Advanced Air Mobility Vertiport Considerations: A List and Overview

Nancy Mendonca,[1] James R. Murphy,[2] Michael D. Patterson,[3]
National Aeronautics and Space Administration
Rex Alexander,[4]
Five-Alpha, LLC
Gabriela Juárez,[5] and
City of Los Angeles Department of City Planning
Clint Harper[6]
Urban Air Mobility Fellow, *Urban Movement Labs*

Advanced air mobility (AAM) is an emerging field in aeronautics that involves utilizing small aircraft for everyday transportation and other services, and many AAM aircraft are envisioned to take off and land at new infrastructure termed *vertiports*. This paper describes a variety of considerations related to AAM vertiports that need to be considered in the planning for and deployment of vertiports in practice. The factors include siting, design, regulations, safety, environmental impact, social acceptance, equity, and operational integration factors. Over 450 considerations were compiled from Subject Matter Experts (SMEs) participating in NASA's AAM Ecosystem Working Groups (AEWGs) in October 2021. This paper consolidates these considerations and broadly disseminates the valuable knowledge of these SMEs. These considerations can be used by researchers to conduct demand and network analysis, local transportation planners to develop AAM networks for their community, and the AAM ecosystem members to identify policy, standards, and research gaps.

I. Introduction

Over the past several years, interest in what is now called advanced air mobility (AAM) has been growing rapidly. AAM is safe, sustainable, affordable, and accessible aviation for transformational local and intraregional missions [1]. Generally, AAM is envisioned to be enabled by novel, small aircraft that utilize electrified propulsion systems and increased levels of automation as well as novel air traffic management techniques that utilize a service-oriented architecture. Current views on AAM can be traced back to at least the early 2010s [2], with a vast expansion in interest since several papers were published in the 2016 timeframe describing one particular mission within AAM: passenger-carrying urban air mobility (UAM) [3, 4]. Many believe that this UAM mission can be enabled via electric vertical takeoff and landing (eVTOL) aircraft that will operate from new takeoff and landing locations, which are generally known as *vertiports*.

The vertiport concept has been around for over four decades. Originally envisioned to meet the needs of a civil tiltrotor (CTR) industry, which expected to have a commercially certified CTR aircraft by 2007, significant efforts were initiated to prepare for these anticipated operations. The Federal Aviation Administration (FAA) undertook a multi-year effort that included the release of a Vertiport Design Advisory Circular (AC) [5] in May 1991 and a Vertiport Characteristics report in February 1996 [6]. During the same timeframe, the Secretary of Transportation established the Civil Tiltrotor Development Advisory Committee (CTRDAC), which released its report in December

[1] Deputy AAM Mission Integration Manager, NASA Headquarters, 300 E St SW, Washington, DC 20546.
[2] AAM Mission System Architect, NASA Ames Research Center, MS: 243-1, Moffett Field, CA 94035, AIAA Associate Fellow.
[3] Emerging Applications & Technologies Group Lead, Aeronautics Systems Analysis Branch, NASA Langley Research Center, 1 N. Dryden St. MS 442, AIAA Senior Member.
[4] President and Executive Director, Five-Alpha, LLC, 12308 Redding Drive, Fort Wayne, IN 46814.
[5] City Planner – Urban Air Mobility Lead, Los Angeles Department of City Planning, 200 N Spring Street, Los Angeles, CA 90012, American Institute of Certified Planners.
[6] Urban Air Mobility Fellow, Urban Movement Labs, 4906 Stratford Road, Los Angeles, CA 90042 Certification Maintenance, American Planning Association

1995 [7]. The findings and recommendations in this report could easily be applied to AAM today; for example, the report stated

"*Vertiport siting is a critical factor in CTR system viability. Planning for CTR infrastructure development should be integrated into national and local transportation system planning.*"

Since there has not yet been a CTR commercially certified, the closest equivalent to a vertiport in today's aviation infrastructure is a heliport, and the term *vertiport* is frequently confused with *heliport*. Although the Dallas Central Business District Vertiport [8] was likely designed using the now-canceled Vertiport Design AC [5], both the Dallas Vertiport and Vertiport Chicago [9] are classified by the FAA as heliports in the airport master record database. Like the terms *freeway*, *highway*, *parkway*, and *thruway*, the terms *heliport*, *vertiport*, *vertiplex*, and *vertistop* are going to matter most to those concerned with using a specific term to convey underlying assumptions, including adherence to specific safety and regulatory standards as well as operational considerations. A companion paper also being presented at the AIAA Aviation 2022 Forum presents a proposed taxonomy for AAM [10], and more detailed descriptions of the current vertiport taxonomy is in [11]. This paper attempts to be independent of future nomenclature and vernacular and provide considerations agnostic of the passenger-carrying-sized eVTOL vehicle configuration or business case.

A. Background

NASA's Aeronautics Research Mission Directorate (ARMD) has been expanding its efforts to help enable AAM over the past few years. These efforts include research, technology demonstrations, partnership development, advancing early adoption communities, and providing informational resources and opportunities for the exchange of information across the ecosystem. One element of the latter is the AAM Ecosystem Working Groups (AEWGs). Comprised of four groups that debuted in March 2020, the AEWGs have conducted over 80 meetings as of April 2022. Of most relevance to vertiport considerations is the Community Integration Working Group (CIWG). The CIWG focuses on the challenging issues associated with integrating AAM into local communities and providing a community-related informational resource for the entire ecosystem. All of these meetings are open to the public, recorded, and announcements for upcoming meetings are distributed to nearly 2000 people who have registered to receive them.[7*]

Topics presented at the CIWG are developed with input from members, an assessment of information gaps in the community, and collaboration with the other groups to preclude duplication by another working group. A March 2021 meeting featured a presentation from Dr. Kapil Sheth on Regional Modeling and Simulation for Vertiport Location Assessment [12], and he has subsequently made presentations and demonstrations of the developed software. At numerous of these events, Dr. Sheth was asked for the factors that were able to be considered within the software. This recurring question from stakeholders across multiple organizations highlighted the need for a more comprehensive effort to start compiling this beneficial information. Consequently, conversations with SMEs and two, hour-long, virtual sessions of the CIWG that were open to the public on October 12th and 13th, 2021 were held to collect input on considerations relevant to the siting, design, and operation of vertiports. These sessions were announced using the AWEG distribution list and attended by approximately 125 people. Inputs, comments, and questions were accepted verbally, in the chat feature, and by e-mail.

B. Paper Scope

This paper provides the over 450 considerations compiled during those October 2021 CIWG meetings, organizing these considerations into relevant groupings. We provide an overview and a discussion of specific considerations that would benefit from additional information for each grouping. Like the UAM Maturity Level 4 Vision ConOps [13], this will be a "living list" that will be updated over time as policies and regulations are developed, taxonomies mature, and vertiports are sited, designed, and begin to operate.

The considerations compiled and contained in this paper were elicited specifically focused on vertiports servicing the most demanding safety case, a passenger-carrying eVTOL aircraft flying within a metropolitan area. Consequently, there are considerations unique to some vehicle types or missions, such as Regional Air Mobility (RAM), that might not be included as part of these considerations. Likewise, this list does not capture considerations that are unique to a vertiport servicing only small unmanned aircraft systems (sUAS). Additionally, considerations unique to heliports, such as requirements from the FAA Heliport Design AC 150/5390, are also not within the scope of this paper. However, the considerations provided in this paper can provide a potential starting point to begin to evaluate whether a heliport can be utilized or modified for eVTOL aircraft.

The following list of considerations is intended to provide value to stakeholders across the AAM ecosystem for various purposes. For example, these considerations may assist prospective vertiport operators in evaluating potential

[*] https://arc.nasa.gov/aam-portal/

business model trades; local communities in evaluating potential vertiport designs and locations; and researchers and consulting companies in conducting site, demand, and network analysis to provide feasibility assessments of potential locations and/or capacity impacts.

Lastly, several assumptions are implicit in the compilation of considerations. These assumptions include that the vertiports will operate in localities utilizing the U.S. regulatory framework and that the FAA is both the U.S. Civil Aviation Authority and the Air Navigation Service Provider. Those interested in exploring vertiports in locations outside of the U.S. should still be able to benefit from the considerations listed below, but they will need to consider the relevant modifications to make the results applicable to their particular location.

II. Overview of Considerations

In this section, we provide the considerations that were solicited in the CIWG meetings along with some discussion of these items. We provide 18 groupings of considerations that are organized primarily to leverage domain subject matter experts (SMEs). For example, physical, cyber and airspace security considerations were consolidated into one group to enable a robust review by security SMEs during the brainstorming meetings. Additionally, the groupings consider areas that are within the purview of particular regulators or decision makers. For example, we separate the federal regulatory considerations from state and local regulatory factors. The groupings are:

- Federal Regulatory
- State, Tribal & Local Regulatory
- Physical - Fixed
- Physical - Mobile and Temporary
- Surrounding Uses
- Vertiport Configuration
- Economic
- Environmental
- Airspace
- Demand
- Contingency
- Equity
- Communications and Data
- Security
- Utilities
- Safety
- Automation
- Other

The groupings utilized in this paper are simply one possible organization that the authors believe is useful. There are many other possible groupings that could be developed. For example, another possible grouping would be based upon life cycle, such as siting, design, nominal operations, and contingency operations. Readers are encouraged to consider other groupings based on their particular needs.

A. Federal Regulatory

The list of federal regulatory considerations obtained in the CIWG meetings are provided in Figure 1. The considerations captured here represent those that are governed by or primarily influenced by federal regulations.

- Federal funding used
- Public vs Private
- Airspace impact evaluation
- Design Circular(s)
- Maturing Design Circular(s)
- Maturing taxonomy
- Grant restrictions
- Occupational Safety and Health Administration (OSHA) and Americas with Disabilities Act (ADA) requirements
- Future climate requirements
- Leadership in Environmental and Energy Design (LEED) Goals/requirements
- Physical security (pax + cargo) regulations
- Applicable existing regulations
- Regs developed for AAM
- Environmental requirements e.g., National Environmental Protection Act (NEPA), FAA 1050.1
- Cross-boarder operations
- Governing regs e.g., Part 135
- FAA Regulatory Roles & Responsibilities (CAA)
- FAA Operational Roles & Responsibilities (ANSP)
- Federal vs Local Roles and Responsibilities
- Species protection regulations
- Registration in National Registry of Airports
- Airport Master Record e.g., 5010-1 forms
- Mitigation Programs e.g., noise abatement
- Interstate commerce regs
- Part 157 Forms 7480 & 7460 Notice of Construction
- 49 USC 5501 National Intermodal Transportation
- Data collection, retention and disposal policies and procedures (for audit and safety trend analysis)
- Federally provided vs commercially provided service
- Engage early with the FAA

Figure 1: Federal Regulatory Considerations

The assumptions of which currently established federal regulations governing aviation infrastructure development, design, and safety that will be applicable to the advanced air mobility (AAM) industry will play a significant role in vertiport site selection, design, protection, oversight, and development of operational procedures. While the requirements for operations conducted under 14 CFR § 121, which we will refer to as Part 121,[8] generally require operations to be conducted at airports that are certified under Part 139, flight operations conducted under Part 135 are much less stringent. Currently, Part 139.1 specifically identifies heliports as not being governed by Part 139, and, as such, these standards do not apply to heliports. Due to this fact, there are no governing federal requirements or processes for heliport certification in the U.S., and, as such, heliports are exempt from federal oversight as well as any afforded federal protection.

