HIGH-DENSITY AUTOMATED VERTIPORT CONCEPT OF OPERATIONS

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5-Alpha

Mr. Alexander is the president of Five-Alpha LLC, and has designed vertical lift infrastructure for private, public, corporate, and DOD applications for 20 years. As a U.S. Helicopter Safety Team volunteer, Mr. Alexander has led, organized, and co-chaired the USHST Government/Industry Infrastructure Summit in Washington, DC for the past six years. As the Vertical Flight Society's (VFS) Infrastructure Adviser, Mr. Alexander is the primary liaison on helicopter and VTOL infrastructure for VFS to the FAA, ICAO, NFPA, GAMA, ASTM, and NASA. His breadth of knowledge and experience in this area are unmatched in the aviation industry.

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List of Acronyms

4D	Four-Dimensional
AAM	Advanced Air Mobility
AC	Advisory Circular
ACARS	Aircraft Communications Addressing and Reporting System
ADS-B	Automatic Dependent Surveillance-Broadcast
AGL	Above Ground Level
AI	Artificial Intelligence
AIP	Airport Improvement Program
ANSP	Air Navigation Service Provider
API	Application Programming Interface
ARTCC	Air Route Traffic Control Center
ASOS	Automated Surface Observing System
ATC	Air Traffic Control
ATCSCC	Air Traffic Control System Command Center
ATD-2	Air Technology Demonstration-2
ATM	Air Traffic Management
AWOS	Automated Weather Observing System
BVLOS	Beyond Visual Line-of-Sight
CBR	Community-Based Rules
CCFP	Collaborative Convective Forecast Product
CDM	Collaborative Decision Making
CFR	Code of Federal Regulations
CNSI	Communications, Navigation, Surveillance, Information
ConOps	Concept of Operations
CONUS	Contiguous United States
CSP	Communications Service Provider
CTAF	Common Traffic Advisory Frequency
DAA	Detect and Avoid
DataComm	Data Communications
DME	Distance Measuring Equipment
D-Taxi	Digital Taxi
EIBT	Estimated In-Block Time
ELDT	Estimated Landing Time
EMS	Emergency Medical Service
EOBT	Estimated Off-Block Time
ETOT	Estimated Takeoff Time
FAA	Federal Aviation Administration
FATO	Final Approach and Takeoff
FBO	Fixed-Base Operator
FOCC	Fleet Operational Control Center
FOD	Foreign Object Debris
GBAS	Ground-Based Augmentation System
GCS	Ground Control Station
GPS	Global Positioning System

GUFI	Globally Unique Flight Identifier
IASMS	In-Time Aviation Safety Management System
ICAO	International Civil Aviation Organization
IFR	Instrument Flight Rule
IIMC	Inadvertent flight into Instrument Meteorological Conditions
ILS	Instrument Landing System
IMC	Instrument Meteorological Conditions
IO	Input-Output
IP	Internet Protocol
IPS	Internet Protocol Suite
LiDAR	Light Detection and Ranging
LoA	Letter of Agreement
ML	Machine Learning
MRO	Maintenance, Repair, Overhaul
MSA	Metropolitan Statistical Area
MSL	Mean Sea Level
MUV	Marine Utility Vessel
NAS	National Airspace System
NASA	National Aeronautics and Space Administration
NavAids	Navigational Aids
NOTAM	Notice to Airmen
NWS	National Weather Service
OCC	Operational Control Center
OV	Operational Viewpoint
PSU	Provider of Services to Urban Air Mobility
RACI	Responsible, Accountable, Consulted, Informed
REST	Representational State Transfer
RF	Radio Frequency
RGB	Red, Green, Blue
SDSP	Supplemental Data Service Provider
SME	Subject Matter Expert
SMS	Safety Management System
SoA	State-of-the-Art
SoS	System of Systems
SSP	Surveillance Service Provider
SSS	Scheduling, Sequencing, Spacing
sUAS	Small Unmanned Aircraft System
TBFM	Time-Based Flow Management
TC	Type Certificate
TDWR	Terminal Doppler Weather Radar
TFDM	Terminal Flight Data Manager
TFM	Traffic Flow Management
TFMS	Traffic Flow Management System
TFR	Temporary Flight Restriction
TLOF	Touchdown and Liftoff

