NATIONAL AERONAUTICS AND SPACE ADMINISTRATION
Advanced Air Mobility (AAM) Vertiport Automation Trade Study

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A. Executive Summary

The NASA Advanced Air Mobility (AAM) Vertiport Automation Trade Study seeks to understand the barriers to scaling AAM takeoff and landing facilities, described in this study as vertiplaces. This trade study provides an overview of AAM, vertiplaces, and insight into the gaps in capability, regulatory certainty, and knowledge needed to sufficiently manage the volume of expected traffic anticipated for vertiplaces. The study also outlines potential mitigations to those gaps based on research conducted by the project team and interviews with 23 individuals in government and industry.

In this report, the elements that make up a vertiport are discussed. The study then defines a vertiplace and introduces a concept for vertiplace categorization based on capability. Capability gaps and mitigations to increasing scale and automation of vertiplaces are then discussed based around four cross-cutting themes the research of our project team found in the interviews and research: Technology, Physical Infrastructure, Policy, and Community Acceptance. The study then concludes by discussing topics requiring further research that were identified by interviewees.

B. Introduction

1. AAM Overview

The concept of Advanced Air Mobility (AAM) refers to the transport of passengers and cargo short- to medium-range distances using new and emerging aircraft technologies. While the terminology and present-day conversation around the future of AAM primarily revolves around the transportation of goods and people using next-generation electric vertical takeoff and landing aircrafts (eVTOL)[1], the general concept of air mobility passenger transport by small aircraft is realized today at heliports across the country that utilize traditional helicopters. The phrase AAM recognizes that recent technological advances in aircraft technology, such as the electric-propelled aircraft, advances in ground infrastructure development, such as UAS Traffic Management, and advances in automation and autonomy technology, will allow next generation aircraft to execute air mobility missions beyond the urban environment. These missions are primarily categorized as those that occur at a greater operational tempo, in a more environmentally sustainable fashion, and at a lower cost point compared to today's helicopter operations.

> **Vertiplace**: A collective term referring to areas designed specifically for AAM aircraft to take off and land. Vertiplaces have varying levels of complexity, automation and services necessary to successfully enable high-density AAM operations and includes vertihubs, vertiports, and vertistops. These terms align with the 14 CFR § 157.2 definition of "airport" as "..or other aircraft landing or takeoff area"

One of the keys to enabling AAM will be evolution and automation of ground tasks and infrastructure, including takeoff and landing areas that have been referred to as vertiports in most literature. In this study, we redefine a vertiport as a takeoff and landing location and platform in order to explore the different gaps to enabling high-density operations at vertiports, including gaps related to the necessary automation technologies to enable high-density operations. We also explore mitigations to these gaps identified through interviews with industry experts and research. By recognizing that the term "vertiport" captures only one type of takeoff and landing facility and a singular level of complexity. The capability necessary to enable multiple manned and unmanned aircraft operations is much broader than those traditionally described as vertiports or heliports, thus in this study we use the term "ventilates" as all encompassing, to capture the additional levels of automation and services necessary to successfully enable complex VTOL operations in a high-density AAM ecosystem, in which vertiplaces could be stand alone or even co-located at legacy aerodrome facilities.

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[1] While eVTOL aircrafts are by far the most touted and prominent use case for AAM, the concept includes other types of aircrafts as well including short takeoff and lift (sTOL) aircraft, hybrid-electric (hTOL) powered aircraft and other forms of propulsion that stand to be viable means of conveyance in metropolitan areas.

The evolution of vertiplaces, beyond traditional heliport operations, will be enabled by research and development of technologies that are in various stages of maturity, evolution of the physical infrastructure to meet the demands of a high-tempo operation, policy developments, and acceptance by the communities in which operations will occur.

The AAM Market

One of the primary factors attracting investment into AAM is the potential market size. Research estimates the near-term market size to be as high as $500 bn[2]. Meeting the existing demand—and increasing future demand—for key segments of the AAM market, such as passenger and cargo transport, will require new ground infrastructure with larger operational capacity capable of achieving the scale and density needed to capture a significant share of the market currently served by ground transportation.

New ecosystem players are expected to enter the market to meet this demand. However, private sector investment into Unmanned Aircraft Systems (UAS) has been historically limited to venture capital expenditures in a few, select segments of the UAS value chain: namely, UAS Traffic Management (UTM), aircraft development, and aircraft operations.

2. Scope

This study provides insight into technology, physical infrastructure, policy, and community acceptance gaps that exist in enabling high-density vertiplace operations. This study also discusses mitigations to these gaps including automation technologies needed to overcome these gaps. In many cases, because the technologies are in the nascent stages of development, a capability-focused analysis is provided rather than a discussion of specific technologies. This study discusses both passenger and cargo operations as they relate to the technology gaps that exist in support of enabling operations at UML-4[3].