Assuming that the aviation industry expects AAM operations to be conducted under Part 135, vertiport requirements will therefore not be held to the standard of Part 139 but rather Part 135. Section 135.229 stipulates that "[n]o certificate holder may use any airport unless it is adequate for the proposed operation." While this may be deemed sufficient for most commuter and on-demand infrastructure, it remains to be seen if the general public and local decision makers will be able to work with this lesser degree of federal engagement and oversight flexibility as it applies to the expected high volume of vertiport operations.

Whereas pilots operating under rules governing Part 121 that routinely operate into and out of airports certified under Part 139 have the expectation that these sites meet specific standards and are evaluated annually, pilots operating under Part 135 are currently not afforded these same expectations. For the general public to allow AAM infrastructure to be developed in their communities, public confidence as it relates to the safety of operations and supporting infrastructure will need to be achieved. Providing assurances to the public that vertiports will in fact be required to meet published standards and that federal transportation agencies will have oversight and enforcement authority likely will be a key factor in achieving this confidence, and hence public perception.

While a vertiport is in fact already classified as an airport under Part 157.2 and proposed explanations for the terms *vertiport* and *vertistop* are included in the draft vertiport design engineering brief [32], many of the other terms associated with AAM, such as vertiplex, have yet to be defined in regulations. To allow for proper governance and harmony at the state and local level, AAM terminology will need to be formally defined at the federal level. The adoption of these formally defined terms by multiple state and local governments will support national harmonization. Adoption will also allow for standardized terminology to be used in the development of zoning criteria, building code, fire code, and ordinances that govern such permitted development.

Under current federal regulations, the FAA has not been provided oversight authority of private-use facilities. While there are standards published for all aviation infrastructure facilities, private-use standards are categorized as recommendations only [5]. In a 2000 FAA survey questionnaire that was distributed by the National Association of State Aviation Officials (NASAO) to all 50 states, the FAA specifically stated*, "To the extent that they choose to do so, the design of private heliports is regulated, NOT by the FAA but by the 50 States"* [14]. The survey asked the specific question, *"Does your state law require a license or some other form of state approval for Private, Hospital or Public Heliports?"* Only 12 states indicated that they required any form of license or approval by the state. This is significant because out of the nearly 6,000 heliports in the U.S. only 58 are categorized as pubic-use with the remaining 99% being classified as private-use [15]. If few states continue to provide significant oversight of private-use infrastructure and the federal government does not provide authority to the FAA for this task, municipalities will then be faced with the responsibilities associated with providing oversight for private vertiports. It is likely that most states do not have the staffing nor the expertise to address the considerations associated with providing this oversight of private vertiports.

Vertiport funding and operating paradigms, as they pertain to state and municipality governance, will be dictated in large part as to how vertiports are both categorized and too what extent different government agencies have oversight and enforcement. As of the writing of this document, the federal government only recognizes two specific use cases in the current regulations, which are Public-Use and Private-Use [16]. While all states and territories recognize these two terms, many states have additional categories that allow for added flexibility as well as increased oversight and regulatory constraints. These categories include but are not limited to commercial-use, hospital, prior permission

[8] From this point forward, we will use shorthand to refer to the relevant sections of Title 14 of the Code of Federal Regulations; specifically, we will say "Part #" to refer to 14 CFR § #. The sections we will refer to are Parts 121 (entitled "Operating Requirements: Domestic, Flag, and Supplemental Operations"), 135 (entitled "Operating Requirements: Commuter and on Demand Operations and Rules Governing Persons on Board Such Aircraft"), 139 (entitled "Certification of Airports"), 157 (entitled "Notice of Construction, Alteration, Activation, and Deactivation of Airports") and Part 77 (entitled "Safe, efficient use, and preservation of navigable airspace").

required, personal-use, and restricted-use. To date, Public-Private collaborative aviation infrastructure funding efforts also identified as the Airport Investment Partnership Program (AIPP)[9], have had very limited success in the U.S.

In the United States (U.S.), pertinent information for a specific takeoff and landing site is captured in the FAA Airport Master Record program, which is now provided for by the FAA's new online Airport Data and Information Portal (ADIP) [15]. From this data interface, the information for a specific takeoff and landing site, which is collated in FAA Form-5010 [17] is readily accessible online.

Unfortunately, the Airport Master Record Program does not currently maintain all the data that would be desired for future vertiports. For example, current federal data capture protocols are likely insufficient to allow for the protection of the airspace of both heliports and vertiports, which is of paramount importance to longevity and overall safety. While FAA Form-7480, entitled "Notice for Construction, Alteration and Deactivation of Airports" [18], does include Approach/Departure headings, it currently only allows for a single one to be recorded. Additionally, after the FAA completes an airspace evaluation and issues their official airspace determination letter, the airport master record and FAA Form-5010 do not have the capability to capture an approach/departure path. In most cases, this information has been completely lost over the years for existing heliports. Currently, the FAA AC 150/5390-2C, heliport design guide allows for curved approach/departure paths, for which there is no current data capture mechanism within the FAA Form-7480, Form-5010 or the Airport Master Record database. Given that the FAA has never been provided oversight authority from Congress for private-use aviation facilities, combined with a significant lack of airspace data capture capabilities, it is extremely difficult for heliport and vertiport owners to protect their airspace from obstructions such as buildings, antennas, power lines and light poles being built within a vertiport's airspace.

The airport master record also allows for the identification of each individual site through a special identifier known as an Airport Location Identifier. This location identifier provides for a searchable database within which interested parties can find relevant information for specific locations at or near which they plan to operate. Entities that use this information for planning purposes include but are not limited to Department of Homeland Security, Federal Emergency Management Agency, Department of Defense, helicopter air ambulances, search-and-rescue operators, first responders, and drone operators. This information is what many pilots use to fulfil their obligation as a pilot in command under Part 91.103 for preflight actions prior to beginning a flight [19].

Due to a lack of incorporated data in the airport master record database on numerous private-use facilities, many facilities do not have an airport location identifier, hence making these facilities unknown and invisible to anyone searching for them. With current advancements in the concept of beyond visual line of sight operations for UAS, this lack of data and awareness of takeoff and landing sites represents a significant risk factor. According to a NASA report issued January 1, 2019, by the Aviation Safety Reporting System (ASRS) there are an estimated 1,600 to 1,800 heliports in the U.S. whose information is not accounted for in the current FAA airport master record database [20]. It would impact planning and operations for future vertiports should vertiport owners and operators not be able to record all the pertinent data related to their facilities and have awareness of nearby facilities.

Applicable regulations, taxonomy, data accountability, and data sources are several of the considerations associated with this federal regulatory grouping. Others include OSHA and ADA requirements for future vertiports and will likely be addressed as the initial considerations are evaluated, reviewed and solutions proposed.

B. State, Tribal, and Local Regulatory

This grouping of considerations captures those related to state and tribal laws, local ordinances, regulations, and rules. The current list is shown in Figure 2. Currently the interactions between aviation and local interests typically occurs at airports, within the vicinity of the airport, at the sites of aircraft mishaps, and over the considerations captured in Figure 2. The stakeholders, their roles and responsibilities and the taxonomy used for these interactions are common enough that communications do typically occur unimpeded. AAM operations are changing that dynamic. Not only are the interactions going to be much more frequent, but the taxonomy of AAM is still evolving.

[9] Originally established by Congress as the Airport Privatization Pilot Program (APPP) under the FAA Modernization and Reform Act of 1996 it was later renamed the Airport Investment Partner Program (AIPP) under the FAA Reauthorization of Act of 2018.

- Zoning of site
- Zoning of surrounding area
- Local/state funding
- Noise ordinances
- Operating hours
- Economic Development Plan
- Building, plumbing code(s)
- Lack of building codes
- Local data requirements
- Adopted fire codes
- Incorporate & adhere to local master and transportation plans
- Support local planning goals
- Current or future land use plans
- Environmental requirements. e.g., Special purpose state/local laws, California Environmental, Quality Act Coastal Commission
- Long term local goals and plans
- Long term transportation integration planning
- Stakeholder groups assembled
- Processes in place to obtain stakeholder input
- Understanding public opinion
- Federal vs Local Roles and Responsibilities
- Digital Policy (flexible & rapid policy implementation tools)
- Information Technology (IT) system requirements for publicly funded infrastructure
- Local mandate of publicly funded vertiport requirements on private vertiports
- Differences in state vs local regulations
- Local airport land use plans
- State Aviation System and other aviation Plans

Figure 2: State, Tribal, and Local Regulatory Considerations

Rather than being able to build upon current terminology used in referring to heliports in local codes and ordinances, many municipalities incorrectly utilize the term helipad in referencing vertical flight infrastructure. The term helipad is not a defined term in the federal regulations nor is it defined in the FAA advisory circular AC 150/5390-2C. The only location that the term helipad is listed is in the Aeronautical Information Manual Pilot/Controller Glossary where it states that a helipad is part of a heliport or airport. In defining a repeatable process for vertiport site selection, harmonized and accurate terminology is going to be extremely important.

Voluntary, consensus standards build upon taxonomies to propose requirements that can be adopted or tailored by localities. For example, a community could exercise its responsibility for fire safety by adopting a specific fire safety standard. Key organizations that publish standards related to local communities include the International Code Council (ICC) [21], National Fire Protection Association (NFPA) [22], ASTM International [23], International Organization for Standardization (ISO) [24], and the Illuminating Engineering Society (IES) [25]. Most municipalities adopt these standards which then become enforceable ordinances. In conducting a vertiport site selection evaluation for potential infrastructure and potential vertiport design, code research and the capability to meet compliance play a large role in what makes a site viable or nonviable. This is currently more challenging as many of the standards associated with vertiports are either still in development or not yet started. A potential consideration while these standards are being developed is to look at older standards that may provide the foundation for future related vertiport standards. While the FAA does publish advisory circular AC 150/5190-4A, A Model Zoning Ordinance to Limit Height of Objects Around Airports, it was published over 35 years ago and has never been updated [26]. This publication still provides some good information for municipalities to consider when developing ordinances for AAM infrastructure.

State laws and local ordinances that are in harmony with accepted federal and international standards will likely be more easily adopted and would contribute to common national implantation of vertiports. When developing local ordinances for vertiport site selection protocols or design requirements, pointing to a federal or international standard rather than a unique local requirement could reduce the entry barriers for local operations by vertiport developers and operators and potentially the need for local governing bodies to become subject matter experts to keep their ordinances aligned with advances in AAM technologies and their localities attractive for AAM operations. For those municipalities looking to embrace AAM, having ordinances and codes in place that address zoning standards for aviation infrastructure along with conditional use permitting processes that recognize that laws and standards are still evolving and will likely require multiple levels of interdependent approvals will greatly assist in the approval processes. An example of this is a conditional-use approval process that incorporates language such as *"Contingent upon a favorable FAA airspace determination letter being received."*

Other considerations with a state, tribal, or local perspective contained in the list are those associated with plans, including planning goals, land use plans, state aviation system plans, and local and master transportation plans. It is likely that many of the stakeholders addressing these issues will need to expand on their areas of expertise whether it is the aviation experts gaining knowledge about ground transportation or the local city planner gaining knowledge about aviation. To enable the gaining of this expertise to occur, resources to be compiled, expertise gained, cross domain challenges appreciated, and it is efforts like compiling these considerations and others that will support stakeholders, planners, and decision makers at the state and local level.