TRACON	Terminal Radar Approach Control Facility
UOE	Urban Air Mobility Operations Environment
UAM	Urban Air Mobility
UAS	Unmanned Aircraft System
UBAC	User-Based Access Controls
UI	User Interface
UML-4	Urban Air Mobility Maturity Level Four
UMMC	University of Mississippi Medical Center
UTM	Unmanned Aircraft System Traffic Management
V2I	Vehicle to Infrastructure
V2V	Vehicle to Vehicle
VAS	Vertiport Automation System
VA-SDSP	Vertiport Automation Supplemental Data Service Provider
VFR	Visual Flight Rule
VFS	Vertical Flight Society
VTOL	Vertical Takeoff and Landing

1 Introduction

The National Aeronautics and Space Administration (NASA) vision for Advanced Air Mobility (AAM) includes Urban Air Mobility (UAM) – a concept involving vertical takeoff and landing (VTOL) aircraft, decentralized (or federated) traffic management, and new infrastructure to support urban, suburban, and rural flight operations. High-density performance-based routes or corridors enable prompt transportation of people and goods from node to node, where each node represents a vertiport, defined as an identifiable ground or elevated area used for the takeoff and landing of VTOL aircraft. In the presence of uncertainty surrounding aircraft turnaround time on the ground, vertiports are the critical end points in scheduling, sequencing, and spacing (SSS) of aircraft in dense metropolitan environments. This Concept of Operations (ConOps) includes vertiports of varying sizes, configurations, service offerings, and locations. UAM air vehicles include conventional rotorcraft, unmanned VTOL aircraft, and novel piloted VTOL aircraft. This ConOps focuses on operations at a high-density vertiport, supported by a Vertiport Automation System (VAS) with high-throughput operation capabilities under conditions defined as NASA's Urban Air Mobility Maturity Level Four (UML-4).

1.1 Purpose and Scope

This ConOps serves multiple purposes, as discussed below.

1) Serve as a communications tool.
    a) The industry is fragmented, and the vision is unclear on how vertiports will be integrated with VTOL aircraft, fleet operators, air charter brokers, and an Unmanned Aircraft System (UAS) Traffic Management (UTM)-inspired Provider of Services to Urban Air Mobility (PSU) Network.
    b) This document provides a consolidated view to guide future technology developers and innovators in creating solutions.
2) Document a representation of community views of an automated vertiport system.
    a) Various stakeholders have unique needs and perspectives on how vertiports should be integrated into UML-4 concepts.
    b) Judgments from 17 subject matter expert (SME) interviews, discussions with NASA engineers, and team partner feedback were consolidated and prioritized to reflect both bullish and bearish views on the functional needs for vertiport automation and integration.
3) Define the roles and responsibilities of vertiport users, vertiport operators, and connected stakeholders.
    a) The ConOps considers a broad range of concepts to identify who is responsible, accountable, consulted, and informed across nominal vertiport operations.

   b) The roles of stakeholders affected by vertiport functional requirements and assumptions under nominal and off-nominal scenarios are key elements to carry forward in developing technical system solutions.

4) Serve as a basis to develop vertiport automation prototype requirements, specifications, data interface requirements, and system performance criteria.
   a) The functions of the vertiport, automation capabilities, functional requirements, and ecosystem integration considerations all play a critical role in developing technical systems for vertiport operations.
   b) This ConOps provides details and information necessary to develop a software architecture and requirements for building a prototype VAS.
5) Identify technology, regulatory, and research needs for vertiport operations.
   a) UML-4 relies on convergence of the maturation of innovative technologies and the modification or development of certification standards. Examples include certification of PSUs, fleet operators, aircraft, vertiport zoning and noise allowances, and autonomy.
   b) Identifying technology and regulatory gaps that must be bridged from the current to the future states will help to achieve the automation capabilities required for high-density operations.

This ConOps focuses on aircraft operations within the Vertiport Operations Area (VOA) and Vertiport Volume (VPV) and on the surface of the vertiport. As illustrated in Figure 1, the VOA is the outermost volume surrounding an individual vertiport or several vertiports in which flight operations much be coordinated with a PSU. The VPV is the innermost volume surrounding an individual vertiport that is managed by that vertiport and within which fleet operators must coordinate with the vertiport operator. More specifically, the scope encompasses the communications (including active negotiations and passive information sharing) among various stakeholders in nominal and off-nominal scenarios. At a high level, this ConOps views the vertiport as a resource ready to accommodate and negotiate reservations to operate into and out of the vertiport. This ConOps works through the complexities of adapting to varying business models with various levels of service capabilities.