3. Approach

Twenty-three government and industry experts were interviewed, and a literature review was conducted to identify and assess technologies that would be necessary to enable and assess the necessary technologies to enable high-density AAM passenger and cargo operations. The literature review and interviews focused on near-term trends and capability gaps that exist between current technology and the technology needed to enable automated and autonomous vertiplace operations.[4]

C. Vertiplace Overview

One of the key barriers towards realizing the vision of UML-4 is the development of physical infrastructure; specifically vertiplaces and the accompanying infrastructure to support the vertiplace.

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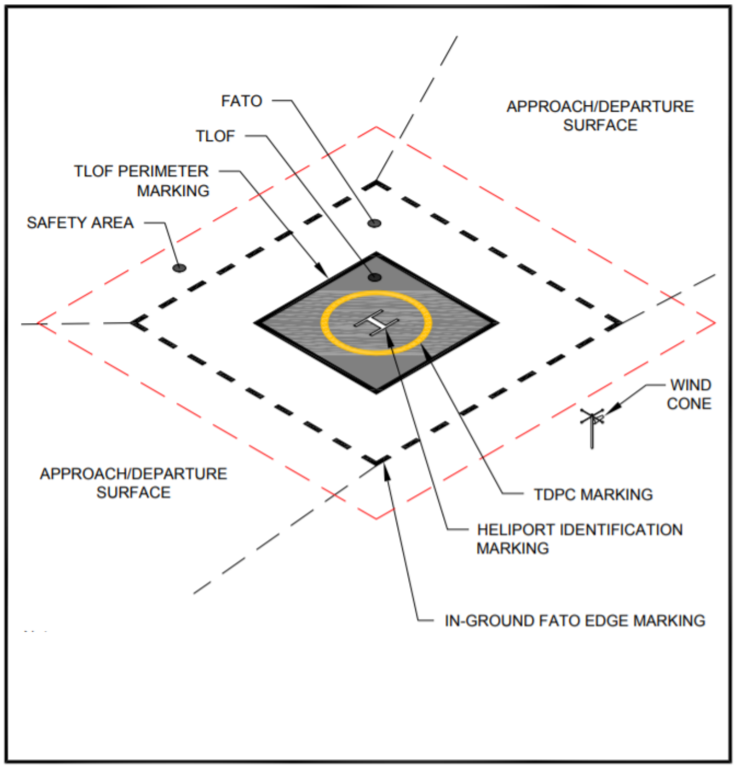
[2] "NASA UAM Market Study – Final Report", NASA, https://ntrs.nasa.gov/citations/20190001472 Accessed: Oct. 21, 2020

[3] Operations at UML-4 are characterized by NASA as those at a medium level of density and complexity of operations with collaborative and responsible autonomous systems. At UML-4 there are 100s of simultaneous operations in a given area; expanded networks including closely-spaced high throughput UAM aerodromes; many federated ATM services available; and low-visibility operations.

[4] Automated systems are defined as those that can operated without human intervention while autonomous systems are those that that are able to not only operate without human intervention but have the decision-making authority to respond and adapt to unexpected hazards. Both are used in this study but are not interchangeable. For example, cargo loading and unloading will need to occur via automated means but traffic management and aircraft navigation will need to have increased autonomy.