C. Physical – Fixed

The considerations in this grouping, which are shown in Figure 3, are physical obstacles or likely permanent regulatory restrictions near a vertiport which could impact operations. They can also be anticipated obstacles, such as if an adjoining property has development rights for a 40-story building but is currently a vacant lot.

- Near-by buildings (e.g., high rises)
- Antennas
- Towers (cell & water)
- Trees
- Power and other lines
- Power poles
- Billboards
- Land use designation of vertiport site
- Compatible with existing airports & their future plans
- Compatible with other transportation infrastructure and plans
- Property owner(s) rights
- Time/ease for multi-modal transportation changes
- Terminal Instrument Procedures (TERPS) evaluation

Figure 3: Physical - Fixed Considerations

Physical obstructions in the area surrounding a vertiport may also impact the available usable airspace. One of the first steps into any vertiport placement analysis, assuming instrument flight rules (IFR) operations, is to perform a Terminal Instrument Procedures (TERPS) evaluation. The purpose of the TERPS evaluation is to identify the required obstacle clearance of existing structures for each landing/takeoff area for applicable procedures, i.e., straight-in, circling, alternate, and takeoff. This allows for flight in instrument meteorological conditions (IMC) without fear of collision with unseen obstacles. [27] Along with possible constraints from existing infrastructure, the allowed uses on abutting properties must be considered in depth as the primary surface of the take-off and landing area sphere/cone of clearance [28] impacts any changes to those abutting properties in the future. Early coordination with the FAA during vertiport location planning is critical to understand these limitations to potential approach and departure procedures prior to building a vertiport.

Regulatory restrictions include both the current land use designation of the vertiport site and the rights of the property owner. There have been cases where property owners have sold the space above a building or property up to its buildable height. In these air rights transactions or transfers of development rights, owners sell their rights to build in the space above their property to buyers who want to construct something larger than they would otherwise be allowed to build [29]. For example, if a parking garage operator sold the air rights above their garage, a proposed vertiport terminal that would extend into this space could likely not be built without the approval of the owner of the air rights. Height districts are geographical areas where maximum building heights are limited, and this should be considered when siting a vertiport as well.

The physical considerations in Figure 3 must be weighed and balanced with consideration of anticipated future development patterns and the vision of the jurisdiction as it seeks to accommodate population shifts, increases, or decreases in density, and development such as the current trend towards mixed use neighborhoods where residential and commercial buildings are in proximity.

D. Physical – Mobile and Temporary

The considerations within this grouping are shown in Figure 4 and are physical things of a changing or temporary nature. They are considerations that are both planned for and anticipated. Planned considerations are those that involve a process where the vertiport operator could have the opportunity to provide input whereas anticipated considerations are those for which there is no or minimal prior notification but would likely occur over the life of a vertiport.

- Temporary vertiport (1 year, disaster recovery, special event)
- Building cranes
- Blowing debris
- Construction staging
- Noise
- Lightening protection equipment
- Non-acoustic annoyance factors e.g., visual
- Static discharge
- Urban wind shadows
- Future local land use

Figure 4: Physical – Mobile and Temporary Considerations

The planned for mobile and temporary considerations include cranes/construction staging and changing land use designations. These things likely require permitting in advance and so the permitting process should include evaluating the impact on vertiport operations. Future local land use is the potential for the locality to decide to change the land use designation e.g., from transportation to industrial of a potential or existing vertiport site, revoke a land use waiver or the vertiport operator desires to expand the vertiport such that they would need to petition the locality for a change to the land use designation. While such things as mobile and temporary cranes are planned for at the federal level under Part 77 with the filing of FAA Form 7460-1 [29.1], only public-use facilities are fully accounted for in the FAA's Obstruction Evaluation / Airport Airspace Analysis (OE/AAA) system [29.2]. Private-use facilities are not accounted for in the OE/AAA notice criteria search unless they have an IFR procedure associated with them, and only then for notification purposes not for airspace protection.

Anticipated considerations include debris, such as a stick from a tree, that blows onto the vertiport from elsewhere or foreign object debris (FOD), e.g., a pen dropped by a passenger on the pad. Another example is lightning protection infrastructure that is only deployed when there is the threat of lightning or an urban wind shadow when the surrounding buildings create an area of calm air over a vertiport under specific conditions such as winds from a specific direction and speed. Another anticipated condition is the potential for static discharges. All aircraft develop electrostatic charge while flying and in large helicopters this can exceed 100,000 volts [30]. While serious injury is typically prevented by grounding the aircraft prior to touching the aircraft, the potential for inadvertent discharges should be considered [31].

While these considerations reflect events that are temporary and potentially insignificant over the operational life of a vertiport, they still merit consideration to support safe and efficient operations. Furthermore, vertiport siting decisions may also be impacted by the anticipated frequency of certain temporary considerations. For example, locating a vertiport adjacent to tall trees increases the likelihood of debris entering the vertiport movement areas on a regular frequency to include at some point in the future, as the trees grow, they may penetrate the vertiport's airspace and become a hazard to navigable airspace.

E. Surrounding Uses

Consideration of the surrounding areas is critical when selecting vertiport locations and designing vertiport operations. [11] This grouping encompasses considerations arising off the vertiport property, but within the local vicinity. These considerations can impact the vertiport during site selection, design, or operations and may also change over the life of a vertiport. The vertiport can also impact the surrounding area and modify these considerations.

The factors shown in Figure 5 can generally be divided into two categories: ones that are impacted by features of the surrounding area and ones that impact those same surrounding areas. As will be discussed below, these categories are not necessarily mutually exclusive.

Impacted by surrounding area

- Critical infrastructure nearby
- Local Fire station
- Metro/bus/train stop
- Building security
- Local land use
- Maturing vegetation
- Compatibility - Business/industrial vs residential
- Connectivity to existing transportation networks
- Distance to Maintenance or Repair Facility (MRO)
- Down wind of wind farm

Affect surrounding area

- School in vicinity
- Property under approach and departure paths
- Noise sensitive area
- Visual distractions e.g., solar panel reflectivity, ambient or artificial lighting, both on ground in and air
- Nearby animals (zoo, domestic)
- Protected wildlife habitats
- Future property values
- Impact on local community, environment or surrounding land use considerations impacts from increased traffic accessing vertiport
- Follow-on development compatibility
- Hazards from specific land uses e.g., birds at landfills, ash from burning, weather radar around wind farms
- Privacy of vertiport neighbors
- Operations distracting other activities e.g., drivers on a freeway

Figure 5: Surrounding Uses Considerations

The proximity of a vertiport to existing infrastructure is a primary siting factor. Infrastructure considerations include current local land use (e.g., school, hospital, park, or other noise sensitive areas), emergency response (e.g., fire stations), and direct connection to other transportation options (i.e., intermodality) [32][33]. For early vertiport siting, proximity to these types of existing infrastructure can enable timely development and operations by reducing the development lead time of these ancillary criteria (e.g., land use designated for transportation). On the other hand, flight operations may be hindered if vertiports are sited too close to other types of infrastructure. For example, proximity to a wind turbine farm may limit approach and departure paths and cause disturbances to airflow that could hinder safe flight operations or interfere with NEXRAD Radars [34, 35].

Understanding where AAM flights are needed or desired is another primary vertiport location criteria. Potential vertiport locations may be selected for proximity to areas of anticipated high demand, such as business centers, sports/entertainment facilities, cargo distribution centers, and transportation centers (e.g., bus stations, train stations, traditional airports). Each of these is likely already located in an area with favorable zoning for industry, business, and a future vertiport. However, many cities recognize the need to protect residential and similar areas. For example, zoning ordinances in Los Angeles County, California state, "Residential Zones preserve, protect, and enhance areas for residential land uses in a range of densities; provide for orderly, well-planned, and balanced growth of residential neighborhoods; and ensure adequate light, air, privacy, and open space for each dwelling. These zones also provide for the appropriate location of public and semi-public uses such as schools, parks, and religious facilities that can serve and complement residential uses." [36] It is in these locations or other sensitive locations where local groups are most likely to raise concerns about privacy, safety, noise, and traffic. To achieve positive public perception of a particular vertiport location, it is important for planners to develop and provide the appropriate mix of services while protecting the community's desires. Several mitigations to help find the right balance include limiting the size and operating hours of a vertiport and limiting the size and types of aircraft the vertiport services.

Vertiport access should also be addressed during planning. For ground traffic, the entrances and exits to/from the vertiport should be designed to reduce large queues or gatherings but enable ease of access to pedestrians and users that arrive via other modes of transport. On the flight side, the airspace approach and departure corridors should be designed to reduce noise impact to identified sensitive areas with the potential for additional noise constraints for vertiports near particularly sensitive areas.

F. Vertiport Configuration

There are myriad factors to consider when determining the configuration of a vertiport, and a list of factors gathered from the CIWG meetings are shown in Figure 6.

- Single pad
- Multi-pad
- Pad separation
- Public vs Private use
- Public vs Private funded
- #s of vehicle configurations, sizes e.g., capable for multiple
- Types of vehicles electric vertical takeoff and landing (eVTOL), small unmanned aircraft system (sUAS), short takeoff and landing (STOL), etc.
- Vehicle ownership – public, commercial, private, personal, etc.
- Vehicles with different propulsion energy sources
- Emergency use only
- In route charging e.g., "rest stop" use
- At ground level
- Height above ground
- Mean Seal Level (MSL)
- Downwash at vertiport
- Adjacent pad downwash
- Water run off
- Contain chemicals (deicing)
- Passenger safety boarding and deplaning
- Passenger comfort
- Planned life-cycle
- Configuration flexibility
- Incorporate new technology and or fuels
- Incorporate new regulations
- Incorporate new safety features
- Expandability
- Arrival & departure routes
- Vertiport equivalent of landside/airside coordination
- Throughput
- Annual, seasonal, daily number of operations
- Ground handling of aircraft e.g., air taxi, towed
- Surface Flow Traffic Management
- Electronic Aids for coordinating surface flow movement, accident& incident mitigation
- Vehicle separation
- Overall footprint
- On & offsite amenities
- Passenger, cargo or hybrid missions (business cases)
- Ground handing safety (existing plus new procedures/guidelines)
- Passenger onsite reservations, ticketing, information, screening including international pax (customs)

- Pax post screening area security
- Appropriate standards incorporated
- Impact of ground procedures on throughput
- Architecture integration with local architecture (visual ascetics)
- Climate appropriate design
- Consistency across vertiports within a "system"
- Vehicle performance impacts e.g., landing/takeoff profile
- Shared or single provider operations
- Shared or single user
- On vertiport Electromagnetic interference (EMI)/Radio Frequency Interference (RFI) e.g., rebar in structure or charging equipment
- Amount of overnight aircraft parking
- Distance to/from aircraft overnight parking locations
- Repurposed or purpose-built infrastructure
- Repurposed from aviation or non-aviation use infrastructure
- Physical access e.g., time to switch modes
- Accessibility (walking/biking distance)
- Surface and airspace scheduling & reservations
- Charging scheduling
- Time to fully charge
- Pre-flight procedures
- Flight line personnel safety e.g., charging cord or battery swap safety procedures
- Specific operating models e.g., battery swaps vs charging
- Usage e.g., passenger, cargo, emergency
- Turn around maintenance needs including reservations
- Pads to charge or conduct minor maintenance
- Prepositioning e.g., overnight parking
- "Down aircraft" parking
- Spares storage
- Minor maintenance facilities
- Movement of aircraft requiring relocation to MRO
- Supply deliveries
- Vertiport personnel certification/qualification requirements
- Impacts from new materials e.g., aircraft construction, building materials
- Mobile Vertiport e.g., on a barge
- Issues for vertiport at an airport
- Passenger visual queues

Figure 6: Vertiport Configuration Considerations

Multiple of these considerations relate to aircraft performance in the vertiport environment. Although eVTOL and other AAM aircraft have been advancing rapidly for the past few years, high-quality performance data is not yet fully known or understood, and, as such, determining the appropriate geometry and supporting airspace required for a vertiport is much more challenging than designing traditional aviation infrastructure. This is likely why the FAA has chosen a conservative approach to designing vertiport infrastructure as outlined in their draft engineering brief, which was released in early 2022 [37].