This document identifies important assumptions based on community SME interviews, NASA's UML-4 ConOps, and internal team expertise. Topics beyond the scope of this ConOps include airspace management, the definition of arrival and departure routes, and day-to-day management of vertiport operations, including landside coordination, maintenance and repair, and vendor management.

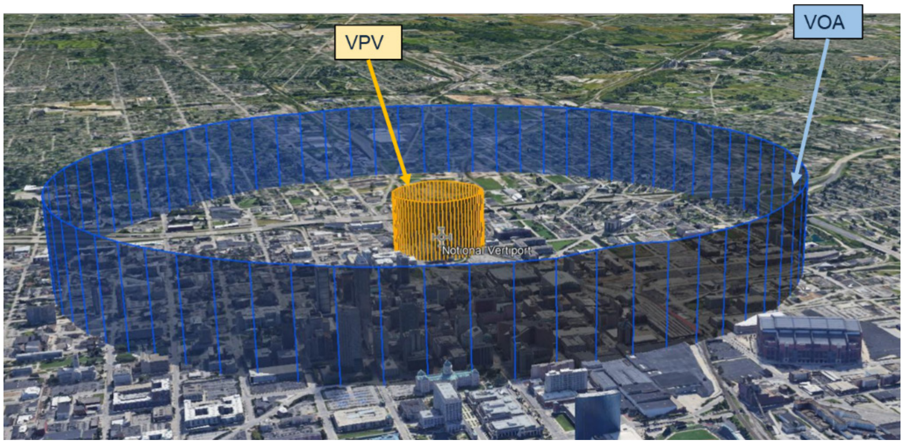

Figure 1: VOA and VPV Sample Boundaries for a Notional Vertiport

This ConOps first addresses the current state of heliport, airport, and vertiport operations. Each element of heliport, airport, and vertiport infrastructure plays a distinct role which is clearly defined in terms of gate-to-gate operations. The document then discusses the current state of the art (SoA) of technologies, with a focus on how automation is integrated into operations. The SoA includes various stakeholders, including aircraft; flight crew; communications, navigation, surveillance, and information (CNSI) infrastructure; fleet operator; and air navigation service provider (ANSP). Future vertiport technologies must be synergistic within the larger ecosystem – i.e., technology across stakeholders must be interoperable under all scenarios. Challenges and barriers associated with current-day operations and technologies establish the motivation for change to a future state. This ConOps next defines the envisioned future state, summarizing community-aligned views on vertiport operations and describing the automation capabilities necessary to support high-density vertiport takeoff and landing operations. Nominal and off-nominal scenarios illustrate the operation of the proposed VAS and the role of external stakeholders in supporting vertiport operations. The scenarios are meant to be agnostic with respect to the mission, aircraft types, or location of operations. The ConOps concludes with an analysis of the proposed solution, including a summary of improvements, disadvantages, and trade-offs considered.

1.2 Assumptions and Constraints

The following assumptions apply throughout this ConOps at UML-4. Assumptions taken from NASA UAM Vision ConOps UML-4 or FAA UAM ConOpsv1.0 are identified as such.

1) UAM operations will be conducted under a new set of regulations derived from 14 Code of Federal Regulations (CFR) Part 61, 91, 119, and 135. (NASA UAM Vision ConOps UML-4)
2) Density refers to air traffic density and is defined as the number of UAM aircraft simultaneously aloft at any time within a single metropolitan area, assumed to be 100s of simultaneous, medium-complexity aircraft operations at UML-4. (NASA UAM Vision ConOps UML-4)

