,552,000 | $516,603,000 | $1,067,143,000 | $6,734,094,000 |
| | **Induced** | $6,261,000 | $71,487,000 | $281,384,000 | $624,847,000 | $1,288,488,000 | $8,149,798,000 |
| | **Total** | $20,857,000 | $246,664,000 | $972,165,000 | $2,266,329,000 | $4,702,326,000 | $29,497,117,000 |

AAM Passenger Mobility will support an estimated $4.7 billion tax revenue (local, state, and federal) in the year 2045. AAM Passenger Mobility will generate an estimated total $29.5 billion from 2023-2045.



ASSURE A41 | Investigate and Identify the Key Differences Between Commercial Air Carrier Operations and Unmanned Transport Operations
Economic Impact Assessment Tool

**Readme**

This workbook tool can be used to explore different economic impact trajectories of the United States and 30 metropolitan statistical areas (MSAs) from the present through year 2045.

The MSAs included in this workbook were determined through a site suitability analysis conducted during ASSURE A36 project reasearch. The research evaluated which MSAs in the United States were the most suitable for AAM passenger operations and those included within the workbook are projected to exhibit the launch and continuation of AAM passenger activities from the present day through 2045.

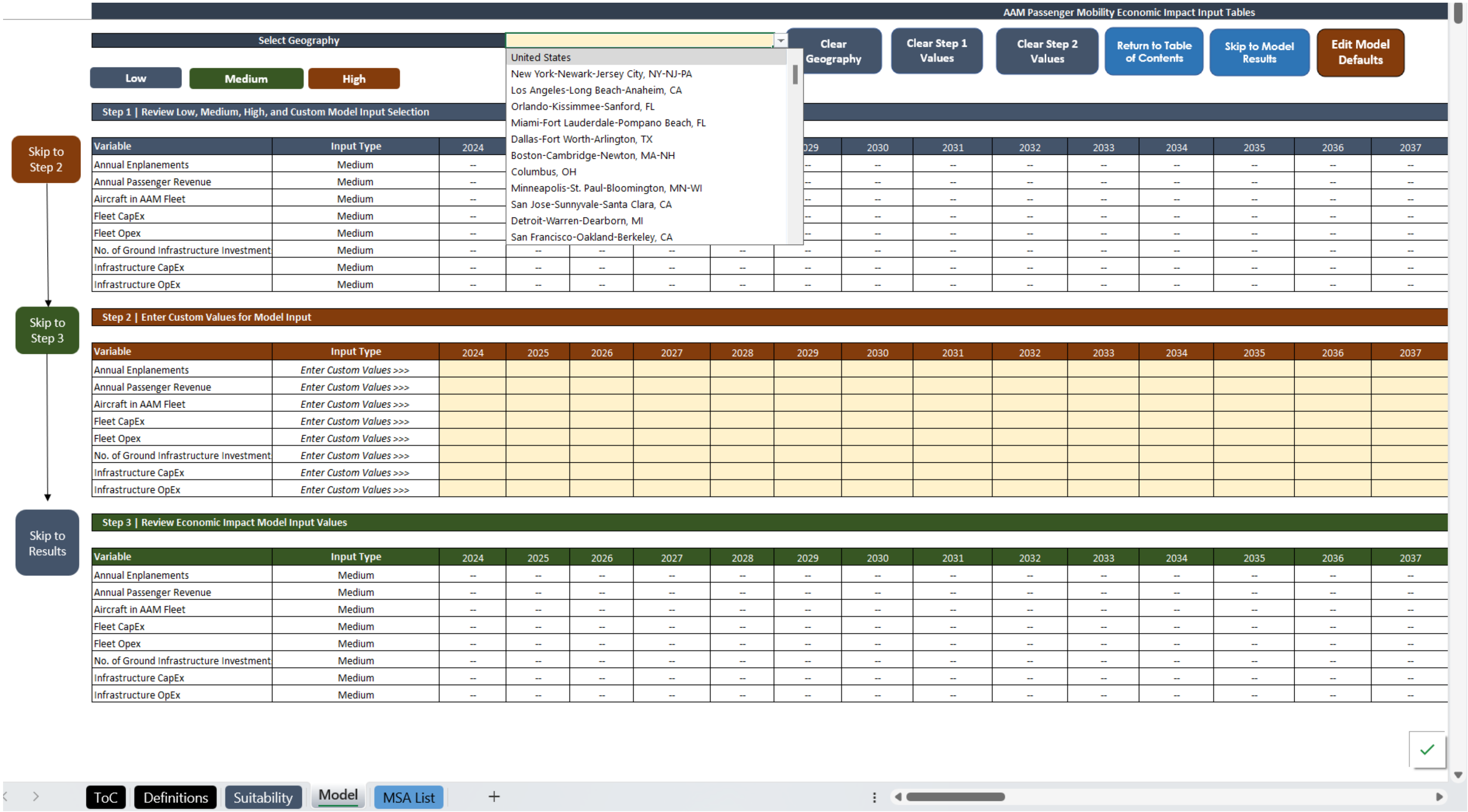
This workbook is meant to enable the FAA to explore economic impact in low, medium, high high, and custom growth trajectories. The workbook can be used to:

(1) Model economic impacts
(2) Customize economic impacts
(3) Explore AAM Passenger Demand
(4) Explore AAM Fleet Expenditure & Maintenance
(5) Explore AAM Infrastructure Investments