While many in industry are indicating that eVTOL aircraft will have equal to or greater performance capabilities than that of most helicopters, this fact has yet to be proven out in real world testing in urban environments. If eVTOL aircraft are to be certified under Part 23, because this standard currently does not require aircraft to demonstrate the same levels of controllability and maneuverability that a helicopter certified under either Part 27 or Part 29 does, early vertiport site selection and design should take into account this performance uncertainty. To allow for these unknowns, increasing of the size of a vertiport's geometry and accounting for the impact on site selection may be one of the better near-term risk mitigation strategies. At such time that validated empirical performance data for each individual eVTOL aircraft has been developed, verified, and shared, these more conservative standards may then be adjusted, as appropriate, to better reflect each aircraft's demonstrated capabilities and/or deficiencies. This is in keeping with the FAA and NASA's concept of the UML 1 – 4 roadmap [38], e.g., the crawl, walk, run approach [39], which has been carefully laid out to assure optimum safety for the flying public.

Passenger comfort considerations can influence vertiport siting, design, and operations. These include such things approach and departure paths that allow the aircraft designer and operator to optimize for vibration, G-loading, noise, temperature, and seating space to name a few [40]. Vertiport site selection will influence the airspace design and consequently, the impact the vibration and G-loading will have in the vertical, lateral, longitudinal, roll, and pitch axes on human physiology [41]. While an aircraft may be able to safely accomplish the required flight maneuvers of landing and taking off at a particular location, it will be the paying public who determines whether or not they are comfortable and confident enough to routinely use these modes of transportation. Site locations whose supporting airspace does not consider the impact that G-loading has on human physiology in all axes will more than likely be negatively impacted by poor community adoption.

A significant concern during the design of aviation infrastructure is what impact flight operations will have on the operational safety of this infrastructure. One specific consideration that must be addressed carefully is rotor wash and downwash. Pad size, the configuration of pads at the vertiport, passenger ingress and egress routes and the placement of vertiport infrastructure needs to consider the amount of rotor wash and downwash that each potential aircraft will create and what impact that will have on vertiport operations. This may require increasing the overall geometry of the landing area as well as increased distances between landing pads and parking areas, for example.

As noted, there are still significant unknows relating to vertiport configurations. As aircraft performance and airspace design questions begin to be resolved it will be possible to begin looking at the other considerations such as safety and operational procedures, regulatory compliance and vertiport performance features such as capacity.

G. Economic

The economic considerations for vertiports gathered from the CIWG meetings are shown in Figure 7. The primary economic considerations for vertiport placement, development, and operations can be divided into three areas: vertiport development costs, how those capital and operating costs are recovered, and revenue generation.

- Existing infrastructure
- Fits business case
- Land purchase cost
- Building cost
- Operational costs
- Maintenance costs
- Improvement costs
- End of life-cycle costs
- Opportunity costs
- Equipment costs (e.g., Ground Support Equipment)
- Supporting infrastructure cost e.g., weather or surveillance equip
- Re-use or purpose built
- Start up costs
- Private or publicly operated
- For profit or non-profit
- Public good contribution
- Funding sources
- Operating infrastructure life cycle costs
- Compatible with long term local/regional economic goals
- Co-located uses e.g., entertainment
- Affordability e.g., ride cost, taxpayer burden
- Funding e.g., bonds, usage fees, grants
- Funding sources - publicly funded "public good" mission % vs commercial % non-profit %

Figure 7: Economic Considerations

Vertiport costs are fairly straight forward and can be broken into capital costs (e.g., land purchase/use, development/building, large equipment, improvements, etc.) and operating costs (personnel, small equipment, upkeep, etc.). Many of these costs are paid up front and are needed for entrance into the market, while others are the part of continued operation. There are ways to reduce out-of-pocket vertiport costs. Localities can obtain grants, aircraft operators can exchange funding for stock or developers can leverage existing infrastructure (e.g., siting a vertiport on an existing parking garage) or utilize vertiports for multiple purposes (e.g., collocating passenger and cargo facility uses). Another good example is leveraging a public/private partnership to subsidize part of the cost of a vertiport that is primarily used for UAM passenger carrying operations to also be an operating location for public good missions, like medical transport during emergencies.

Capital, operational, and maintenance costs are typically captured through users' fees (e.g., the price for the ticket). Additional sources of revenue could include private sources (e.g., through a corporation, non-profit, or local business investment organization), public sources (e.g., subsidies or payment for services), or revenue generated as a result of the commercial ventures co-located with a vertiport (e.g., restaurants or rental space). Regardless of the sources of funding, to be economically viable, the vertiport will need to recover both start up and operational costs.

The anticipated means of cost recovery and continued revenue generation can impact the overall system and should be considered during planning. A critical economic factor will be the expected demand for AAM services and that demand's responsiveness to the price (i.e., its elasticity). Demand can be influenced by non-cost factors, like availability of other options and acceptability of the service. On the supply side, a major factor is the capacity of the system, i.e., how many users (or operations) the system can support. These non-cost factors impact the price users are willing to pay. There is a relationship between the price of AAM services and the number of users requesting those services. If prices are too low, demand could increase beyond capacity, which would increase service time (long lines). On the other hand, if prices are too high, demand will be hampered, and AAM services may only be practically usable by a small portion of the population. The right balance must be found to provide cost recovery and revenue generation from the infrastructure without either overly stimulating or limiting demand.

H. Environmental

The environmental grouping contains considerations related to climate, weather, and the local environment, such as if the potential vertiport is in a flood plain or on or next to a body of water. The environmental considerations captured in Figure 8 have been divided into two themes; those requiring significant effort to mitigate and those that have necessary or likely manageable mitigations. The thinking in dividing the considerations into two themes was to begin to categorize them into ones that would either entail substantial costs or large design choices and those that could be addressed with minimal costs or minor design choices. Recognizing that not all vertiports would be required to address considerations in these categories an example of the first theme could be a vertiport in Miami would likely be planned to survive hurricanes and projected sea level rises and an example of the second category is the likely routine design feature to slightly slope a vertiport pad allow for rain to flow off the pad.

Significant Effort to Mitigate

- Heat islands
- Winds near vertiport, e.g., up and down drafts
- Local prevailing winds
- Lightning
- Issues associated w/ vertiport on or next to a body of water
- Wildlife water, food sources or nesting locations nearby
- Impact on migratory paths and/or navigation
- For vertiports near water – impacts on fresh and saltwater ecosystems, animals and plants
- Seasonal weather
- Hazardous weather
- Typical ceiling & visibility
- Typical climate
- Local environment e.g., humidity, salt water, dust
- Land suitability, e.g., flood plain, over a fault
- Impacts of climate change

Necessary or Manageable Mitigations

- Micro weather sensing capability
- Micro/hyperlocal weather
- Downwash beyond pad
- Operational impacts on wildlife e.g., lights on sea turtle nesting
- Water runoff
- Snow removal
- Equipment for low visibility operations
- Aircraft emissions
- Impacts of heat and cold e.g., batteries, other equipment
- Rules associated with weather predictability (vertiports in mountains likely have different rules than ones in Los Angeles)
- Hazmat storage & cleanup facilities
- Electromagnetic Interference (EMI)/Radio Frequency Interference (RFI) emanating from non-vertiport sources e.g., 5G impacts on Global Positioning Systems (GPS), altimeters or impacts on navigation equip

Figure 8: Environmental Considerations

Within the significant effort to mitigate theme are both the vertiport's climate and potential changes to that climate over the expected life of the vertiport. Generally speaking, the impacts of climate change are attributed to multiple worsening events, including increased frequency and intensity of fires, tornadoes, and hurricanes [42]. Similar to other infrastructure, vertiports will need to have procedures for severe weather e.g., suspending operations for specific weather conditions or provide pre-planned alternative landing sites as localities anticipate increases in violent weather episodes. Another climate change concern for vertiports is data is indicating that bird migration patterns have shifted northward and towards higher elevations since the 1940s [43]. For example, while a vertiport in Georgia could anticipate seeing birds migrate through on their way to Florida—1.2 million nocturnally migrating birds flew through Georgia on just April 26, 2022 [43]—in the future these birds could overwinter in Georgia. As a result, consideration of the climate change for the life of a vertiport should consider both the direct impact to the vertiport and aircraft operations, e.g., aircraft performance at higher temperatures, and the indirect impact, e.g., rising sea levels or increasing frequency of hurricanes or fires.

Within the second theme are the necessary or manageable environmental mitigations for consideration. The National Environmental Policy Act (NEPA) requires federal agencies to assess the environmental effects of their proposed actions prior to making decisions. The range of actions covered by NEPA is broad and includes making decisions on permit applications, adopting federal land management actions, and constructing highways and other facilities such as vertiports which for example, would impact the waters of the United States [44]. Inventory and assessment of NEPA's categories must be conducted to understand the baseline of required environmental assessments of siting and operating new vertiports. Additionally, in 20 U.S. states, additional local environmental reviews are required [45]. Once a baseline for the affected environment is established under NEPA and any relevant state law guidelines, then the local jurisdiction must assess if there are additional studies that should be conducted to fully assess any environmental impacts that may occur as a result of a vertiport location or operations. The emergency landing sites associated with a proposed vertiport must also be considered as part of the environmental assessment to ensure that the environmental issues associated with these emergency sites are also factored into the environmental analysis. Noise and potential emissions concerns need to be assessed to assure that the NEPA and any relevant local levels are met, otherwise additional mitigations may be required. Assessment of any potential environmental justice [46] impacts must also be reviewed at the local level to ensure that potential unintended consequences from the vertiport or associated transportation planning decisions are identified and addressed.

I. Airspace

The Airspace considerations in Figure 9 capture how the management of the surrounding airspace impacts the vertiport. The airspace grouping is intended to be scoped to the airspace within the local vicinity of the vertiport along with considerations resulting from other airspace structures in this same local area. Because of this scope the grouping also captures considerations that result from these airspace structures.