3) Throughput rate refers to the number of aircraft takeoffs and landings within a one-hour time span at a vertiport.
   a) This value is taken as the assumed average value of hourly throughput rates.
   b) High-density vertiports refer to the throughput rate at UML-4.
   c) The UML-4 peak hourly rate for busier vertiports could be as high as 80 to 120 operations per hour, per interviews with a potential UAM Operator[1].
4) Air navigation services are provided by PSUs qualified by the Federal Aviation Administration (FAA) and may include FAA involvement in air traffic operations. (NASA UAM Vision ConOps UML-4)
   a) The PSU Network is federated, wherein multiple PSUs may operate in a geographic area. (NASA UAM Vision ConOps UML-4)
   b) The PSU may rely on third party supplemental data service providers (SDSPs) to assist in managing air traffic, such as providing low-altitude surveillance or weather information, as well as middleware providers, including telecommunications and security providers. (NASA UAM Vision ConOps UML-4)
5) Aircraft will be required to be properly equipped to meet applicable standards for operation in the Urban Air Mobility Operations Environment (UOE) and subscribed to a PSU to operate in a UOE. (NASA UAM Vision ConOps UML-4)
6) A UOE is a volume of airspace in which only PSU-participating aircraft can operate safely. It may be a corridor surrounding high-density routes, a UAM departure or arrival area around a Vertiport, or in the farther term it may evolve to envelop multiple high-density routes or airspace serving only UAM-like vehicles.
7) The FAA has on-demand access to UOE operational information and can dynamically modify the allowable UOE airspace or high-density routes. (NASA UAM Vision ConOps UML-4) (FAA UAM ConOpsv1.0)
8) All vertiport operations assume predetermined approach and departure fixes, and the vertiport does not manage air traffic in the VOA. The PSU manages the airspace and may switch between established fixes due to several reasons and constraints, such as weather.
9) Air traffic will be a mix of manned and unmanned aircraft (remotely piloted or supervised), comprising manually piloted, semi-automated, and fully automated air vehicles. (NASA UAM Vision ConOps UML-4)

[1] The notional range of throughput values is derived from NASA's UML-4 description ("hundreds of simultaneously airborne aircraft in a metropolitan region") and from interviews from potential UAM Operators

10) Flight crews, either remote or onboard the aircraft, are responsible for control-by-exception in case of off-nominal situations and can support voice instead of digital communications with the vertiport operator (onsite or remote) as needed. Several state governments are currently developing concepts for remote operations. (NASA UAM Vision ConOps UML-4) (FAA UAM ConOpsv1.0)

11) Operations within a UOE require performance authorization from the FAA. (NASA UAM Vision ConOps UML-4) (FAA UAM ConOpsv1.0)

12) CNSI technology will be onboard the aircraft to share necessary data with the necessary stakeholders, such as the vertiport. (NASA UAM Vision ConOps UML-4)

13) Vertiports may need to comply with local, state, or federal regulatory policies, maintain and collect compliance data, and provide compliance documentation as needed. (NASA UAM Vision ConOps UML-4) (FAA UAM ConOpsv1.0)

    a) FAA will establish new standards for vertiports of varying sizes (vertihubs, vertiports, vertistops) or modify existing 14 CFR Part 139 Airport Certification standards for public vertiports.

14) The PSU is responsible to act as the broker of departure time, arrival time, routing, and contingency alternative vertiports, as well as assisting in SSS for departures and arrivals down to the vertiport touchdown and liftoff (TLOF) pads.

    a) The VAS manages ground-based scheduling, sequencing, and movement across the vertiport surface, provides aircraft with surface movement four-dimensional (4D) surface trajectories (latitude, longitude, height above vertiport surface, and time), and assures that the 4D trajectories are clear of obstacles and other traffic.

    b) The VAS provides a standard interface for PSUs to access vertiport information about resource availability, aircraft servicing, and any other vertiport-supplied resources.

    c) Information is shared bidirectionally between the PSU and vertiport.

    d) Aircraft have vehicle-to-vehicle (V2V) and vehicle-to-infrastructure (V2I) communication capabilities for tactical air and ground separation and spacing. (NASA UAM Vision ConOps UML-4)

15) The VAS is responsible for the scheduling and sequencing of vertiport resources and coordinating with external stakeholders to support high-density operations. The VAS will have a highly automated scheduling tool capable of vertiport pad allocation and 4D surface trajectory sequencing or other vertiport resource assignments, leveraging vertiport ground-based sensor infrastructure and information shared from supporting stakeholders.

16) Vertiports will be owned by private or public entities and may be owned by a fleet operator, air charter broker, or private PSU organization. (NASA UAM Vision ConOps UML-4)

17) Vertiports are classified based on size, relative height of pad above ground level, throughput, aircraft capability accommodation, gates, and type of ownership entity.