**Geographies**
**United States**
**30 Metropolitan Statistical Areas**
Allentown-Bethlehem-Easton, PA-NJ
Atlanta-Sandy Springs-Alpharetta, GA
Boston-Cambridge-Newton, MA-NH
Bridgeport-Stamford-Norwalk, CT
Chicago-Naperville-Elgin, IL-IN-WI
Cleveland-Elyria, OH
Columbus, OH
Dallas-Fort Worth-Arlington, TX
Detroit-Warren-Dearborn, MI
Hartford-East Hartford-Middletown, CT
Houston-The Woodlands-Sugar Land, TX
Indianapolis-Carmel-Anderson, IN
Los Angeles-Long Beach-Anaheim, CA
Madison, WI
Miami-Fort Lauderdale-Pompano Beach, FL
Milwaukee-Waukesha, WI
Minneapolis-St. Paul-Bloomington, MN-WI
New York-Newark-Jersey City, NY-NJ-PA
Orlando-Kissimmee-Sanford, FL
Philadelphia-Camden-Wilmington, PA-NJ-DE-MD
Pittsburgh, PA
Portland-Vancouver-Hillsboro, OR-WA
Poughkeepsie-Newburgh-Middletown, NY
Providence-Warwick, RI-MA
Riverside-San Bernardino-Ontario, CA
San Francisco-Oakland-Berkeley, CA
San Jose-Sunnyvale-Santa Clara, CA
Seattle-Tacoma-Bellevue, WA
Washington-Arlington-Alexandria, DC-VA-MD-WV
Wichita, KS

Site Suitability Analysis Results (ASSURE A36, 2022).

Figure 28. Illustration of the Workbook Tool's Opening Menu.



Select Geography

- United States
- New York-Newark-Jersey City, NY-NJ-PA
- Los Angeles-Long Beach-Anaheim, CA
- Orlando-Kissimmee-Sanford, FL
- Miami-Fort Lauderdale-Pompano Beach, FL
- Dallas-Fort Worth-Arlington, TX
- Boston-Cambridge-Newton, MA-NH
- Columbus, OH
- Minneapolis-St. Paul-Bloomington, MN-WI
- San Jose-Sunnyvale-Santa Clara, CA
- Detroit-Warren-Dearborn, MI
- San Francisco-Oakland-Berkeley, CA

Step 1 | Review Low, Medium, High, and Custom Model Input Selection

| Variable | Input Type | 2024 | | | | | 029 | 2030 | 2031 | 2032 | 2033 | 2034 | 2035 | 2036 | 2037 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Annual Enplanements | Medium | -- | | | | | -- | -- | -- | -- | -- | -- | -- | -- | -- |
| Annual Passenger Revenue | Medium | -- | | | | | -- | -- | -- | -- | -- | -- | -- | -- | -- |
| Aircraft in AAM Fleet | Medium | -- | | | | | -- | -- | -- | -- | -- | -- | -- | -- | -- |
| Fleet CapEx | Medium | -- | | | | | -- | -- | -- | -- | -- | -- | -- | -- | -- |
| Fleet Opex | Medium | -- | | | | | -- | -- | -- | -- | -- | -- | -- | -- | -- |
| No. of Ground Infrastructure Investment | Medium | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- |
| Infrastructure CapEx | Medium | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- |
| Infrastructure OpEx | Medium | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- |

Step 2 | Enter Custom Values for Model Input

| Variable | Input Type | 2024 | 2025 | 2026 | 2027 | 2028 | 2029 | 2030 | 2031 | 2032 | 2033 | 2034 | 2035 | 2036 | 2037 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Annual Enplanements | *Enter Custom Values >>>* | | | | | | | | | | | | | | |
| Annual Passenger Revenue | *Enter Custom Values >>>* | | | | | | | | | | | | | | |
| Aircraft in AAM Fleet | *Enter Custom Values >>>* | | | | | | | | | | | | | | |
| Fleet CapEx | *Enter Custom Values >>>* | | | | | | | | | | | | | | |
| Fleet Opex | *Enter Custom Values >>>* | | | | | | | | | | | | | | |
| No. of Ground Infrastructure Investment | *Enter Custom Values >>>* | | | | | | | | | | | | | | |
| Infrastructure CapEx | *Enter Custom Values >>>* | | | | | | | | | | | | | | |
| Infrastructure OpEx | *Enter Custom Values >>>* | | | | | | | | | | | | | | |

Step 3 | Review Economic Impact Model Input Values

| Variable | Input Type | 2024 | 2025 | 2026 | 2027 | 2028 | 2029 | 2030 | 2031 | 2032 | 2033 | 2034 | 2035 | 2036 | 2037 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Annual Enplanements | Medium | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- |
| Annual Passenger Revenue | Medium | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- |
| Aircraft in AAM Fleet | Medium | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- |
| Fleet CapEx | Medium | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- |
| Fleet Opex | Medium | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- |
| No. of Ground Infrastructure Investment | Medium | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- |
| Infrastructure CapEx | Medium | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- |
| Infrastructure OpEx | Medium | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- |

Figure 29. Illustration of the Workbook Tool’s Economic Impact Module.

# 4 CONCLUSIONS

This project investigated important aspects of AAM that set it apart from traditional views of aviation. More specifically, researchers explored some of the bigger considerations for AAM, its growth, and likely trajectory. As AAM continues to evolve, markets forecasts show regional air mobility and air taxi use cases capturing nearly two thirds of all passenger markets (UAM Geomatics, 2021) with AAM passenger transport also occurring via airport shuttle and corporate shuttle use cases. Due to their large shares of the AAM passenger mobility market, the research team focused on two primary subsets of AAM, UAM and RAM for the designed experiments (Tasks 3 and 4), obtaining meaningful data from the largest market segments. For the economic assessment (Task 5), the research team analyzed the economic impact of air taxi, short-haul regional air mobility (flights ranging from 0-200 miles with STOL and VTOL aircraft), airport shuttle, and corporate shuttle use cases. This enabled the research team to assess the current state of the industry, plausible use cases, and analyze economic impacts and forecasts from the standpoint of users and industry stakeholders.