- Class of airspace, E, B?
- Distance to airport
- Helicopter corridor usage, procedures, approval process
- Traffic volume nearby
- Migratory patterns
- Special Use Airspace (SUA)
- Military Use Airspace (MUA)
- No fly zones (e.g., prisons)
- Flights over sensitive infrastructure, events, etc.
- Multiple approach & departure routes available
- Future airspace uses
- Expandability
- sUAS, passenger sized eVTOL & STOL vehicles operating in vicinity of a vertiport (mixed operations)
- Cross boarder flights
- Nearby airport airspace uses
- Metropolitan airspace strategy
- Airspace system and individual route density
- Distribution vs consolidation of traffic impacts
- Vertiport traffic density
- Number of types of aircraft
- Aircraft performance impacts
- Passenger arrival/departure experience
- Tailorable approaches (both VFR and instrument, vehicle performance and operator energy management goal driven)
- Ability to support dynamic system balancing
- Managing airspace design changes
- Community inputs on routing of aircraft between vertiports
- Vertiport operator role & responsibility for airspace in vicinity of vertiport
- Vertiport at airport considerations
- Closely located vertiports
- Separation violation reports (Electronic Occurrence Reports (if applicable to AAM Operations)
- Route planning to minimize hazard to population etc. below flight path
- Entry and exit into air traffic controlled (ATC) airspace
- Access to a vertiport at an airport
- Distance between ground and Mean Sea Level (MSL) e.g., a vertiport at 9,000ft could impact the number and shape of routes with class E airspace at 10,000' MSL

Figure 9: Airspace Considerations

The immediate airspace surrounding a vertiport and how that airspace is managed has a significant impact on operations and should be considered when researching vertiport placement. Several factors have a direct impact on the amount of airspace available to support operations close to the vertiport, these include location within or near controlled airports, no-fly zones, special use airspaces, or sensitive flight areas (e.g., over schools, hospitals, churches, etc.). These nearby airspace restrictions may limit the size and/or location of approach paths, departure corridors, or holding areas.

Adhering to these restrictions can reduce the overall number of operations the vertiport can support. Thipphavong et al. provides a good discussion regarding many airspace considerations (not just vertiport related) for UAM operations [47].

The density of operations in the vicinity of the vertiport is also a consideration for placement. This can be due to operations at that new vertiport alone or when combined with air traffic from other vertiports and/or traditional airports. As the density of operations increases, the need for both tactical and strategic management of the traffic flow also increases. However, options for managing traffic while aircraft are airborne may be limited, depending on several factors. For example, the relative size of the available airspace surrounding the vertiport for urban operations may be insufficient for the envisioned demand and result in an alternative vertiport site selection. In addition, eVTOL aircraft envisioned for such operations may have limited energy capacity to support significant holding times and may require additional landing pads at a vertiport or within the vicinity of the vertiport. Ground holds may be an effective traffic management technique, but could impact the design of a vertiport, requiring space to accommodate extra ground traffic that does not restrict the use of the vertiport for other cleared takeoff and landings.

Additional airspace considerations include allowing for anticipated aircraft performance, migratory patterns, and the passenger experience resulting from steep or shallow approach and departure paths. Understanding and addressing airspace considerations will require close coordination with the FAA.

J. Demand

Demand considerations for AAM services shown in Figure 10 should be weighed across missions and consider costs to understand their impact. First consider UAM passenger-carrying operations. An early assessment for locating vertiports would be to determine travel needs of the population, including origins, destinations, and trip purposes, because AAM services will generally provide more time benefits when they are located closer to desired origins and destinations. This will require consideration of the implications of locating vertiports close to residential and business facilities which could include locating many small vertiports near these areas and/or co-locating vertiports with existing urban ground services (i.e., multimodal integration) to move passengers the "last mile." Passenger-carrying trips to other areas of high demand (e.g., an airport) could leverage the same neighborhood vertiports used for commuting purposes and would feature at least one vertiport with commensurate capacity. AAM services to special events could also feature a vertiport with flexible capacity to be able to meet the high demand periods and scale down when no events are scheduled.

- High traffic area
- Seasonal demand
- Multimodal integration
- Impacts of demand or congestion across multiple modes
- Existing or generating demand
- Capacity – Demand feedback loop
- Dynamic sizing of vertiport
- Dynamic sizing of system of vertiports
- Scheduling capability
- Interoperability with other modes of transportation
- Special event demand
- Prioritization of access e.g., emergencies, first come first served, greatest benefit
- Need for dynamic rebalancing (early outbound needs exceed late inbound needs)
- Demand prediction capability
- Analysis models for understanding and optimizing transition amongst modes.
- Roles and responsibilities for balancing capacity and demand both at each vertiports and across the AAM system
- Impact of individual vertiport throughput on the AAM system

Figure 10: Demand Considerations

AAM cargo services would have different use cases and hence a different demand profile. The need for vertiport locations would map to where goods are located and needed (i.e., distribution centers, seaports, airports, etc.), but not necessarily people. One concept is for larger AAM aircraft to move packages from goods distribution centers out to neighborhood facilities where customers can pick them up directly or receive a last mile delivery by sUAS or ground vehicle. These neighborhood pickup facilities can be collocated with neighborhood vertiports, sharing operations between passenger- and cargo-carrying aircraft or using passenger aircraft to also carry cargo. This sharing of operations may also be true for vertiports located at airports.

Another AAM mission to consider is air medical flights. While many hospitals already have heliports to support medical emergency flights, future AAM concepts include the common use of new air ambulances, which will require more hospitals to either retrofit their existing heliport to meet vertiport operational standards or build a new vertiport. Medical flights also include delivery of necessary emergency care personnel and equipment to the site of an emergency. Similar to today's emergency operations, there will continue to be the need to identify and develop Predesignated

Emergency Landing Areas (PELA) suitable for safe emergency medical takeoff and landing operations throughout an urban area. As AAM proliferates, medical-related services, including transport of non-emergency patients, workers, visitors, and surgical supplies can be considered. While those operations are more in line with passenger carrying AAM operations, from a facility point of view, a hospital will need to consider whether patients' needs will require the separation of emergent and non-emergent vertiport facilities. Another demand-related consideration for these "public good" flights is the anticipated positive public perception for these missions.

Regardless of the mission, there will likely be times when the demand for landing services at a vertiport will be greater than capacity. This may be caused by many factors, including reductions in capacity due to weather or an increase in demand for a particular vertiport due to a special event. The demand capacity balancing (DCB) at the vertiport and the surrounding airspace will need to be managed [39]. Strategic DCB can be managed through price increases. This is common with current ride-sharing and express lane dynamic pricing [48, 49]. DCB is also an issue for vertiports collocated with other modes of transportation.

Other demand considerations include analysis models and tools that can evaluate different DCB methods and tools such as dynamic pricing and the roles and responsibilities associated with DCB and include dynamic sizing of both the vertiport and the AAM system. Dynamic sizing could include pads or vertiports that are only open during peak periods such as a vertiport at an office park only being open during "rush hour". During off peak periods these pads could be used for parking, maintenance, or the vertiports could be used for suitable outdoor activities.

K. Contingency

The contingency considerations grouping in Figure 11, captures non-routine events at the vertiport and across the multiple systems that interface with the vertiport. While most are captured here, some appear in other groupings, such as lost communications procedures in Section M. Contingencies are an area where the multiple dependencies of potential AAM operations are on full display. Contingency considerations can be identified in multiple ways, including scenarios, exercising contingency plans, and lessons learned. The considerations here reflect three themes: contingencies involving the aircraft, those involving the vertiport, and those related to procedures and preparations for potential contingencies.

Involving the aircraft

- Availability of nearby landing site(s) – hours open
- Nearby Emergency landing site(s)
- "Down" aircraft procedures
- Search and Rescue Procedures
- Event containment e.g., isolation of event on one pad
- Propulsion unique contingency procedures
- Aircraft lost comm procedures common and specific to one vertiport
- Understand contingency flight plan data available to and needed by the vertiport operator, vs Providers of Services for UAM (PSUs) vs vehicles operating out of that vertiport

Involving the vertiport

- Other signal losses e.g., navigation, surveillance
- Operation during loss of utilities e.g., blackout
- Impacts from short term external disruptions e.g., physical demonstrations

Contingencies procedures and preparations

- Backup power
- Grid resiliency
- Firefighting needs (e.g., foam system?)
- AAM system resiliency
- Fire codes - International Fire Code (IFC)/National Fire Protection Association (NFPA) (adopted/developed)
- Locally driven building/fire codes (e.g., earthquake)
- Local emergency response time(s)
- Distance to medical care
- Distance to local law enforcement
- Accident & incident investigation procedures
- Drill planning
- Resiliency to AAM disruptions
- Resiliency contribution to entire transportation system
- Role in local disaster plans e.g., shelter or search and rescue
- Hazmat procedures
- Fire suppression technologies e.g., water, chemical, or new technologies e.g., automated mobile systems
- Fire thermal, gas, particulate and suppression system venting during the fire and containment for clean up
- Procedures for passenger flight changes e.g., weather delays
- Surface incident reporting e.g., Mandatory Occurrence Reports (if applicable to AAM operations)
- Contingency policies, standard operating procedures (SOPs) for graceful degradation of vertiport operations
- Understanding Emergency Procedures that are common across multiple vertiports vs procedures unique to each vertiport
- Vertiports accounted for in Flight Termination System requirements
- Widespread disasters vs localized
- Natural vs man-made disasters
- Conditions when private vertiports open for public use or contingency operations

Figure 11: Contingency Considerations

Aircraft contingencies are those that originate with the aircraft, but impact vertiport design and operations. A "land immediately" aircraft emergency could have a mitigation of building sufficient emergency landing sites or the operational requirement to keep one pad open at a multipad vertiport. A fire aboard an aircraft would be mitigated in the vertiport design phase by installing firefighting equipment, and additional mitigations could include conducting drills to test the fire response plan along with shutting down the vertiport until the aircraft fire is extinguished.

Vertiport contingencies include loss of power, a hazardous material spill, fire, sensor signal losses, equipment failures, or weather-related events that impact vertiport operations. Because the vertiport will likely be more closely integrated within the community than typical airports or heliports, risks associated with the integration of the vertiport within the community and its proximity to specific locations should be considered. These considerations could be potential risks associated with large, unplanned activities near a vertiport, such as a fire in a nearby building or demonstration. Some of these contingencies are more likely to occur than others and can be addressed through a Safety Management System (SMS) risk mitigation process. This risk management process can also identify additional contingencies and considerations.

Some of the considerations included in Figure 11 are the anticipated need for procedures or areas that should be considered when the vertiport is located and designed. Anticipated required procedures include addressing hazardous materials (HAZMAT) spills, an aircraft mishap on a pad, or the closure of a single or multiple pads. These procedures would also include Emergency Action Plans, steps for required notifications, reporting, and the potential need for an investigation. Contingencies to be considered during the vertiport planning phase would include the travel distance and time to emergency responders, the types of medical facilities within easy travel distance, or more mundane contingencies, such as passengers being able to access other forms of transportation to get home if the vertiport is shut down due to weather.

Identification of contingency considerations should be subject to a rigorous process during the planning and design phase to enhance the safety of vertiport operations and to seek to reduce the need for potentially expensive retrofits to mitigate unconsidered contingencies.

L. Equity

Many past transportation planning efforts and projects have not given much consideration to equity. Consideration of equity in the planning process allows for evaluating if the approval process, the impacts of the planned operations, and the realization of the goal(s) of the project (e.g., a new vertiport on a specific site) are equitable to all stakeholders. Equity means that everyone in a community has access to the same opportunities and that the considerations and results of a vertiport development bring reasonable benefits to all without unduly penalizing one segment of a population. Taking an inclusive approach throughout the entire process of planning and operating AAM is imperative in achieving equity. Having a continuous dialogue with all segments of the population affected can help ensure equity is achieved. Stakeholders in this process include aviation professionals, aircraft designers and operators, and the community stakeholders that represent all residents, business owners, private property owners, and any other population that local jurisdictions have in their communities.