1. Heliports

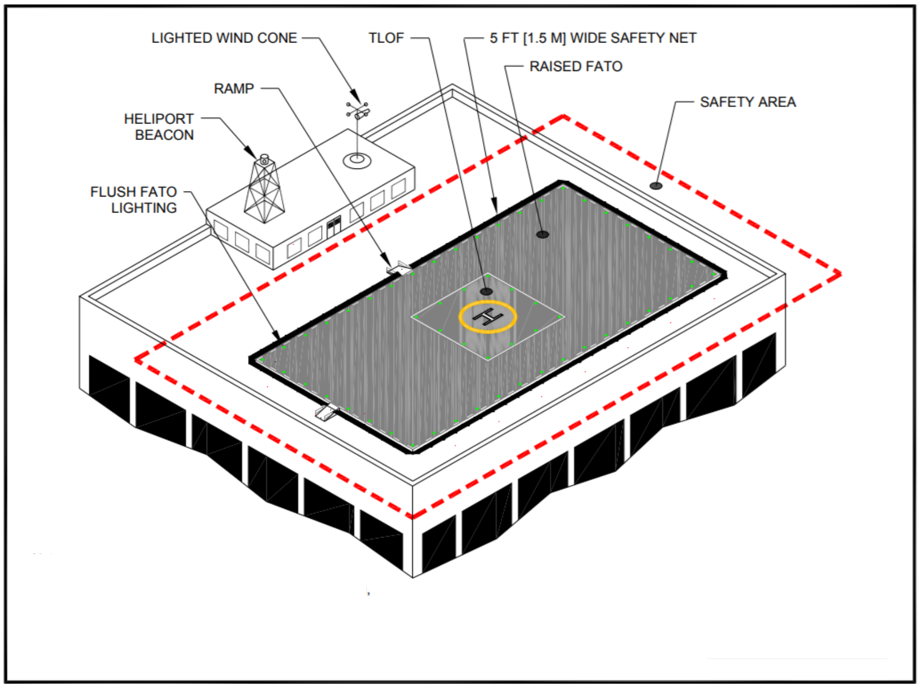


General Aviation Heliport

Source: FAA AC 150/5390-2C

Today's heliports serve as the basis for development of future vertiplaces. Heliports are likely to be some of the first locations converted from basic takeoff and landing pads today to vertiplaces that enable a full-service passenger and cargo transfer experience using automated technology. While heliports can vary in levels of complexity, most heliports are basic designs with the requisite Touchdown and Liftoff (TLOF) area to support helicopter landing and takeoff operations, surrounded by the Final Approach and Takeoff area (FATO) and Safety Area to provide clear space for both maneuvering and for the approach/departure surfaces. Heliports are also required to have a windsock to allow pilots the ability to maximize energy management of both approach and departure paths to and from the heliport. If night operations are anticipated, then the heliport must also be lighted as well as the windsock. Operations at general aviation heliports tend to be infrequent and on-demand such as for helicopter air ambulance operations or charter passenger transport. The expectations placed upon general aviation heliport infrastructure is that they will be a safe place to drop off and pick up passengers while infrastructure-heavy tasks, such as aircraft refueling, will be done at a base of operations. The majority of general aviation heliports lack security screening facilities (due to being used primarily for low-tempo charter operations) and have limited passenger holding and cargo facilities. Additionally, instrument approaches that enable takeoff and landing in visibility-restricted conditions are an exception rather than a rule.

The complex transport heliport designed and outlined in the FAA heliport design advisory circular FAA AC 150/5390-2C would contain passenger holding facilities as well as additional safety areas, lighting, and possibly passenger screening facilities. To date, however, a transport heliport has not been developed or constructed in the US. These types of heliports could have multiple parking positions for helicopters to park after clearing the FATO area to allow passengers to embark and



Elevated Heliport: Transport

Source: FAA AC 150/5390-2C

disembark. Even these transport heliport designs lack cargo facilities. To enable high-density vertiplace operations, such as those envisioned for AAM, new technologies and infrastructure capabilities will be necessary beyond those found at existing heliports and those designs found in the existing FAA Advisory Circular. Many of these will be akin to what is traditionally found at airports, such as refueling (or charging in the case of electric aircraft), cargo transfer facilities, and sophisticated passenger facilities capable of high-throughput operations. Enabling the development of these facilities will require major modifications of the infrastructure feeding resources to the transport facility.

2. Vertiplaces

The term “vertiport” is generally categorized as the next step in the evolution of heliports necessary to enable AAM operations. However, not all takeoff and landing locations will have equal capabilities or identical roles in the AAM ecosystem. There will be some functions, such as charging, instrument approach procedures, and weather monitoring capabilities, that will be common to all vertiplaces. Most vertiplaces will have quick battery swap and recharging facilities designed for quick passenger disembarkation while others will be designed as multimodal hubs intended to be points of connection to additional modes of traditional longer distance transportation to concurrent destinations. Based on their function, most vertiplaces can be characterized in one of three categories (defined below) which are defined as vertihubs, vertiports, or vertistops.

Ground infrastructure (vertiplaces):
Vertihubs, vertiports, and vertistops

Source: Deloitte analysis.

Vertihubs

Vertihubs are the largest category facility and will likely exist on the periphery of urban areas due to the large physical footprint and demands on the power grid and other physical infrastructure. These vertihubs will have enough space to store aircraft overnight when not in use as well as serve as multimodal hubs connecting passengers to public transport and private vehicles. Vertihubs will also have significant maintenance, repair, and overhaul (MRO) capabilities to allow aircraft to undergo more intensive maintenance than other vertiplaces. Vertihubs may also provide passenger facilities similar to an airport, such as retail facilities and passenger screening facilities, if necessary.

Vertiports

Vertiports will be placed in heart of urban cores and serve as major sites for both passenger and cargo boarding and disembarkation. Compared to vertihubs, vertiports will lack heavy MRO facilities but will likely have a basic maintenance staff. Vertiports will have multiple pads, but likely one or two primary TLOF areas. Energy infrastructure needs will be significant, but not as demanding as vertihubs and be limited to quick charging and battery swapping. Basic customer waiting areas similar to those that heliports have today are likely to exist as well as some basic security screening.

Vertistops

Vertistops will be the smallest element of the vertiport network and contain one TLOF area with one or two pads. Vertistops have the lowest physical footprint and serve as a connection point to the vertiplace network for suburban areas. Vertistops will also serve as multimodal connection points, but only to a handful of transport modes and will serve primarily to connect passengers with automobiles, buses, and other mobility options for transportation to deliver them the last mile. MRO facilities will likely be scant to nonexistent and basic passenger holding areas and weather monitoring systems will exist to enable flights.

D. Analysis

1. Gaps and Mitigations

During discussions with industry experts, it was evident that there are a number of gaps in understanding regarding the exact technologies needed to scale vertiplaces. These gaps were divided into broad categories, and common themes reported from the interviewees were highlighted . We have defined these categories as technology, infrastructure development, policy, and community acceptance. This list is not fully inclusive and highlights common themes from our research and discussions with industry experts.