During this research, the team (1) assessed the current state of the industry and identify market trends, (2) developed use cases based on the state of the industry and market trends, and (3) conducted experiments and economic assessments that enabled the team to generate forecasts for the AAM industry. This approach provided a means to address questions regarding the growth of AAM, how it will impact existing transportation modes, and its potential social and economic impacts.

## 4.1 Summary of Findings by Task

The following sections offer general conclusions drawn from relevant project tasks. Information in these sections is drawn from project deliverables and data collected throughout the project. Many of these findings represent the high-level outcomes of research tasks and serve to support more specific conclusions drawn to answer research questions.

### *4.1.1 Summary of Findings – Literature Review*

The literature review (Section 3.1) assessed the current state and future trajectory of AAM passenger transport. AAM passenger transport is a complex issue, as there are a host of considerations when addressing new types of aircraft, new infrastructure, and regulatory issues. Early AAM aircraft may largely be piloted, but regulatory changes may be required with the introduction of higher levels of autonomy. Both pilot/operator and vehicle certification procedures may require revision to accommodate new modes of aircraft control, simplified control interfaces, and new traffic procedures. Operator training and certification should reflect the anticipated SVO concepts and the move toward higher levels of autonomy. Streamlined vehicle certification procedures must maintain rigorous testing, especially of the developing autonomy components, as well as allow flexibility to appropriately certify the wide range of vehicle designs, configurations, and mission profiles. In addition to regulatory changes, a safe and incremental approach to integrating automation will make AAM more practical and feasible. The scope and scale of these changes, as well as the scale of AAM passenger transport, will increase substantially over time.

### *4.1.2 Summary of Findings – Market Analysis*

The team conducted an initial market analysis (Section 3.1.2)in parallel with the literature review, which informed both the literature and the use cases for further study. The market analysis conducted for Task 1.2 is based upon past work from the ASSURE A36 site suitability analysis and derived data regarding market viability, direct/indirect impacts of the AAM market, infrastructure requirements, and AAM use cases. Not only did the market analysis inform use cases for this study, but it also formed the foundation for a deeper economic assessment that expanded upon AAM market drivers, infrastructure, and larger economic forecasts.

Based upon data from UAM Geomatics (2022), the most prominent use cases were determined to be air taxi and RAM operations. Briefly, the definition of air taxi operations consists of on-demand air-transport services for urban areas (i.e., high-density, short duration). RAM operations are either scheduled or on-demand medium range (between 50 and 500 miles) air-transport services operating from existing general aviation airport facilities. Detailed scenario descriptions defined variables of interest. A two-pronged approach allowed researchers to explore the influence of the defined variables, soliciting input from both projected AAM relevant technology OEMs, as well as prospective air taxi and RAM passengers.

### *4.1.3 Summary of Findings – OEM Interviews*

Verbal interviews (Section 3.4.3.5) provided insight from OEMs and AAM stakeholders on key issues such as infrastructure requirements, design/airworthiness considerations, and economic/demand factors. The primary results of these interviews include input on the transition to autonomy, interoperability, and a need for standardization.

OEMs and stakeholders were in general agreement that there would be a transition between pilot and uncrewed aircraft for AAM. However, there was no consensus as to when and how that transition would occur. OEM estimates on timelines for the transition varied, ranging from 18 months to within the next decade. However, OEMs for air taxi aircraft seemed less confident in their timelines than those in air cargo.

OEMs and other AAM stakeholders also largely agreed on the need for interoperability and data exchange with the broader ATC system, to include UTM networks. Except for one logistics-focused OEM, all OEMs and stakeholders expressed a clear need to interface with, and be part of, the broader air traffic ecosystem. This points to a clear understanding among OEMs and stakeholders interviewed for this research that there is a need for AAM vehicles to integrate into the NAS. This includes using ADS-B (in/out), communicating with ATC, and understanding the movements of other traffic. Two OEMs indicated they believed AAM aircraft would operate within dedicated corridors.

One of the more significant themes identified through interviews was the need for regulatory changes and standardization. OEMs expressed a need to make changes to regulations and standards to accommodate the new technologies, such as autonomy, electric propulsion, and others. This was especially true for OEMs pursuing a TC. For OEMs pursuing a TC, experiences varied, and the common themes emphasized a need for process improvements and standardization. One stakeholder referred to the TC process as a “moving target,” a statement corroborated by other respondents. The consensus was that standards would be helpful to address questions regarding type certification and better guidance for new entrants would be beneficial.

### *4.1.4 Summary of Findings – Survey*

The research team leveraged an online survey (Section 3.4.3) to explore the influence of the developed variables on end users' willingness to fly in autonomous vehicles and willingness to pay for such services, as well as assess the impact of the pandemic and other factors influencing demand for RAM and air taxi services. These results are detailed in Sections 3.4.3.1 through 3.4.3.4. Survey results suggest that, while the COVID-19 pandemic did affect respondents comfort level flying, the effect was smaller among those likely to be first adopters of AAM. These trends appeared consistent nationwide in an average sense. Researchers compared the responses of respondents who reported using public transportation for their commute with those who reported using a personal vehicle. Public transportation users reported equal willingness to pay for AAM services. Responses also indicated greater comfort levels with AAM services than those reported in the literature. This may suggest that cultural considerations have a significant impact on potential end-users' comfort level with AAM. Additionally, time savings was the largest anticipated motivation to use AAM services. The research team identified several other strong correlations, including some that were not anticipated. Future work should explore additional connections and correlations between data points that were not addressed in this research.