Social Equity

- Local median income
- Visual "pollution" (from low-flying aircraft on approach/departure paths)
- Impact to property value
- Impact to land value
- Public vs private vertiport impacts
- Equity failure lessons
- Environmental justice e.g., flying over low-income neighborhoods
- Fair allocation of negative impacts
- Locations of supporting infrastructure e.g., comms, nav
- Business models incentivized to be more equitable

Access Equity

- Equal access to "public" resources in normal conditions e.g., airspace when safety related requirements are met
- Ability to prioritize flights e.g., emergency services
- Operators (vehicle and vertiport) may determine and operate at their "optimal" performance e.g., turn around times
- Ability to equitably allocate limited or scarce resources
- Cost as a percentage of income
- Accommodation for people with disabilities
- Distance of traveler's starting and ending point from vertiport
- Mode choice

Figure 12: Equity Considerations

A list of equity considerations from the CIWG meetings are given in Figure 12. These equity considerations primarily address two types of equity: social and access equity. Social equity is concerned with providing impartiality, fairness, and justice to all members of the community. Such social equity considerations include ensuring individuals across socioeconomic demographics realize benefits from AAM services and that negative impacts of operations (e.g., noise, visual pollution) are also appropriately distributed.

Access equity considerations have two themes. One is the ability of all members of the community to be able to utilize this new form of transportation and is a key part of the definition of AAM [10]. The other access equity theme is the equitable access to scare resources. The current list of considerations for this second access theme highlight the fact that the airspace surrounding a vertiport and the vertiport itself can likely only accommodate a limited number of vehicles. These considerations highlight the desire for means to equitably allocate the capacity of the vertiport and its surrounding airspace, including the appropriate prioritization of operations, such as giving priority to emergency services.

The multifaceted nature of equity considerations will make addressing them over the life of a vertiport project a substantial challenge and will likely have significant implications to the viability of a locality's AAM system.

M. Communications and Data

Communications and data considerations are closely intertwined with many of the considerations in the other groupings, including contingency, security, and automation. When considered from a broader ecosystem perspective, the communications and data considerations provided in Figure 13 are needed to integrate the vertiport with the vehicle and airspace systems. For this list, the considerations were bounded to the vertiport environment and its interfaces with other AAM systems. So, the location of navigation and surveillance equipment at the vertiport is captured in the vertiport configuration considerations grouping, but considerations of the navigation and surveillance systems beyond the vertiport environment are not captured as part of this paper. For this current list show in Figure 13, the considerations have three themes: the data or information itself, procedures and interfaces with other systems, and the actual communications system and its characteristics.

Data

- Data for performance metrics
- Comms needs for vertiport operator
- Minimum Operational Data Exchange requirements between stakeholders
- Understand flight plan data available to and needed by the vertiport operator, vs PSUs vs vehicles operating out of that vertiport
- Datalink for advisory and clearance data, etc.
- Exchange of flight plan and surveillance data between Air Traffic Control (ATC) & PSUs
- Data needed for or automated systems

Procedures and Interfaces

- Interoperability with 1st responder equipment
- Comms Plan(s)
- Need for intra Provider of Services for UAM (PSU) comms data exchange for strategic deconfliction
- Data integration w/ other transportation modes
- Lost comm procedures
- Data security
- Data sharing policies and procedures (external data requests)
- Passenger data connectivity
- Vertiport data connectivity
- AAM system data/comms connectivity
- Data "chain of control" policies and tools to trace data "chain of events" and actions taken e.g., communications between PSU and FAA, or pilot and vertiport operator
- Data exchange between PSU, UAS Service Suppliers (USSs), Extensible Traffic Management (xTM) and National Air Space (NAS) system
- Flight Information System (FIMS) data exchanges.

Communications system

- Approved spectrum
- Bandwidth
- Available spectrum
- Infrastructure (towers, transmitters, etc.)
- Interference, e.g., Electromagnetic Interference (EMI) or Loss of Signal (LOS)
- Comms/data availability
- Vertiport operations and performance awareness and reliability of data systems e.g., flight plans, individual aircraft performance weather, surveillance sensors

Figure 13: Communications and Data Considerations

Data considerations are associated with the information itself. This information could be vertiport weather information, advisory or flight clearances, local surveillance data, or navigational data. These considerations focus on the information that is needed by the personnel and systems working to ensure the vertiport operations are safe and efficient.

Procedures and interface considerations capture the rules or expectations governing communications and the systems that will need to gather or exchange data. The brainstormed procedure considerations include communications plan(s), lost communications procedure(s), and data sharing policies and procedures. Interface considerations include the expected data exchanges between actors and/or system components and the paths that the information is expected to take through the communications hardware. Data interfaces reflect the vertiport entities' requirements to exchange information to function safely and efficiently, such as the vertiport operator receiving flight plans from the aircraft operator or the vertiport operator communicating with the FAA through FIMS [50]. Interface considerations also include information access for things like passenger connectivity to the internet or the locality remaining aware of operations to be able to deploy first responders or add extra buses in the event of a vertiport closure.

The third theme contains considerations related to the vertiport communications systems themselves. These considerations include the hardware/infrastructure, spectrum, wires, and lines over which data travel and performance metrics for these systems, such as reliability, availability, and susceptibility to interference. Concerns here include whether the spectrum is approved and available, whether there is interference or loss of signal, and if the system transmits data in a timely manner. Communications paths capture connectivity to where data are needed (e.g., the vertiport operator) or how the information is transmitted (e.g., wirelessly, land line, fiber, or via the Internet).

N. Security Considerations

Currently the security grouping captures security considerations across three areas and notes some considerations that are likely common to all three. The three areas are physical, cyber, and airspace. It was decided for this initial collection of considerations to keep them within one grouping for the potential synergies and efficiencies. Like other groupings, this initial list of security considerations shown in Figure 14, was intended to be broad with the thought that at this stage, more considerations were better when balanced against the potential of not capturing ones that later turned out to be significant.

All Types

- Detection
- System Security Plans
- Security requirements
- Security procedures
- Security drills
- Security personnel
- Federal regulations
- Assessment of vulnerabilities, risks, criticality, priorities and attach mechanisms
- Assessment, mitigation and impact of attack types

Physical

- Passenger physical security
- Cargo theft and tampering prevention
- Pax and cargo screening
- Separation of screened from non-screened
- Building (Vertiport) security
- Cross-boarder operations
- Access to hazardous areas
- Security of sensitive areas and systems

Cyber

- Network & data security
- Network and data reliability/continuity
- Detection
- Security of automated systems
- Comms/data integrity
- Data at rest and data in transit policies
- Internal & external access system control policies and procedures
- Cybersecurity risk quantification metrics e.g., probability of occurrence, consequence, cost
- Ability to differentiate between cyber attacks and other faults e.g., system, human-machine interaction
- System cyber robustness e.g., real-time analytics, fault containment, use of redundant sensors
- Layered cyber security procedures e.g., people, technology, processes

Airspace

- Temporary Flight Restrictions (TFR) e.g., Presidential movements
- Special Government Interest (SGI) Waivers for time-critical life-saving UAS operations
- Aircraft Operator Standard Security Program (AOSSP)
- Private Charter Standard Security Program (PCSSP)
- Twelve-Five Standard Security Program (TFSSP)
- GPS testing
- Counter UAS Operations and Testing
- Communication and Lines of Authority with FAA, DHS and TSA
- Rogue aircraft and communication and authority with DoD
- Diplomatic clearances into vertiports
- Aircraft stolen from vertiports
- Sensitive Mission Data e.g., ADS-B OUT OFF Authorization

Figure 14: Security Considerations

Physical security considerations are related to ensuring threats to the physical elements of the vertiport or its operations are mitigated, e.g., passenger and cargo screening, prevention of cargo theft and tampering, and restricting physical access to portions of the vertiport. One unanticipated consideration came out during discussions: the need for physical security associated with vertiports located close to an international boarder. Though eVTOL aircraft may have short range missions, this would not preclude them from conducting international fights in some locations, and those international vertiports would need the capability to screen international passengers, conduct customs inspections, and ensure other requirements associated with entering or leaving the U.S. are met.

Considerations associated with cyber security are more challenging as expertise in this area is still resident with a small number of people who are working to inform other members of the ecosystem. While the cyber ecosystem is still maturing, some generalizations can be made about the considerations captured so far. Cyber-related considerations generally consist of those for the protection of: electronically stored data, the sensors and networks that collect or create data, and the software that runs these systems, provides access to the data, or verifies that security systems are functioning properly. In the vertiport environment, examples of things requiring cyber security could be the list of passengers who have already been cleared by security, the system that tells the vertiport operator that a pad is empty and ready for operations, or the software that allows or restricts access to information, such as proposed aircraft departure times.

The third area in this grouping is airspace security. Programs, tools, and procedures listed in Figure 14 provide means to increase safety. Examples of these include the Private Charter Standard Security Program, tools such as Temporary Flight Restrictions (TFRs) or procedures such as global positioning system (GPS) testing. Other programs increase safety by preventing unauthorized use or by creating procedures such as those to intercept rogue aircraft. These programs also develop and exercise procedures for communication and clarify lines of authority for areas with overlapping or unclear responsibilities, such as with law enforcement entities in the case of stolen aircraft or for operations of a vertiport co-located with an embassy.

O. Utilities

Today, heliports can be sited and operated with minimal consideration to utility availability or capacity. Often, private heliport owners can plan basic facilities needing only water access. The National Wildfire Coordinating Group standards for helicopter operations states that only water for drinking and utilities are required for a permanent helibase [51]. There is a recognition as AAM is explored that, while electric service will be critical to eVTOL aircraft operations, future vertiports will also likely need to allow for other energy sources, such as hydrogen, data connectivity, and integration with utility services, e.g., sewage, natural gas, etc.

- Electrical service
- Electrical demand
- Projection of future demand
- Source of energy e.g., on/offsite, renewable
- Integration with grid
- Data networks e.g., fiber
- Water demand (fire, pax)
- Energy storage
- Impacts on peak electrical demand
- Impacts of large voltages e.g., human health, equipment, incidents
- Fast or slow charging amps
- Impact of variable utility costing, incentive policies or availability e.g., electricity more expensive during peak demand
- Ability to pass along variable utility costs to user/consumer(s)
- Fuel deliveries & storage (e.g., gas/avgas for hybrid aircraft, Auxiliary Power Units (APUs) or Ground Support Equipment (GSE)
- Future fuel compatibility (hydrogen, new batteries)
- Septic and other utilities e.g., local natural gas distribution system
- Graceful degradation of critical utilities
- Planning and providing service timelines and approvals
- Competition and/or demand pricing for limited utilities
- Resiliency
- Climate or carbon neutral policy, goals or requirements

Figure 15: Utilities Considerations

Infrastructure and utilities play a large role in vertiport siting and design considerations. Having access to the required utilities, like an adequate power grid, is crucial. Older infrastructure may require large overhauling or expansion to support AAM operations at vertiports. This kind of improvement would require a large amount of collaboration with various jurisdictions in many cases, such as town, city, and county coordination. Utility infrastructure projects could potentially also take considerable time to complete and be very costly to upgrade, extend, and/or provide to vertiports.