Technology

Gaps

Aircraft

Technology gaps exist regarding aircraft designs, required navigational and positioning needs, and associated data communication protocols to enable scalable vertiplace operations. According to interviews with key stakeholders in the market, aircraft-related technology gaps are one of the key challenges to enabling AAM operations at vertiplaces. A primary concern is the functional allocation of responsibility between the aircraft, infrastructure, and architecture of the traffic service provider to enable high throughput operations in an environment where position sourcing and navigation can be a challenge. The aircraft must have the appropriate communication technology to conduct vehicle-to-vehicle communication as well as vehicle-to-infrastructure to communicate directly with the vertiplace.

Original equipment manufacturers (OEMs) and avionics experts have indicated that high accuracy positioning and navigation technologies are necessary to enable the use of precision approaches in an AAM environment. In order to meet the demands of high-density vertiplace operations, experts expect that aircraft will likely be flying closer to structures, people, and other obstacles than what currently occurs with helicopter and fixed-wing aircraft today with less separation than what is currently acceptable to traditional manned aviation.

Due to the proximity in which AAM aircraft will be operating, aircraft-to-aircraft and aircraft-to-infrastructure digital communication will be necessary to enable spacing and separation for vertiplace operations planning to ensure an adequate number of pads are available at a vertiplace. Industry interviewees have told us that communications technology to enable this is in active development. This technology will need further support to achieve the necessary positioning granularity for full scalability in UML-4 and beyond.

Traffic Management

Gaps in traffic management exist around implementation of traffic management services, airspace monitoring, and communication between the elements of the AAM ecosystem. Another technological challenge as indicted by interviewees is implementation of traffic management systems. Consensus is Providers of Services to UAM (PSUs) will primarily be non-governmental digital traffic management service suppliers that manage AAM aircraft by enabling pad-to-pad flight planning, navigation services, and data communication from aircraft-to-aircraft and aircraft-to-infrastructure that is secure and reliable. Disagreement exists as to whether a PSU/USS will actually issue flight control inputs to these aircraft. Vertiplaces will also need to provide routine status updates to the network of PSUs to ensure that the network is aware of the operating status of the vertiplace, pad availability, etc.

- Vertiplace Operations Area Management
  Interviewees indicated vertiplace operations area (VOA) will need to be managed by autonomous systems to ensure smooth and safe departure and arrival of traffic through the use of trusted data sources. This will likely occur either through the PSU or as a supplemental data service that the vertiplace owner subscribes to. If not a PSU, this system will need to work closely with the PSU network to enable safe traffic management.

- Navigation - Precision Approach and Departure Procedures
  For AAM to scale to where it becomes a routine mode of transport, flight operations must be able to routinely occur during instrument meteorological conditions (IMC). Flights occur in IMC today using traditional air navigation infrastructure; however, given the anticipated density and tempo of AAM operations, a more precise approach and departure system designed to operate in space-constrained environments will absolutely be necessary.

Command and Control Standards + Cybersecurity

Expert interviews have told us that gaps exist in the definition of command-and-control (C2) standards. This gap is directly attributable to the level of autonomy that will be emerging in the systems of C2 present in UML-4 for optionally piloted or unmanned aircraft. Additionally, expert interviewees were concerned about the level of cybersecurity needed for C2 networks responsible for managing UML-4 operations. In a vertiplace context, secure C2 is especially important because AAM aircraft will be operating closer to each other during takeoff and landing than during all other phases of flight. This will require ultra-low-latency communication systems with highly protected spectrum and anti-spoofing characteristics along with appropriate protocols between the aircraft and other actors (infrastructure, other aircraft, PSU, etc.) in the AAM ecosystem. The proximity to occupied buildings and the ground makes C2 around vertiplaces a potential target for malicious actors.

Mitigations

A common theme of the technological gaps discussed is the importance of interconnectivity and appropriate infrastructure buildout. Fortunately, industry is in the process of addressing most of these challenges and many solutions are already in the prototype stages. Mitigations to these gaps include the following:

- Aircraft: Allocation of safety responsibilities between aircraft, infrastructure, and traffic management provider in many cases will be technology dependent. Investment in research and development by industry and academia will be key in resolving these responsibilities. The same can be said for the development of accurate positioning technology that can accommodate high-density vertiplace operations. Active aircraft-to-aircraft and aircraft-to-infrastructure information exchange will need to occur via a standardized protocol. Steps to develop these protocols are already underway in standard settings bodies such as ASTM International.
- Traffic Management: Challenges with current traffic management technology requires further research and development by industry. NASA's AAM National Campaign is one entity doing this but further action on the part of industry in pushing forward these technologies can help accelerate high-density vertiplace operations. High density operations including those in and around the VOA is an area ripe for automation, and automated systems could be implemented to monitor pad availability and feed that information to PSUs, and in turn aircraft and fleet operators. Automated systems could also be utilized for taxiway path illumination and other tasks near the vertiplace pad. VOA monitoring will likely need to be highly automated due to the high number of aircraft likely to be in a VOA at any given time during critical phases of flight (takeoff and landing) and the need to adapt to unpredictable hazards in this area. Precision approaches and departures that function in urban environments will need to be developed and can leverage exciting precision approach development methods combined with new techniques that account for the unique nature of the urban environment.
- Command and Control + Cybersecurity: Aircraft manufacturers, PSUs, and vertiplace developers need to work together to develop industry standards for both robust C2 when needed as well as CNSI that are interoperable and contain adequate security measures (especially cybersecurity) to ensure safety of flight. The foundation for this work is occurring in the standard setting bodies, for example RTCA is in the process of developing standards related to the use of C-band for secure communications for UAS. This could be adapted for AAM as demand for AAM C2 increases.