### *4.1.5 Summary of Findings – Economic Assessment*

The research team leveraged the site suitability analysis and advanced passenger mobility demand findings from the ASSURE A36 project as a basis for this economic assessment (Section 3.5). Using assumptions for flight demand, the research team leveraged IMPLAN to estimate the economic impact of UAM and RAM activities from the present day through 2045 stemming from ticket revenue, infrastructure expenditures, aircraft expenditures, and business-to-business purchases within the UAM and RAM supply chains. Expectations show that UAM and RAM use cases could gross $72.5 billion in ticket sales, resulting in the manufacture of more than 3,890 new STOL & VTOL aircraft, and the construction of approximately 870 new vertiports (including appropriate infrastructure, e.g., electric grid upgrades), all by the year 2045. Projections show AAM passenger mobility facilitating 126,385 jobs, $9.8 billion in employee earnings, $18.8 million in gross domestic product, $32.8 billion in economic output (business sales), and $4.7 billion in tax revenue when accounting for direct, indirect, and induced economic impacts (appraised in 2022 US dollars) in the year 2045. Over the forecast period this equates to 799,795 job-years, $62.3 billion in cumulative earnings, $118.2 billion in cumulative gross domestic product, $207.6 billion in cumulative economic output, and $29.5 billion in cumulative tax revenue.

## 4.2 Answers to Research Questions

This section provides an overview of research questions and identified findings related to each. While this project addressed a wide variety of topics and research questions, no single task or subtask was able to answer all research questions. For the sake of simplicity, this section provides an overview of findings for research questions and identify the associated task, section, appendix, or subtask.

Research Question 1: *What is the potential for large Unmanned [Uncrewed] Aircraft Systems (UAS) in carrying passengers in the US? Starting from road transportation and existing air transportation, it is expected that a potential market scope will be laid out.*

AAM passenger mobility is continuing to evolve as a feasible alternative to traditional aviation and ground transportation. Serving estimated 135,000 AAM enplanements in 2024, the market is projected to grow to 85.4 million enplanements in 2045 (this equates to approximately 5 percent of the air carrier and commuter enplanements forecast in 2045 using APO Terminal Area Forecast Summary Report [FAA, 2023]). Over this time horizon, an estimated 525.4 million enplanements are projected to be serviced through AAM passenger mobility market segments (not including emergency medical missions), generating approximately $72.5 billion in ticket revenue.

AAM operations are anticipated to begin in a handful of launch cities and expand to service in approximately 30 metropolitan statistical areas by 2045. The 30 MSAs projected to become AAM markets can be found in Table 2.

Research Question 2: *What are the likely locations of large UAS to meet demand and growth of air transportation over a period of 10 years?*

Within the next 10 years. Several domestic AAM markets are projected to come online to directly service passenger operations. These markets may include New York, Chicago, Los Angeles, San Francisco, and Orlando, among various locations in southeastern Florida (SMG Consulting, 2023). In addition to these markets, dozens of metropolitan statistical areas (MSAs) that are suitable for AAM passenger mobility and are anticipated to host passenger operations by 2045. The entire list of the 30 MSAs anticipated to become AAM markets can be found within the report in Table 2

Research Question 3: *Will this change significantly following the recovery from COVID-19?*

Survey results show that respondents' comfort level flying with regard to COVID-19 may have already recovered somewhat. Additionally, those who may be first adopters (those who expressed comfort with autonomous flight, come from higher income households, and indicated greater willingness to pay more for AAM services) generally expressed greater comfort flying, with regard to COVID-19. This may indicate that potential end users' concern due to COVID-19 will not have a significant effect, at least on the initial roll out of AAM services. The general location analysis performed showed no statistically significant (at the $p < 0.05$ level) trends (relative to location) related to change in comfort flying commercially due to COVID-19. Site specific analyses should be conducted for individual MSAs of interest.

Research Question 4: *What interface characteristics are necessary for UAS passenger (e.g., UAM) to maintain awareness of aircraft system state with automated aircraft system and subsystem control?*

The research team did not identify any specific characteristics for passenger interfaces necessary to maintain awareness of aircraft automation state or subsystem control. The literature review component of this research (Appendix A) did not identify specific considerations for passenger interactions with the aircraft themselves, so the research team used interviews with OEMs to determine how they were approaching this question. The research team used interview questions 4 and 5 to address this research question, framing it in terms of passenger information displays to provide data on their trip, routing, and status. This provided an analog to common passenger information displays available on commercial flights while allowing researchers to ask OEMs what may be different or unique for their systems.

Interviews did not reach a consensus regarding available flight information, but they did highlight that OEMs are making considerations for providing flight information to passengers. However, there was no specific agreement on what that information should be. Interview results showed that AAM cargo OEMs made no provisions for passengers, which was not surprising. Of the four OEMs building aircraft for passenger transport, two were uncertain what data to provide to passengers, one did not provide any detail, and one offered that passengers would be able to tap into as much of their experience as possible, being offered similar data to what is available on passenger flights and with information similar to that of existing ride sharing apps.

More at the heart of this research question is what kinds of safety data is available to passengers, particularly in automated aircraft. Of the OEMs interviewed, two referenced avionics available in the cockpit provide flight critical information to the pilot. This implied that the pilot was the primary conduit for aircraft status and system/subsystem information. However, one OEM did state that they intend to offer important flight metrics, such as fuel consumption, airworthiness reporting, and system safety assurance reporting to passengers. They did not provide further clarification on what this information would be.