Zoning and land use designations also have an impact on utilities. For example, a vertiport could need a specific zoning to be able to store fuels onsite, or a local land use plan that prioritizes agricultural uses could preclude a vertiport access to adequate electrical service. The requirement for easements across private property to provide access to the electric grid or other utilities is another aspect that is crucial to assess for a potential vertiport site. The approval process for access to utilities will likely go beyond simple physical considerations and also include community goals, such as a desire for carbon neutrality, and the impact on other community services, such as disruptions to utility service and traffic that may occur if a freshly paved, four-lane thoroughfare had to be torn up to provide access to the desired utilities.

The utility considerations grouping shown in Figure 15 captures not only the current focus on electrical service, but also looks out to the future with considerations around graceful degradation, resiliency, and future fuels.

P. Safety

Safety has a very large scope. The considerations captured in Figure 16 are safety-related items that did not neatly fit into one of the other groupings. This list of considerations is focused on vertiports specifically, and so it does not include many other safety considerations, such as the safe operation of the vehicles while in flight, that are important to AAM in general. However, the list does include more general safety considerations that touch on vertiports, such as the FAA program to mitigate hazards posed by wildlife.

Safety Management System(s)

- In-Time System-wide Safety Assurance tools & techniques

Processes to improve safety

- Wildlife Hazard Mitigation Program
- Accident reconstruction capability
- Rapid identification of improvements
- Understanding failure modes and relationship with vertiport operations
- Simulation and modeling tools to discover failure modes

Figure 16: Safety Considerations

The current list of safety considerations has two themes: SMSs and processes to improve safety. SMSs include both the systems themselves and the tools and techniques used to enable these systems. Part 139 certified airports in support of Part 121 operations are required to have a SMS [52]. With the upcoming FAA rule making that will now mandate all Part 135 operations to have an SMS, it is yet to be seen if heliports and vertiports that support these Part 135 operations will be required to have an SMS. While a having a vertiport SMS may not end up be a requirement, it could be a great capability that can provide benefit if integrated into the early stages of the site selection process.

Processes to improve safety include accident reconstruction capability, simulation, and modeling tools to discover failure modes that identify tools and techniques that can be included as part of SMSs, and the wildlife strike query process and database [53]. Pilot education has been identified as a major issue in regard to rotorcraft infrastructure accidents in that neither the FAA nor the aviation industry have an education or training program in place that teaches pilots what constitutes properly designed vertical lift infrastructure [54]. Vertiport operational risk analysis processes could be utilized in the future to provide specific education and testing as to what constitutes proper site selection criteria and for developing AAM infrastructure.

Like with other groupings, this set of considerations will continue to grow, and, because of the universality of safety considerations, it will be important to note the relationships and touch points with other closely related groupings, such as contingency, communications and data, and automation. An example of linked considerations is the execution of a contingency triggers an automated collection and transmission of the relevant data to the appropriate entities.

Q. Automation

The automation considerations grouping is likely the least mature of the groupings. Those shown in Figure 17 capture some services, functions, and capabilities that are anticipated to be automated. They are grouped here because they are thought to utilize some degree of automation irrespective of the potential role of the human in enabling that function. A resource for a pathfinding effort related to identifying automation considerations is the Vertiport Automation Software Architecture and Requirements document sponsored by NASA's High Density Vertiplex (HDV) subproject that identifies vertiport-specific automation functions [17].

Passenger/Cargo Handling

- Passenger/cargo reservations, ticketing, and check-in systems
- Security screening
- Passenger processing, routing and gate waiting areas
- Cargo inspection, transfer, and storage while awaiting automated pick up

Operational interfaces

- Charging
- Performance based routing
- Automated signage & lighting e.g., hazards, nighttime
- Aids to assist surface movement separation
- Automation to prevent unauthorized entry to movement areas, TLOF etc.
- Virtual vertiport (surface traffic, etc., controlled remotely)
- Digital vertiport (building on non-towered vertiport)
- Operations with remote pilot
- Integrated arrival, departure, surface planning & management allowing for ops with multiple vehicle types and configurations

Automation performance monitoring

- Surface operations management (Ground handling)
- Surface movement and traffic control
- Reliability
- Graceful degradation
- Availability
- Accuracy/performance
- Automated workflow processes for error and status reporting and approval
- Understanding of human vs automation functions for fault analysis
- Monitoring of sensor performance

Figure 17: Automation Considerations

The themes emerging from this initial list of automation functions include passenger/cargo handling, interfaces between automated systems, and functions that monitor automation performance. Passenger/cargo handling automation functions could include security screening and reservations as well as ticketing/check-in systems. Automation interface functions examples include identifying when a vertiport has available capacity or how operations are coordinated across vertiports with close geographic proximity. The UAM Airspace Research Roadmap [55] has initial automation interface considerations, and subsequent updates of the roadmap document will likely contain greater detail. The third theme, monitoring automation functions, includes the capability for graceful degradation, error reporting, and reliability.

R. Other

Even with 17 groupings of considerations, a number of considerations did not logically fit within one of the previously discussed groupings. These considerations are captured in this 18th "other" grouping and shown in Figure 18. The considerations here reflect three themes: strategic, synergistic, and informed evolution.

Strategic

- Multi-modal integration
- Sustainable city planning
- Prediction of near and long-term desires e.g., urban vs exurbs vs rural living
- Integration into a long-term AAM system plan(s)
- Balancing demand across multiple transportation modes

Synergistic

- Visual aesthetics e.g., does the vertiport structure visually integrate with community & surroundings
- Occasional uses e.g., Olympics
- Synergies with ground electric vehicles and or automated ground vehicles
- Navigational aid infrastructure, cost, interference, reliability, accuracy
- Surveillance aid infrastructure, cost, interference, reliability, accuracy
- Ability to rapidly incorporate system improvements, lessons learned

Informed Evolution

- Incorporation of long-term infrastructure lessons learned e.g., Olympics
- Taxonomy – verti- stop, place, hub port
- Applicable and evolution of case law
- Incorporation of personal pads or UML-6 operations
- Modeling and simulation tools for characterizing vertiport and system performance
- Leveraging Subject Matter Experts and Lessons Learned

Figure 18: Other Considerations

The strategic considerations are typically long-term, cross domain, have large unknowns, are highly dependent upon external factors, and require collaboration across a wide variety of stakeholders to address. Some of the more challenging of these considerations include multi-modal integration, sustainable city planning, and anticipating public travel preferences over time. Multi-modal integration is the integration of vertiport facilities with other modes of travel. While this is often thought of as co-locating vertiports with other existing or planned transportation hubs, it also goes beyond the physical integration of transportation modes. For example, integrated transportation planning could consider the tradeoffs to achieve resiliency benefits by being able to shift demand across the other modes when one or more modes are disrupted. Sustainable city planning; forecasting trends, such as whether people will migrate into or out of city centers; or accounting for other strategic types of considerations, such as local impacts of climate change, will require considering the long-term view and will impact both individual vertiports and the design of the entire system of vertiports.

The synergistic considerations within this grouping are cross domain and also require collaboration across a wide variety of stakeholders. The capability to utilize common or compatible infrastructure for communications, navigation, surveillance, data networks, and charging equipment across multiple forms of transportation will support addressing these considerations. Also within this theme is the visual integration of infrastructure in harmony with the community's culture and the ability to rapidly incorporate improvements across modes of transportation. Another synergistic consideration is evolving taxonomies. The same term can have a different meeting in different domains or be used and received by the public differently. For example, in English, the word nova refers to a particularly bright star, but in Spanish "no va" means "does not go". Consequently, the release of the Chevrolet Nova car experienced poor sales in Spanish-speaking markets since it was called the Chevrolet "No Go".

The last theme in this grouping is informed evolution. These considerations capture the ability to incorporate lessons learned to improve the design, operation, and safety of vertiports. Lessons learned can come from multiple sources including existing heliports, vertiports that will be built while guidance is being finalized, and vertiports built for special events, such as the Olympics. Lastly, evolving ordinances and case law will impact the planning, operations, and public perception of vertiports.

Over time it is likely that these considerations can be defined in greater detail and either move to one of the other groupings or evolve into one or multiple additional groupings.

III. Conclusions

In this paper we have collated and overviewed over 450 considerations applicable to siting, designing, and operating a vertiport. The purpose of this paper was to fill an identified knowledge gap, document the results of the crowdsourcing effort capturing the extensive experience of ecosystem members across multiple domains, and provide a document that can be a starting place for local decision makers and researchers as they begin to study various multi-vertiport systems and plan for early adoption of AAM. The effort validated that planning and designing vertiports will require expertise across the entire AAM ecosystem. Although this paper makes progress in this direction and 450 considerations vastly exceeded the number expected to be identified, we did not attempt to categorize the considerations by the degree of potential impacts on safety. We also did not conduct a gap assessment within each grouping or organize the considerations by the timeframe in which they need to be considered. For this reason and the fact that new considerations are continuing to be added to this "living list," this paper must be viewed as a snapshot in time with needs for updates to continue to provide benefit into the future.

Acknowledgments

The list of considerations was the result of approximately 125 people contributing their time and expertise to provide a product beneficial and impactful across the entire AAM ecosystem. The authors would like to express thanks to all those participating and to the entire membership of the AEWG and CIWG specifically who made this effort possible. We also appreciate NASA's Aeronautics Research Mission Directorate (ARMD) for its support of the AEWG and this paper.

References

[1] Patterson, M. D., "Advanced Air Mobility (AAM): Overview and Integration Considerations," *Virginia Aviation Conference*, Aug 2021, https://ntrs.nasa.gov/citations/20210020125.

[2] Moore. M. D., Goodrich, K. H., Viken, J., Smith, J., Fredericks, W. J., Trani, T., Barraclough, J., German, B. J., and Patterson, M. D., "High Speed Mobility through On-Demand Aviation," *2013 Aviation Technology, Integration, and Operations Conference*, AIAA 2013-4373, https://ntrs.nasa.gov/citations/20140002448.

[3] Antcliff, K. R., Moore, M. D., and Goodrich, K. H., "Silicon Valley as an Early Adopter for On-Demand Civil VTOL Operations," *16th AIAA Aviation Technology, Integration, and Operations Conference*, AIAA 2016-3466, https://ntrs.nasa.gov/citations/20160010150.

[4] Holden, J., and Goel, N., "Fast-Forwarding to a Future of On-Demand Urban Air Transportation," Uber, Oct 2016.

[5] Federal Aviation Administration, Advisory Circular 150/5390-3 "Vertiport Design," May 1991. Available online at https://www.faa.gov/regulations_policies/advisory_circulars/index.cfm/go/document.information/documentID/ 23096

[6] Peisen, D. J., Berardo, S. V., Dyment, R. J., Ludders, J. R., and Ferguson, S., "Vertiport Characteristics," Federal Aviation Administration DOT/FAA/RD-94/10, Jan. 1996. Available online at https://apps.dtic.mil/sti/pdfs/ADA313609.pdf.

[7] Civil Tiltrotor Development Advisory Committee. Report to Congress. Volume 1. Dec 1995. https://apps.dtic.mil/sti/citations/ADA306654.

[8] AirNav website: http://www.airnav.com/airport/49T. Accessed 29 April 2022.

[9] AirNav website: http://www.airnav.com/airport/43IL. Accessed 29 April 2022.

[10] Garrow. L. A., German, B. J., Schwab, N. T., Patterson, M. D., Mendonca, N. L., Gawdiak, Y. O., and Murphy, J. R., "A Proposed Taxonomy for Advanced Air Mobility," AIAA Aviation 2022 Forum.