Physical Infrastructure

Gaps

Energy Grid

Interviews and research indicate a key gap in understanding how to scale vertiplaces is understanding the capacity and distribution of the energy grids that currently exist in cities. With high throughput operations using eVTOLs, it is anticipated that there will be significant demand on the energy grid. Powering aircraft independent of traditional fuels will result in increased demands on electricity to charge the aircraft's batteries. Energy grid capacity and resilience is another challenge. Energy is not equally distributed throughout most cities and the demand on the grid posed by AAM aircraft will likely require some degree of reinforcement. This unequal distribution also needs to be considered when planning vertiplaces, requiring evaluation for each location within the metropolitan region where the vertiplaces sit.

Energy Replenishment Facilities

Capability gaps surrounding energy replenishment technology stands to be a challenge in scaling AAM and vertiplace development. Experts have told us for this technology to scale, energy replenishment will need to be automated to minimize aircraft time on the pad. The two primary proposals for energy replenishment have been “battery swapping” by physically removing a depleted battery from the aircraft and replacing it with a charged battery, or “quick charging” by rapidly charging the battery itself. Technology to enable these capabilities is still in the early stages of development but is necessary to enable scalable AAM operations.

Vertiplace Footprint and Space Constraints

Vertiplaces, particularly vertiports located in urban settings, are inherently limited in size. For example, a vertiport in an urban environment may be limited by the layout of the city and not exceed the size of a single city block. In such cases, the entire vertiplace operation is limited due to space constraints in urban environments. While it is anticipated that much of the maintenance and storage of AAM aircraft will occur in vertihubs and other facilities that are removed from the urban centers of cities, everyday support for the aircraft, such as aircraft and battery charging infrastructure, light maintenance, and possibly some aircraft storage, will all need to occur within this limited footprint.

Many of the most high-profile use cases for AAM envision use of aircraft in urban areas where space for new construction is at a premium and adapting existing structures to accommodate AAM may be challenging given preexisting surrounding structures. Industry experts have told the research team these locations will face challenges accommodating a high throughput of passengers and the facilities necessary to do so, such as terminals, security screening, and waiting areas.

Ground and Spaced-Based Navigation Infrastructure

Industry experts noted that AAM will require ground- and space-based navigation infrastructure to enable safe and efficient operations with increased required navigational performance compared to what is available today. For example, Ground Based Augmentation Systems (GBAS), which can be used to enhance position sourcing for manned aircraft, is costly and designed for operation in an airport environment where space constraints are accounted for in the original design of the airport. In contrast, many vertiplaces, especially once operations begin to scale, will be adaptations of existing infrastructure with surrounding structures that likely predate the vertiplace. GPS, the primary tool for space-based navigation will require augmentation to permit at-scale operations in congested urban areas where signal strength can be unreliable or multipath interference is likely to occur.

Cargo Handling Facilities

AAM cargo handling will require significant investment in automated cargo handling technology. Today, cargo loading and unloading is done manually by humans; however, given the volume of traffic anticipated as AAM operations scale, these functions will need to occur via automated means. This can be challenging as automated cargo loading and unloading may have aspects that are unique to each aircraft if not standardized. Standardization would require cooperation between multiple manufacturers and equipment designers, many of which have indicated they are hesitant to share their designs.

Passenger Management Technology

Managing passenger flow in a congested vertiplace presents challenges. Active helicopter traffic areas are often lightly trafficked by passengers as charter operations typically peak at a handful of passengers. High-tempo operations at a vertiplace may present new challenges to safely navigating passengers to and from aircraft, similar to those passenger management challenges faced at airports. Adding to this complexity is the vertical transportation component that would be needed at many elevated rooftop facilities to provide the required conveyance to move passengers from the ground level. This management could be added by automated systems to help passengers navigate the vertiplace facility. Maintaining ADA compliance must also be considered.