The research team was unable to arrive at definitive conclusions as to what specific characteristics are necessary for passengers to maintain awareness of automated systems. However, the research team did receive input from OEMs implying that piloted aircraft will likely rely on more conventional means to convey flight information – i.e., relaying information to passengers via a pilot in command. Interviews imply that OEMs are making considerations for safety and the overall passenger experience, providing both trip and status information to passengers. However, there was not a consensus among OEMs interviewed as to what that information should be.

Research Question 5: *What are the envisioned characteristics of transition from piloted UAS to fully autonomous UAS in carrying passengers? What are the likely conditions that enable piloted UAS to transition into fully automated UAS and likely timeline?*

Findings from the literature review from Task 1 (Appendix A) indicated that the transition from piloted to autonomous aircraft that carry passengers will likely be gradual and calculated, following an increase in sophistication of aircraft, simplification of aircraft controls, and a gradual shift to greater autonomy as technology is vetted. However, interview responses from OEMs provided a different perspective regarding how that transition might occur and the timelines for doing so. OEM interviews showed that different OEMs have different ideas regarding the role of autonomy and the timeline(s) for its implementation.

OEM responses to interview questions 6 – 9 implied that the predicted trends in literature are generally sound, but they are not necessarily universal. Each OEM took a different perspective on the role of autonomy in their aircraft. For example, OEMs for air cargo aircraft were more eager to embrace higher levels of autonomy than those for passenger carrying aircraft as of the time of interviews. Overall, OEMs interviewed for this study displayed a broad spectrum of attitudes on the path to autonomous aircraft, ranging from conservative, focusing on a piloted system, to being more willing push technological boundaries early on.

Timelines for this transition were left unclear, both from the literature review and interviews. OEMs interviewed for this study provided broad assessments of 18 months to simply, "within a decade." At least one OEM stated that non-US markets were attractive for further development of capabilities.

Findings from the literature review show a relatively ordered, logical transition from piloted to unpiloted aircraft that follows the path of technological progress. While this general approach was generally acknowledged by OEMs interviewed for this research, OEMs had varying opinions of how and when to implement different levels of autonomy within their aircraft.

Research Question 6: *What interface characteristics are necessary for the UAS pilot to manage the aircraft's flight path with automated navigation?*

The literature review (Appendix A) did not identify specific characteristics of remote pilot interfaces and displays – e.g., specific information, information presentation, alerts, or interface designs, and the research team did not identify any standard means for presenting flight information for AAM aircraft. However, the research team did identify trends in cockpit information displays that support the transition from crewed to uncrewed AAM aircraft within the literature review. Interviews with OEMs provided little in the way of approaches to displaying flight data and identifying specific characteristics of their control interfaces.

The literature review identified that AAM will follow a path to automation that is marked by phasing out human pilots and moving to remotely piloted and autonomous systems over time. These changes will be marked by a simplification of controls, presenting only what the pilot needs to control the aircraft. More specifically, the literature review identified that Simplified Vehicle Operations (SVO) are the path forward for the immediate future, which incorporates technologies to make the aircraft easier and safer to operate (NASA, 2021b). This was reinforced in a paper by NASA regarding the RAM and the path from piloted to unpiloted aircraft.

> … 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, 2021b)

Interviews with OEMs did not identify specific characteristics of control interfaces, despite OEMs pursuing a diverse range of aircraft with differing control modalities. Interviews did identify that OEMs, in large part, have an understanding that the move to higher levels of autonomy and simplified controls will be a process. Specifically, three of the four AAM OEMs interviewed mentioned a need to validate technological approaches to autonomy over time before making the leap to remotely piloted or autonomous systems. As such, a portion of these OEMs referenced a reliance on more traditional cockpit interfaces until the regulatory environment and the necessary infrastructure can support remotely piloted and autonomous passenger carrying aircraft.

Research Question 7: *How can autonomous systems be evaluated or certified such that safe integration of UAS in the existing ATM environment or emerging Unmanned [Uncrewed] Traffic Management (UTM) is enabled?*

The research team found even with established paths for type certification – i.e., addressing novel designs by establishing a certification basis via Title 14 CFR 21.17(b), there are still gaps where OEMs struggle to comply with existing regulatory requirements. According to findings from the literature review (Appendix A), the certification of AAM vehicles follows a risk-based continuum, accounting for operational considerations, design features, and overall risk associated with the operation of a given system. Existing pathways for type certification of novel aircraft via 14 CFR 21.17(b) allow aircraft manufacturers to define means of compliance for novel designs/design features, but overall, the research identified a dearth of standards that provide guidance on key issues.

The ANSI *Standardization Roadmap for Unmanned Aircraft Systems, Version 2.0* (ANSI, 2020) identified gaps in standards regarding commercial cargo transport via UAS, commercial passenger air taxi transport via UAS, and commercial passenger transport via UAS (long-haul flights) as gap areas where additional work is required (pp. 337 – 351). The gaps identified in the ANSI *Standardization Roadmap* were mostly aligned with responses to interview questions 15 – 16 in which respondents identified "moving targets" within the certification process, stemming from the unique aspects of their systems and a cited lack of standards. However, despite challenges, the OEMs interviewed largely concluded that the TC process was difficult but overall manageable. OEM resposnes reflected that while there is a need for greater standardization and a desire to see standards to address their [unspecified] challenges with the process, most OEMs interviewed stated that the process was rigorous and took time.