[11] Northeast UAS Airspace Integration Research Alliance (NUAIR), "High-Density Automated Vertiport Concept of Operations," National Aeronautics and Space Administration Contractor Report, May 2021. https://ntrs.nasa.gov/citations/20210016168.

[12] Sheth, K., "Regional Modeling and Simulation for Vertiport Assessment", Presentation at NASA AAM Ecosystem Working Group Meeting, March 2021. Available online at https://aam-cms.marqui.tech/uploads/aam-portal-cms/originals/161ad529-b338-40f8-ad6e-683f0c4578dd.pdf. Accessed 29 April 2022.

[13] Hill, B. P., DeCarme, D., Metcalfe, M., Griffin, C., Wiggins, S., Metts, C., Bastedo, B., Patterson, M. D., and Mendonca, N. L., "UAM Vision Concept of Operations (ConOps) UAM Maturity Level (UML) 4", 2020. https://ntrs.nasa.gov/citations/20205011091.

[14] Smith, R. D., "State Regulation of Heliport Design," DOT/FAA/ND-00/2, May 2001. Available online at https://apps.dtic.mil/sti/pdfs/ADA413730.pdf.

[15] FAA Airport Data and Information Portal (ADIP). Available online at https://adip.faa.gov. Accessed 2 May 2022.

[16] Code of Federal Regulations, Title 14 Aeronautics and Space, Part 1, Definitions and Abbreviations. (14 CFR Part 1). https://www.ecfr.gov/current/title-14/part-1. Accessed 2 May 2022.

[17] Federal Aviation Administration (FAA), "Airport Master Record", Form 5010-5, August 2019. Available online at https://www.faa.gov/forms/index.cfm/go/document.information/documentID/185478. Accessed 2 May 2022.

[18] Federal Aviation Administration (FAA), “Notice for Construction, Alteration and Deactivation of Airports”, Form 7480-1, July 2020. Available online at https://www.faa.gov/forms/index.cfm/go/document.information/documentID/185334. Accessed 2 May 2022.

[19] Code of Federal Regulations, Title 14 Aeronautics and Space, Section 91.103, Preflight Action. (14 CFR Part 91.103). https://www.ecfr.gov/current/title-14/section-91.103. Accessed 2 May 2022.

[20] Hospital Heliports Not Identified in B4UFLY Drone/UAS/UAV Database, NASA Aviation Safety Reporting System (ASRS), ACN No. 1599969, January 31, 2019.

[21] International Code Council website: https://www.iccsafe.org. Accessed 29 April 2022.

[22] National Fire Protection Association website: https://www.nfpa.org. Accessed 29 April 2022.

[23] ASTM International website: https://www.astm.org. Accessed 29 April 2022.

[24] International Organization for Standardization website: https://www.iso.org. Accessed 29 April 2022.

[25] Illuminating Engineering Society website: https://www.ies.org. Accessed 29 April 2022.

[26] Federal Aviation Administration, Advisory Circular 150/5190-4A “A Model Zoning Ordinance to Limit Height of Objects Around Airports,” December 1987. Available online at https://www.faa.gov/regulations_policies/advisory_circulars/index.cfm/go/document.information/documentID/22826

[27] Federal Aviation Administration (FAA), “United States Standard for Terminal Instrument Procedures (TERPS)”, Order 8260.2E September 2020. Available online at https://www.faa.gov/documentLibrary/media/Order/Order_8260.3E.pdf. Accessed 19 April 2022.

[28] Code of Federal Regulations, Title 14 Aeronautics and Space, Section 77.23, Heliport imaginary surfaces. (14 CFR Part 77.23). https://www.ecfr.gov/current/title-14/section-77.23. Accessed 8 May 2022.

[29] Hartmann, S. L., “What Are “Air Rights” and Why Are They Important to Central?”, Central Docents, Los Angeles Public Library, Feb 2017. Available online at https://www.lapl.org/collections-resources/blogs/lapl/what-are-%E2%80%9Cair-rights%E2%80%9D-and-why-are-they-important-central. Accessed 29 April 2022.

[29.1] Federal Aviation Administration, “FAA Form 7460-1, Notice of Proposed Construction or Alteration”, Available online at https://www.faa.gov/forms/index.cfm/go/document.information/documentid/186273 Accessed 9 May 2022.

[29.2] Federal Aviation Administration, Obstruction Evaluation / Airport Airspace Analysis (OE/AAA) system website: https://oeaaa.faa.gov/oeaaa/external/portal.jsp Accessed 9 May 2022.

[30] Pechacek, R. E., Greig, J. R., Murphy, D. P., and Spelz, J., “Electrostatic Charging of the CH-53E Helicopter”, Naval Research Lab, Nov. 1985. Available online at https://apps.dtic.mil/sti/citations/ADA161936. Accessed 25 April 2022.

[31] Department of Defense (DoD), “Electrical Grounding for Aircraft Safety”, MIL-HDBK-274A(AS), Nov. 2011. Available online at http://everyspec.com/MIL-HDBK/MIL-HDBK-0200-0299/MIL-HDBK-274A_39159/. Accessed 29 April 2022.

[32] Cohen, M., “The Vertiport as an Urban Design Problem”, SAE Technical Paper 965523, 1996, https://doi.org/10.4271/965523.

[33] National Air Transportation Association, “Urban Air Mobility: Considerations for Vertiport Operation”, June 2019. Available online at https://www.nata.aero/assets/Site_18/files/GIA/NATA%20UAM%20White%20Paper%20-%20FINAL%20cb.pdf. Accessed 29 April 2022.

[34] Mulinazzi, T. E.; Zheng, Z. C., "Wind Farm Turbulence Impacts on General Aviation Airports in Kansas", Report No. K-TRAN: KU-13-6, January 2014. https://rosap.ntl.bts.gov/view/dot/26908

[35] Vogt, R., Timothy Crum, T., Greenwood, W., Ciardi, E., and Guenther, R., "New Criteria for Evaluating Wind Turbine Impacts on Nexrad Weather Radar, NOAA 2011. https://www.roc.noaa.gov/WSR88D/Publicdocs/WINDPOWER2011_Final.pdf.

[36] A Codification of the General Ordinances of Los Angeles County, California, Section 22.18.010. Available online at https://library.municode.com/ca/los_angeles_county/codes/code_of_ordinances?nodeId=TIT22PLZO_DIV3ZO_CH22.18REZO, Accessed 19 April 2022

[37] Federal Aviation Administration (FAA), "Vertiport Design", Engineering Brief #105 (Draft) June 2022. Available online at https://www.faa.gov/airports/engineering/engineering_briefs/drafts/media/eb-105-vertiport-design-industry-draft.pdf. Accessed 2 May 2022.

[38] Goodrich, K. H., and Theodore, C. R., "Description of the NASA Urban Air Mobility Maturity Level (UML) Scale," *AIAA Scitech 2021 Forum*, AIAA 2021-1627, https://doi.org/10.2514/6.2021-1627.

[39] Federal Aviation Administration (FAA) (2000). "Urban Air Mobility (UAM) Concept of Operations v1.0". Available online at https://nari.arc.nasa.gov/sites/default/files/attachments/UAM_ConOps_v1.0.pdf. Accessed April 19, 2022.

[40] Dempsey, T. K., Leatherwood, J. D., and Clevenson, S. A., "Discomfort Criteria for Single-Axis Vibrations", NASA Technical Paper 1422, May 1979.

[41] Jacobson, I. D., Kuhlthau, A. R., Richards, L. G., and Connor, D. W., "Passenger Ride Quality in Transport Aircraft", Journal of Aircraft, November 1978. https://doi.org/10.2514/3.58438.

[42] Kossin, J. P., Hall, T., Knutson, T., Kunkel, K. E., Trapp, R. J., Waliser, D. E., and Wehner, M. F., 2017: "Extreme storms". In: Climate Science Special Report: Fourth National Climate Assessment, Volume I [Wuebbles, D.J., D.W. Fahey, K.A. Hibbard, D.J. Dokken, B.C. Stewart, and T.K. Maycock (eds.)]. U.S. Global Change Research Program, Washington, DC, USA, pp. 257-276, doi: 10.7930/J07S7KXX.

[43] Website: https://dashboard.birdcast.info/region/US-GA?night=2022-04-26. Accessed on May 2, 2022.

[44] United States Environmental Protection Agency, "What is the National Environmental Policy Act?". Available online at https://www.epa.gov/nepa/what-national-environmental-policy-act. Accessed 29 April 2022.

[45] Department of Energy website: https://ceq.doe.gov/laws-regulations/states.html. Accessed on May 2, 2022.

[46] Environmental Protection Agency website https://www.epa.gov/environmentaljustice/learn-about-environmental-justice#:~:text=Environmental%20justice%20(EJ)%20is%20the,environmental%20laws%2C%20regulations%20and%20policies. Accessed on May 5, 2022.

[47] Thipphavong, D. P., Apaza, R. D., Barmore, B. E., Battiste, V., Burian, B. K., Dao, Q. V., Feary, M. S., Go, S., Goodrich, K. H., Homola, J. R., Idris, H. R., Kopardekar, P. H., Lachter, J. B., Neogi, N. A., Ng, H. K., Oseguera-Lohr, R. M., Patterson, M. D., and Verma. S. A., "Urban Air Mobility Airspace Integration Concepts and Considerations". *In 2018 Aviation Technology, Integration, and Operations Conference,* American Institute of Aeronautics and Astronautics, 2018. https://doi.org/10.2514/6.2018-3676.

[48] Yan, C., Zhu, H., Korolko, N., and Woodard, D., "Dynamic Pricing and Matching in Ride-Hailing Platforms", October 1, 2018. Naval Research Logistics, Forthcoming, Available at http://dx.doi.org/10.2139/ssrn.3258234

[49] Transurban website: https://expresslanes.com/learn-the-lanes#approximate-schedule. Accessed on April 19, 2022.

[50] Federal Aviation Administration, "NextGen Unmanned Aircraft System (UAS) Traffic Management 813 (UTM) Concept of Operations v.2.0", Washington D.C., March 2020.

[51] National Wildfire Coordinating Group, "NWCG Standards for Helicopter Operations", PMS 510, May 2019. Available online at https://www.dnr.wa.gov/publications/rp_fire_aviation_helicopter_operations_guide.pdf. Accessed 29 April 2022.

[52] Code of Federal Regulations, Title 14 Aeronautics and Space, Part 5, Safety and Management Systems. (14 CFR Part 5). https://www.ecfr.gov/current/title-14/chapter-I/subchapter-A/part-5. Accessed 2 May 2022.

[53] Federal Aviation Administration, "FAA Wildlife Strike Database", Available online at https://wildlife.faa.gov/home. Accessed 29 April 2022.

[54] Alexander, R. J., Syms, R. A., Johnson, C., and Roberts, J., "Retrospective & Historical Analysis of Vertical Lift Infrastructure Accidents for the Purpose of Operational Risk Identification and Accident Prevention." Vertical Flight Society Forum 77, May 14, 2021.

[55] Levitt, I., Phojanamongkolkij, N., Witzberger, K., Rios, J., and Cheng, A., (2021). "UAM Airspace Research Roadmap." NASA/TM-20210019876. NASA, Washington D.C. https://ntrs.nasa.gov/citations/20210019876.