Mitigations

Gaps pertaining to physical infrastructure include challenges with the energy grid, energy replenishment, vertiplace footprint, navigation equipment, and passenger management. An underlying constraint in these challenges is being able to work with the existing infrastructure and the cities where the vertiplaces are to be located. The mitigations the research team heard in our interviews primarily involve collaboration between infrastructure developers and manufacturers. These include:

- Energy Grid Capabilities: Collaboration and partnerships between vertiplace developers and energy companies early-on in the development or conversion process of vertiplaces is paramount to ensure that the vertiplace is not an undue burden on the community and is successfully able to accomplish its mission. Interviewees have told us this can occur through existing industry associations or can be facilitated by local governments or the companies themselves prior to vertiplace development.
- Energy Grid Capabilities: To understand the load on the power grid, a better understanding of the energy demands of AAM aircraft is necessary. Given many of these aircraft are still in the R+D phase, this would likely require partnerships between aircraft manufacturers, energy companies and infrastructure owners.
- Energy Replenishment Facilities: To address energy replenishment, vertiplace developers need achieve a more thorough understanding of the energy demands of AAM aircraft and the necessary facilities to restore energy. Estimates of how many batteries will need to be charged per day, storage requirements, and other relevant information to appropriately design structures that can accomplish efficient energy replenishment via battery swap, quick charging, or some other future method.
- Vertiplace Footprint and Space Constraints: Vertiplace developers have told the research team that to address space limitations, vertiplace developers need to understand the needs of the aircraft operators and the demands of the consumer to understand how much space must be allocated to the operation and upkeep of the aircraft as well as the amenities, waiting areas, and security of the passengers. Interviewees also said vertiplace developers need to consider the turbulence conditions in the urban environment when evaluating vertiport site locations.
- Vertiplace Footprint and Space Constraints: To address the varying degree of geometry and dimensional requirements necessary to accommodate differing types of eVTOL concepts, aircraft manufactures will need to work with and supply performance data for their concepts to standards development bodies. By providing this information, it will allow physical infrastructure developers to develop the necessary facilities to accommodate their aircraft.
- Vertiplace Footprint and Space Constraints: Vertiplace developers can explore vertiplace designs that create additional space without extending the footprint, such as multi-level designs.
- Ground and Space-Based Navigation Infrastructure: Industry stakeholders told the research team that PSUs, aircraft manufacturers, and vertiplace operators are working closely with FAA to advise on new ground and space-based system systems that will be needed.
- Cargo Handling Facilities: Aircraft manufactures told the research team that modularization can address some of the cargo handling challenges. Collaboration among industry to standardize container specifications could allow for interoperable automated cargo handling. Several manufacturers we talked with for this study plan to transport cargo via modular containers.
- Passenger Management Technology: This is an area ripe for automation. Passenger management can leverage many of the technologies being developed for traditional airports, such as automated entry and exit gates and guided pathway lighting to help passengers navigate their way to their aircraft. These technologies are already designed for frequent use major airports and can likely be adapted for high-tempo vertiplace operations.

Policy

Gaps

Adaptation of Heliport Requirements

Based on research and interviews, the current regulatory environment for heliports manifests two gaps related to vertiplace construction and operation. First, the FAA does not currently have a standard to certify a heliport or a vertiplace, and currently aids in heliport design guidance through the issuance of FAA Advisory Circular AC150/5390C. Under current federal regulatory guidance, the FAA has no legal authority to enforce any of the guidance or standards in the advisory circular for "Private-Use" heliports, which make up 99% of the 5,918 heliports on file with the FAA. While this is acceptable for lightly trafficked charter operations, the high tempo of operations combined with the anticipated passenger demand and additional on-vertiplace infrastructure will likely necessitate guidance, oversight, or certification more robust than is currently provided by FAA (possibly something closer to that which exists for airports).

Second, the FAA Advisory Circular (AC)150/5390-2C does not clarify if the rules applying to heliports apply to vertiplaces as well. While heliports and vertiplaces may, in practice, be used by similar aircraft (i.e., rotorcraft), this overall lack of clarification presents challenges to those intending to develop vertiplaces for the nascent UAM and AAM markets. This will not be able to be addressed or clarified until regulators have actionable performance data for each eVTOL concept intending to operate in this next generation of aviation transportation that can then be compare to our current understating of helicopter performance as it relates to supporting infrastructure.

Aircraft Certification

Another gap that exists is determining a path to certification for UAM aircraft. FAA is in the initial stages of determining the appropriate part of Title 14 of the Code of Federal Regulations (14 C.F.R.) in which to certify VTOL aircraft. Aircraft certification standards inform aircraft performance standards which in turn help determine vertiplace development requirements. Uncertainty on what AAM aircraft will look like once certified has led vertiplace designers to base their designs off the current heliport AC.

Local Zoning

Development of vertiplaces may be curtailed by local regulators through zoning ordinances. Although there is no clear rule on how this applies to vertiplaces, and while zoning ordinances vary among different jurisdictions, it is foreseeable that zoning ordinances could also curtail the development of vertiplaces. This presents challenges that may include vertiplace site selection, vertiplace design, and limitations on commercial activity.

State and Local Policy Standardization

While there may be one recognized guideline for heliport design at the federal level in today's environment, each state adopts and interprets this guidance differently creating a patchwork of regulatory models from state to state. This standardization of policy integration, or lack thereof in many cases, becomes even more challenging at the local level. To keep costs and time constraints within a manageable framework for future infrastructure development, state and local policy will need to be standardized in a way that has never been done in the past.