Research Question 8: *How will the UTM paradigm integrate with the large UAS environment? Or will a separate paradigm be needed? How will these paradigms be integrated with the NAS ATM that is already in place?*

Indications from literature and interviews with OEMs indicate that UTM and broader ATM infrastructure will be linked and rely on data exchange. Hill et al., (2020) describes the UAM operating environment (UOE) and as being built around UTM concepts (Hill et al., p. 10, 2020). Similar to UTM, UAM traffic systems are anticipated to coexist with conventional airspace classes, constructs, and traffic systems, instead relying heavily on third-party service suppliers (Hill et al., p. 10, 2020).

The notion that UAM airspace and traffic systems are anticipated to interface with both conventional air traffic systems and UTM systems was reflected in responses to interview questions 10 – 12. All OEMs interviewed anticipated the need to interface with UTM traffic systems on some level, emphasizing that interoperability and compatibility with available resources in the NAS to maintain safety.

Research Question 9: *How will strategic scheduling of large UAS occur?*

AAM passenger mobility is anticipated to be scheduled in a number of ways, depending on the market segment.

Airport shuttles, which will transport people to and from airports, are expected to provide an invaluable transportation option for domestic and global business travelers who fly into commercial airports and very quickly need to reach nearby destinations for business appointments. Similarly, airport shuttles are expected to provide transportation services to leisure travelers seeking fast and reliable transportation. Airport shuttle services are expected to emulate the existing scheduling models of helicopter companies like Blade, which currently offers traditional helicopter charter services that connect people from John F. Kennedy International Airport (JFK) and Newark airport (EWR) to select locations in Manhattan for $195 (Blade, 2022).

In a fully mature AAM paradigm, air taxis are envisioned to offer thousands of people autonomous or semiautonomous air mobility services on a daily basis in major cities (Hill et al., 2020). Air taxis will likely involve a combination of ground transportation, ride sharing, and air transport. During its June 3, 2021, Analyst Day presentation, Joby Aviation demonstrated examples of what an initial air taxi concept would look like in California. A trip from Santa Monica Airport (SMO) airport to Burbank Airport (BUR) would take an estimated 10 minutes, compared to 39 minutes of driving time. As new AAM ground infrastructure (vertiports, vertipads, helipads with fueling and charging) is constructed, additional flight paths would become available, creating air transportation services that dramatically improve travel times.

RAM is likely to revolutionize travel in megaregions, which have large urban centers that attract people for business or leisure. Lilium has developed initial concepts of RAM that it is exploring for future operations in California and the Northeast with flight ranges up to 186 miles. RAM aircraft are anticipated to carry passengers between 50 and 500 miles, generate less noise, handle steep climb/descent profiles, and operate from short runways (eventually vertiports) within smaller communities (NASA, 2021; UAM Geomatics 2021). Like air taxis, a combination of ground transportation ridesharing and air transport will be used as passengers schedule their AAM passenger mobility services.

Corporate shuttle services are anticipated to complement a corporation's aviation fleet and solve their "last mile" challenges by connecting corporate staff to business meetings or other locations in the city center. Corporate shuttles are expected to be electric or hybrid aircraft capable of VTOL. Scheduling corporate shuttle services will likely involve a mix of contracting services from existing AAM passenger mobility providers and establishing "in-house" mobility options.

Research Question 10: *How will non-scheduled large UAS be handled?*

While the research team did not identify a specific methodology for the handling of non-scheduled large UAS, the research team did identify a key factor that governs their operation. The literature review identified that operational efficiency is a critical factor in UAM service[9]. The literature review (Appendix A) identified that throughput is key. As such, scheduling should minimize turnaround time. Vascik (2020) identified that vertiport throughput as the key variable when scaling UAM systems. Minimizing turnaround time is essential to ensure high-demand facilities are able to maintain and maximize capacity.

Research Question 11: *What other resources and NAS investment may be necessary to facilitate growth of UAS in air passengers?*

Advanced air mobility will require enabling infrastructure investments for domestic markets to reach maturity. Research findings demonstrate that ground infrastructure investments will need to take place in approximately 870 distinct locations within 30 metropolitan statistical areas in the United States (see Table 10). Varying levels of investment and different types of enabling infrastructure are anticipated throughout the United States (see Table 8 and Table 10). Of the total enabling infrastructure facilities, an estimated 79.3 percent of investments by volume would need to support existing airport retrofits and the construction of new vertipads (600 square-feet VTOL and STOL aircraft takeoff, landing, and parking infrastructure with an average of 2 parking and

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[9] Appendix A, pp. A-44 – A-45

charging spaces), 12.4 percent would support new vertibases (23,000 square-feet VTOL and STOL takeoff, landing, and aircraft parking infrastructure with an average of 6 parking and charging spaces), 8.2 percent would support vertihubs (70,000 square-feet VTOL and STOL aircraft takeoff, landing, and aircraft parking infrastructure with an average of 20 parking and charging spaces) and 0.1 percent of investments would support megahubs (VTOL and STOL aircraft takeoff, landing, and aircraft parking infrastructure with an average of 40 parking and charging spaces). In addition to ground enabling infrastructure, aircraft certification, aircraft capital investment (an estimated 3,490 AAM aircraft by the end of 2045), and consumer readiness will be required for AAM domestic markets to reach maturity.

Research Question 12: *What will be the aggregated economic benefits, i.e., direct, indirect, and induced, of integrating large UAS in transporting passengers on the overall economy?*

The economic impact assessment from Task 5 focuses on quantifying the aggregated economic benefit of integrating large UAS into passenger transport. Using the forecasts developed within this research, it is anticipated that large UAS will generate the following impacts on the overall economy:

- 799,795 cumulative job-years from the present through 2045 (225,525 direct, 237,860 indirect, and 336,410 induced job-years). In the year 2045, AAM passenger mobility will support a total of 126,385 workers (35,665 direct, 37,615 indirect, and 53,105 indirect jobs).