18) UML-4 is backward-compatible with the business use cases in UML-1 to -3. (NASA UAM Vision ConOps UML-4)

19) The VOA and VPV will be charted on aeronautical charts for informational purposes.

20) There will be a system-wide community-based or FAA-established UAM prioritization scheme for arrivals and departures across vertiports. (NASA UAM Vision ConOps UML-4)

21) UAM aircraft will fly precise navigation paths within high-density routes or corridors. The characteristics of that navigation will be determined by research; whether it is by precise trajectory following or by linkage (and spacing) with other cooperating aircraft within the corridor is to be determined.

22) UAS are permitted to enter the UOE only when its UAS Service Supplier (USS) coordinates entry with the PSU Network. (NASA UAM Vision ConOps UML-4)
    a) UAS may use a PSU, in lieu of a USS, to support vertiport arrival or departure operations.

1.3 Urban Air Mobility Maturity Level Mapping

Alignment with NASA's UAM Framework is critical to enable scaling from current-state operations to highly automated flights in densely populated urban environments. Accordingly, we developed four unique mission-level use cases (referred to as use cases) aligned with UMLs 1 to 4 as a method to describe scaling of automation capabilities at each UML. The four use cases are Utility Inspection, AAM Medical Delivery, Urban Air Freight, and Urban Passenger Air Metro. Although a use case may align with more than one UML, each use case is described in terms of an individual UML to clearly illustrate improvements between UMLs. Figure 2 is a graphical representation of this relationship.

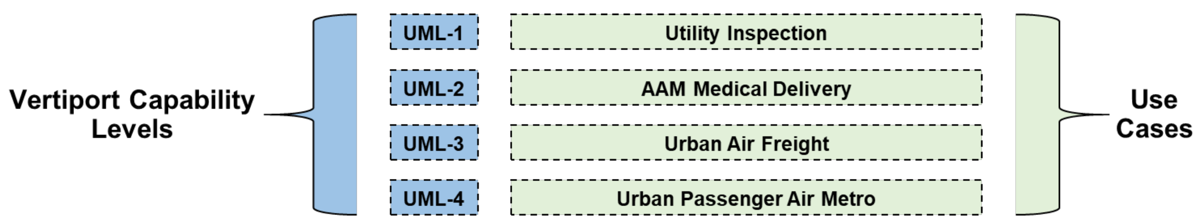

Figure 2: UML-to-Use-Case Progression

1.3.1 Use Case 1: Utility Inspection

Description: Medium-sized UAS are remotely deployed from vertiports to inspect and collect data on structures such as transmission and distribution towers, utility lines, bridges, or buildings. The UAS fleet is remotely monitored by the fleet operator at the fleet operational control center (FOCC), who ensures fleet network safety by manually triggering flight operations, monitoring aircraft health and system integrity, tracking aircraft maintenance needs, and performing flight-planning activities.

Operations are centralized at the vertiport operational control center (VOCC), with geographically distributed vertiports that house medium-sized UAS that are ready for remote deployment and pre-loaded with mission data. Mission-critical data is shared via a cyber-secure network consistent with industry standards such as ISO/IEC 27000-series. The driving business case is inspection of remote assets, which involves the inspection and data collection of long lateral or tall vertical assets. Information derived from flights could include red, green, blue (RGB) imagery, light detection and ranging (LiDAR) point clouds, thermal imagery, and multispectral imagery. The fleet operator is responsible for coordinating departures with the subscribed PSU, pre-flight planning, individual aircraft health monitoring, fleet surveillance, keeping maintenance logs, and time- or need-based inspection of aircraft. Operational routes will be FAA pre-authorized routes for beyond-visual-line-of-sight (BVLOS) automated operations in which the aircraft performs a defined mission, executing the pre-programmed mission and returning to the origin or destination vertiport. A human vertiport manager monitors events such as aircraft launch and recovery, successful internet connection for data upload or download, and infrastructure health status. Activities to support operations take place routinely, either on a set frequency or in programmed cadences. A remote pilot will monitor several aircraft through a centralized fleet management system.