Mitigations

The consensus from our interviews is that policy gaps stem primarily from regulatory uncertainty. Addressing these gaps requires collaboration between industry, the FAA, and state & local governments to either obtain clarification of the existing rules or the development of new rules for vertiplaces. In such cases, industry, vertiplace developers, aircraft manufactures, and others can engage in the regulatory process. Solutions include:

- Adaptation of Heliport Requirements: Regulatory clarification from FAA on what aspects of the heliport AC they intend to apply to vertiplace regulation in the short-term, and either a vertiplace AC (which FAA has indicated is under development) or vertiplace-focused regulation in the long-term would provide certainty to developers.
- Aircraft Certification: Industry interviewees told the research team that a regulatory clarification and better determination of aircraft certification methodology for eVTOL aircraft will allow them to

optimize their designs to meet anticipated federal safety requirements. This would then allow them to better assist vertiplaces by allowing them to provide vertiplace developers with more information regarding aircraft specifications and vertiplace needs.

- Local Zoning: At the local level, stakeholders should examine zoning regulations, building codes, fire codes, and conditional use permitting processes early on to organize any efforts to amend the zoning ordinances, codes and processes through community-based effort.
- State and Local Policy Standardization: State and local governments need to take a regulatory approach to AAM that involves development of AAM laws and regulations based on a “whole of metropolitan area” approach. This approach develops a consistent set of laws and regulations that go beyond traditional political barriers of cities and counties and encourages the development of laws and regulations that apply to metropolitan areas and enable consistency of vertiplace regulation.

Community Acceptance

Gaps

Demand

A fundamental challenge to development of vertiplaces according to developers is determining passenger demand. This requires determining both the community appetite for this mode of transportation as well as where within the urban environment demand is strongest to select appropriate sites for vertiplaces that will enable a utilized and profitable market. Demand must be balanced against other challenges including the distribution of the energy grid, vertiplace size, noise, and zoning.

Perceived Safety & Privacy

Another key gap that makes community acceptance challenging (especially when operating in urban areas) according to interviewees is proving to the community that vertiplaces are built in safe locations and aircraft transiting the vertiplace will respect the privacy of their neighbors. Most general aviation heliports operate charter flights and see infrequent traffic. Many of the most heavily trafficked heliports have FATOs that are over water, in rural areas, or above neighboring buildings that keep helicopters at a distance from their neighbors. Vertiplaces, however, are expected to see a higher level of traffic and have the ability to fly closer to structures that are occupied due to their reduced noise footprint. This may create more concern about safety and privacy than seen around heliports today.

Noise

Aircraft noise presents challenges to the development of vertiplaces for AAM. Noise standards for AAM have not yet been developed, therefore aircraft manufactures have proceeded to develop aircraft using existing aircraft noise standards as a baseline, then attempting to maximize the reduction of noise. This may pose a challenge as AAM noise standards will likely be developed in parallel with those developed for vertiplaces.

Community Input

State and Local governments have indicated a desire for more robust community input on vertiplace development compared to what exists for heliport development today. In addition to today’s public hearing and comment avenues of input, state and local governments have indicated they want a say in the actual forming of regulations from the idea stage rather than commenting on drafts proposed by federal entities. The form this will take could hinder rapid growth of AAM and construction of vertiplaces as additional consultations may be required.

Mitigations

Community acceptance related challenges include noise ordinances, safety and security, and overall demand for this service. Solutions to these challenges can include:

- Demand: Interviewees told us that additional studies need to be conducted to better determine the demand characteristics of the AAM marketplace and to better prove to communities that they stand to benefit. By devoting additional resources to this pursuit then operators can not only help articulate the benefits of AAM but also help spur demand.
- Perceived Safety & Privacy: Engaging the with state and local leaders early in demonstrations of AAM aircraft is one way some interviewees suggested for promoting the safety aspects of their aircraft. Further certainty in the regulatory process would also help convince communities that AAM aircraft are certified to levels that are acceptable by the FAA's safety standards.
- Noise: To address noise, vertiplace developers can engage communities early on to establish an understanding of noise expectations from AAM aircraft. Industry can explore the efficacy of noise-reducing technologies and whether they can be applied areas near vertiplaces adversely impacted by aircraft noise. Urban planners can also support development by beginning to measure noise in proposed areas in order to determine if anticipated vertiplace operations will result in an increase in noise levels and by how much to develop trade-off policies.
- Community Input: A more robust community engagement structure than that currently utilized by FAA will be necessary. Federal regulatory changes would likely be needed to give state and local entities a formal role in rulemaking, however greater use of the federal advisory committee process could be a way to increase community involvement without the need for regulatory changes.