- $62.3 billion in cumulative earned income over the forecast period ($25 billion direct, $17.5 billion indirect, and $19.8 billion induced). In the year 2045, AAM passenger mobility will support the total earnings of $9.8 billion ($4 billion direct, $2.7 billion indirect, and $3.1 billion induced).

- $118.2 billion in cumulative gross domestic product over the forecast period ($50.6 billion direct, $31.3 billion indirect, and $36.3 billion induced.) In the year 2045, AAM passenger mobility will support a total gross domestic product of $18.8 billion ($8.1 billion direct, $5 billion indirect, and $5.7 billion induced).

- $207.6 billion in cumulative economic output ($89.3 billion direct, $55.8 billion indirect, and $62.5 billion induced.) In the year 2045, AAM passenger mobility will support a total economic output of $32.8 billion ($14.1 billion direct, $8.8 billion indirect, and $9.9 billion induced).

- $29.5 billion in cumulative tax revenue ($2.6 billion collected by subcounty general districts [city and townships], $2.7 billion collected by subcounty special districts [fire, school, etc.], $1.8 billion collected by counties, $7.5 billion collected by states, and $14.9 billion collected by the federal government).

# 5 REFERENCES

Ackert, S. (2011). *The Relationship Between an Aircraft's Value and its Maintenance Status.* http://www.aircraftmonitor.com/uploads/1/5/9/9/15993320/the_relationship_between_an_aicrafts_value__its_maintenance_status___v1.pdf

Al Haddad, C., Chaniotakis, E., Straubinger, A., Plötner, K., & Antoniou, C. (2020). Factors affecting the adoption and use of urban air mobility. *Transportation Research Part A: Policy and Practice*, *132*(December 2019), 696–712. https://doi.org/10.1016/j.tra.2019.12.020

ANSI. (2020). *Standardization Roadmap For Unmanned Aircraft Systems, Version 2.0* (June). https://share.ansi.org/Shared

Archer. (2023). *United Airlines and Archer Announce First Commercial Electric Air Taxi Route in Chicago.* https://investors.archer.com/news/news-details/2023/United-Airlines-and-Archer-Announce-First-Commercial-Electric-Air-Taxi-Route-in-Chicago/default.aspx

ASSURE. (2023). *Urban Air Mobility Studies*. Retrieved August 4, 2023, from https://www.assureuas.org/projects/urban-air-mobility-studies/

Battles, B. (2003). *Maintenance Costs: Significant but Tricky.* Aviation Pros. https://www.aviationpros.com/aircraft/maintenance-providers/mro/article/10387195/aircraft-maintenance-costs-significant-but-tricky

Booz, Allen, Hamilton. (2018). *Urban Air Mobility (UAM) Market Study.* https://ntrs.nasa.gov/citations/20190001472

CINT. (2023). *Academic Research*. Retrieved November 2, 2023, from https://www.cint.com/academic-research

*Communities by Zip Code Los Angeles County*. (2023a). Los Angeles Almanac. Retrieved November 3, 2023, from https://www.laalmanac.com/communications/cm02a91001-93599.php

*Communities by Zip Code Los Angeles County*. (2023b). Los Angeles Almanac. Retrieved November 3, 2023, from https://www.laalmanac.com/communications/cm02a90001-90899.php

Crown Consulting Inc., Ascension Global, Georgia Tech Aerospace Systems Design Lab, McKinsey & Company, & NASA. (2018). *Urban Air Mobility (UAM) Market Study*. https://ntrs.nasa.gov/api/citations/20190001190/downloads/20190001190.pdf

EASA (2021). Study on the Societal Acceptance of Urban Air Mobility in Europe. Online: https://www.easa.europa.eu/sites/default/files/dfu/uam-full-report.pdf

Federal Aviation Administration. (2023). *APO Terminal Area Forecast Summary Report.* https://taf.faa.gov/

Garrow, L. A., Mokhtarian, P. L., German, B. J., & Boddupalli, S.-S. (2019). Commuting in the Age of the Jetsons: A Market Segmentation Analysis of Autonomous Ground Vehicles and Air Taxis in Five Large U.S. Cities. Atlanta: Georgia Institute of Technology. https://doi.org/10.2514/6.2020-3258

Hill, B., DeCarme, D., Metcalfe, M., Griffin, C., Wiggins, S., Metts, C., Bastedo, B., Patterson, M., & Mendonca, N. (2020). *UAM Vision Concept of Operations*. 0–94. https://ntrs.nasa.gov/citations/20205011091

Hussain, A., and Silver, D. (2021). *Advanced Air Mobility: Can the United States Afford to Lose the Race?* Deloitte. https://www2.deloitte.com/us/en/insights/industry/aerospace-defense/advanced-air-mobility.html

Jiang, T., Geller, J., Ni, D., & Collura, J. (2016). Unmanned Aircraft System traffic management: Concept of operation and system architecture. *International Journal of Transportation Science and Technology*, *5*(3), 123–135. https://doi.org/10.1016/j.ijtst.2017.01.004

Joby (2022). Press Releases. Online: https://ir.jobyaviation.com/news-events/press-releases

Johnston, T., Riedel, R., and Sadhev, S. (2020). *To take off, flying vehicles first need places to land.* McKinsey & Company. https://www.mckinsey.com/industries/automotive-and-assembly/our-insights/to-take-off-flying-vehicles-first-need-places-to-land

KPMG (2019). *Getting Mobility Off the Ground – Urban Air Mobility is Poised to Take Off As Premium Service Option in the World's Largest, Most Congested Cities.*

Lascara, B., Spencer, T., DeGarmo, M., Lacher, A., Maroney, D., & Guterres, M. (2018). *Urban Air Mobility Landscape Report: Initial Examination of a New Air Transportation System*. https://www.mitre.org/publications/technical-papers/urban-air-mobility-landscape-report

Moore, R. (No Date). *Maintenance Costs as a Percent of Asset Replacement Value: A Useful Measure?* https://reliabilityweb.com/en/articles/maintenance-cost

Munroe, D. K. (2005). *Input–Output Analysis.* Encyclopedia of Social Measurement. https://www.sciencedirect.com/topics/agricultural-and-biological-sciences/input-output-analysis#:~:text=Input%E2%80%93output%20(IO)%20analysis,base%20and%20input%E2%80%93output%20models.

NASA (2021a). Community Annex Teams. For Internal Use Only.

NASA. (2021b). *Regional Air Mobility: Leveraging Our National Investments to Energize the American Travel Experience*. https://sacd.larc.nasa.gov/sacd/wp-content/uploads/sites/102/2021/04/2021-04-20-RAM.pdf

*New York City Zip Codes*. (n.d.). NYC by Natives. Retrieved November 3, 2023, from https://www.nycbynatives.com/nyc_info/new_york_city_zip_codes.php

Olivares, G. et al. (2022). *Evaluation of UAM Market Potential: Economic Feasibility, Potential Size and Growth, Characteristics of Population, and Ground Infrastructure (ASSURE project 36 WP 1)*. FAA Center of UAS Excellence. https://assureuas.org/projects/urban-air-mobility-studies/

Prevot, T., Rios, J., Kopardekar, P., Robinson III, J. E., Johnson, M., & Jung, J. (2016). UAS Traffic Management (UTM) Concept of Operations to Safely Enable Low Altitude Flight Operations. *16th AIAA Aviation Technology, Integration, and Operations Conference*, *June,* 1–16. https://doi.org/10.2514/6.2016-3292

Rimjha, M., Hotle, S., Trani, A., Hinze, N. (2021). *Commuter Demand Estimation and Feasibility Assessment for Urban Air Mobility in Northern California.* Transportation Research Part A: Policy and Practice, Volume 148, 2021, Pages 506-524, ISSN 0965-8564, https://doi.org/10.1016/j.tra.2021.03.020.

Rothfeld, R., Straubinger, A., Fu, M., Al Haddad, C., & Antoniou, C. (2020). Urban air mobility. In Demand for Emerging Transportation Systems (pp. 267–284). Elsevier. https://doi.org/10.1016/B978-0-12-815018-4.00013-9

Sedov, L., & Polishchuk, V. (2018). Centralized and Distributed UTM in Layered Airspace. *8th International Conference on Research in Air Transportation*, 1–8. https://www.semanticscholar.org/paper/Centralized-and-Distributed-UTM-in-Layered-Airspace-Polishchuk/3e0be72e26c79ec00ac7582db4f53880741fb72d

Serrao, J., Nilsson, S., & Kimmel, S. (2018). *A Legal and Regulatory Assessment for the Potential of Urban Air Mobility (UAM)*. 1–32. https://doi.org/10.7922/G24M92RV

SMG Consulting. (2022). *Advanced Air Mobility Reality Index. https://aamrealityindex.com/aam-reality-index*

SMG Consulting. (2023). *Advanced Air Mobility Reality Index. https://aamrealityindex.com/f/advanced-air-mobility-reality-index-august-2023-release*

Straubinger, A., & Fu, M. (2019). *Identification of Strategies How Urban Air Mobility Can Improve Existing Public Transport Networks*. 1–3. https://webarchiv.typo3.tum.de/BGU/mobil-vt/fileadmin/w00bqi/www/mobilTUM2019/Sessions/1A/6101_abstract.pdf

Straubinger, A., Rothfeld, R., Shamiyeh, M., Büchter, K.-D., Kaiser, J., & Plötner, K. O. (2020). An overview of current research and developments in urban air mobility – Setting the scene for UAM introduction. *Journal of Air Transport Management, 87*(August 2019), 101852. https://doi.org/10.1016/j.jairtraman.2020.101852

UAM Geomatics (2022). Global Analysis: UAM Geomatics Dashboards. Online: https://www.nexa-uam.com/global-analysis

U.S. Postal Service. (n.d.). *41,704 ZIP Codes*. Postal Facts. Retrieved November 3, 2023, from https://facts.usps.com/42000-zip-codes/

van Leeuwen, E.S, Nijkamp, P., Rietveld, P. *Regional Input–Output Analysis*, Editor(s): Kimberly Kempf-Leonard, Encyclopedia of Social Measurement, Elsevier, 2005, Pages 317-323, ISBN 9780123693983, https://doi.org/10.1016/B0-12-369398-5/00349-2. (https://www.sciencedirect.com/science/article/pii/B0123693985003492)

Vascik, P. D. (2020). *Systems Analysis of Urban Air Mobility Operational Scaling*. *February*. https://hdl.handle.net/1721.1/123692

Vascik, P. D., Balakrishnan, H., & Hansman, R. J. (2018). Assessment of Air Traffic Control for Urban Air Mobility and Unmanned Systems. *8th International Conference on Research in Air Transportation*, *June*. http://hdl.handle.net/1721.1/117686