E. Future Research Questions and Next Steps

Development and scaling for vertiplaces will be challenging. Heliports provide an excellent foundation for vertiplace design; however, given the increased traffic levels and heavy passenger throughput anticipated as the volume of operations in AAM grow, new technologies will be needed to address changes in policy aimed to combat emerging problems. Some key areas interviewees identified to explore for future research:

- **Assessment of Automation Needs:** What aspects of the vertiplace need to be automated? What aspects will need to be autonomous? How do automated systems interconnect and work together? In our interviews we learned a lot about capabilities that are necessary for vertiplace development; however, there's still significant uncertainty about the specific details of how systems will work and interact with each other.
- **Energy grid requirements for vertiplaces:** How much energy is needed to sustain the AAM market at the advanced maturity level? Extrapolate the energy needs for the average AAM aircraft to the scale of the market at the mature level in order to determine appropriate investment in infrastructure.
- **Validate battery technology** to manage energy density, energy replenishment in collaboration with grid/infrastructure modernization.
- **Consumer expectations for vertiplaces:** What does the consumer expect in terms of amenities at vertiplaces? Will there be retail? How should the vertiplace integrate into an intermodal transportation system to provide a seamless experience for the passenger?
- **Security at vertiplaces:** There has been some discussion on this issue but need clarification on what the screening process will look like as this impacts the amount of space needed and the flow of passengers at the vertiplaces. Will it be traditional TSA screening, trusted traveler, biometric, or something else? How is passenger safety ensured?
- **Communication, navigation, surveillances, and information requirements and technologies to enable vertiplace operations:** For AAM to scale to where it becomes a routine mode of transport flight operations, it must be able to routinely occur during instrument meteorological conditions (IMC). Traditional technologies may not be applicable in highly urban settings, thus new standards and nonconventional technologies may need to be further developed to satisfy the requirements.
- **Scheduling of high throughput operations:** eVTOLS are much more sensitive than helicopters to hovering delays caused by non-availability of a vertiport due to their more limited energy reserves.

This places much more stringent requirements on operations scheduling, particularly in an urban environment where there are few landing alternatives. To handle the projected high throughputs, the development of sophisticated and resilient scheduling technology is necessary.

F. Conclusion

Advanced Air Mobility stands to revolutionize how the public utilizes airspace in and around urban areas. Key to fully utilizing this airspace and fully achieving the promises of AAM requires the ability to handle high-tempo operations in the urban environment which can only be realized through the automation of technological functions ranging from passenger management to vehicle and infrastructure communication. In addition to these technological gaps, gaps need to be mitigated in relation to physical infrastructure, policy, and community acceptance. While significant progress has been made in mitigating these gaps there still remains much to be done. Through collaboration between government, industry, and academia these gaps can be bridged and the full potential of AAM can be fulfilled.

G. Glossary

Term	Acronym	Definition
Advisory Circular	AC	A type of publication offered by the Federal Aviation Administration (FAA) to provide guidance for compliance with airworthiness regulations, pilot certification, operational standards, training standards, and any other rules within the 14 C.F.R. Aeronautics and Space Title.
Advanced Air Mobility	AAM	Advanced Air Mobility refers to the transport of passengers and cargo short to medium-range distances using aircraft. AAM is generally correlated with the use of next-generation aircraft including eVTOL aircraft.
Automation	N/A	Automation refers to the ability of a system to control a vehicle, like autopilot or cruise control. Automation may involve human involvement or assistance.
Autonomy	N/A	Autonomy is the ability of a system to not only control a vehicle but respond to unexpected hazards without human intervention.
Code of Federal Regulations	C.F.R.	The Code of Federal Regulations (C.F.R.) is the codification of the general and permanent rules published in the Federal Register by the executive departments and agencies of the Federal Government
Command and control	C2	The exercise of authority and direction by a properly designated commander over assigned and attached forces in the accomplishment of the mission
Electric Vertical Takeoff and Landing	eVTOL	eVTOL refers to electric powered vertical takeoff and landing aircraft.
Federal Aviation Administration	FAA	The Federal Aviation Administration (FAA) is the agency of the United States Department of Transportation responsible for the regulation and oversight of civil aviation within the U.S., as well as operation and development of the National Airspace System. Its primary mission is to ensure safety of civil aviation.
Global Positioning System	GPS	A global navigation satellite system (GNSS) that provides location, velocity, and time synchronization information to allow for successful navigation.
Ground based augmentation systems	GBAS	A civil-aviation safety-critical system that supports local augmentation -at takeoff and landing facility level- of the primary GNSS constellation(s) by providing enhanced levels of service that support all phases of approach, landing, departure and surface operations.
Heliport	N/A	A landing place for helicopters.
Hybrid vertical takeoff and landing aircraft	hVTOL	Aircraft that are propelled by engines that utilize a combination of batteries and traditional combustible fuels.
National Environmental Policy Act	NEPA	NEPA requires federal agencies to assess the environmental effects of their proposed actions prior to making decisions.
Vertiplaces	N/A	Vertiplaces are takeoff and landing facilities of various size differing levels of automation and services for AAM aircraft.
Vertihubs	N/A	Vertihubs are multimodal facilities designed for AAM aircraft takeoff and landing that have advanced MRO capabilities and are capable of handling high passenger throughput operations.

Vertiports	N/A	Takeoff and landing pads that would be constructed and/or placed in the heart of a city and serve as major sites for both cargo and passenger on-boarding and off-boarding and takeoffs and landings.
Vertistops	N/A	The smallest element of the network of vertiplaces, typically containing just one or two landing pads.

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