Figure 3: Utility Inspection Visualization

1.3.2 Use Case 2: Advanced Air Mobility Medical Delivery

Description: Patients, medical personnel, or equipment are transported within metropolitan areas by conventional helicopters and UAM aircraft with or without a pilot onboard supported by both the PSU and air traffic management (ATM) air traffic control (ATC).

Scaling from Use Case 1 with limited vertiport traffic, Use Case 2 air and surface traffic densities are greater than for utility inspections, although Use Case 2 total demand is largely the same as current medical delivery demand. Vertiport surface monitoring and surveillance will be automated through additional sensor technology distributed on TLOF pads, while the vertiport is still monitored with distributed cameras. Elements of the communications and negotiation with arrival and departure traffic, using 4D trajectory-based operations (TBO) concepts, will be increasingly automated to promote the efficient coordination of vertiport resources.

Traffic will be a mixture of highly automated aircraft and manned helicopters operating within this business model. This mixture of traffic introduces complexity in the separation of traffic and requires automation of routine coordination between digital systems with humans in or on the loop for voice communications when required. Additionally, both streams of traffic are managed either by the PSU for pilotless UAM aircraft or by ATC for piloted helicopters in controlled airspace (ATC may delegate separation responsibility to the pilot for a visual approach). The VAS must be compatible with both types of operations. The higher tempo of operations will be supported through automation, including data link communications with pilotless aircraft, interfacing between the vertiport and PSUs, and simplified vertiport surface operations using methods such as navigational aid lighting or signals.

Surface trajectory generation and conformance monitoring are vertiport manager manual functions in this use case, ripe for future automation. PSU-requested information, such as vertiport pad status, availability, pad configuration, and service offerings, are retrievable from a standardized vertiport external interface. The vertiport manager coordinates with the PSU Network and ATC-managed traffic for arrivals and departures based on prioritization of urgent medical deliveries and adherence to existing operational flight rules, to include visual flight rules (VFR), and instrument flight rules (IFR). Vertiport facilities can range from one parking spot at a remote location to multi-aircraft facilities at regional medical centers.

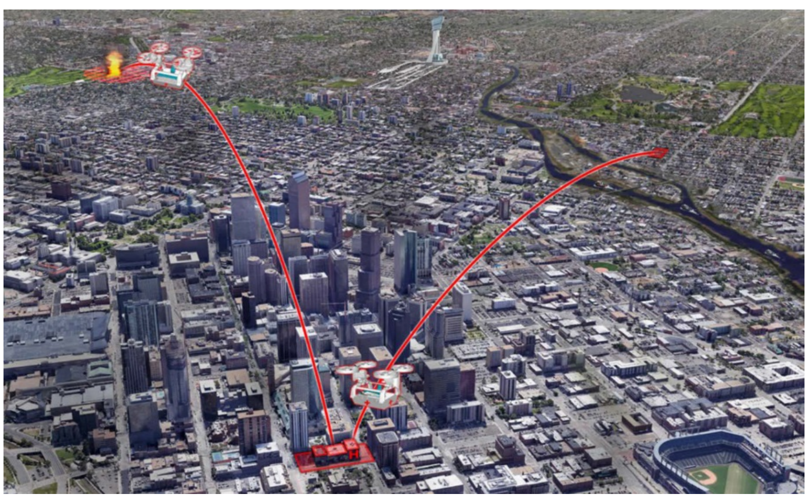

Figure 4: AAM Medical Delivery Visualization[2]

[2] Price, G., Helton, D., "Urban Air Mobility Operational Concept (OpsCon) Passenger-Carrying Operations," NASA Technical Reports Server.

1.3.3 Use Case 3: Urban Air Freight

Description: A mix of piloted and highly automated pilotless cargo aircraft operating in the same airspace in a metropolitan area deliver or transport goods at a rapid operational tempo between sites such as airport and regional distribution centers.

Vertiport traffic will be a mix of piloted, remotely piloted, and automated aircraft operating in and out of vertiport pads at a rate as high as 40 to 80 operations per hour[3]. Use Case 3 introduces a regional vertiport control capability, whereby multiple vertiports in a vicinity are managed from a central VOCC to dynamically schedule resources across vertiports. This concept can be referred to as a vertiplex comprising interdependent vertiports with potentially differing arrival and departure operations. All information will be shared digitally between the vertiport and negotiating stakeholders, requiring stringent cybersecurity standards and built-in system resiliency. The complete conversion to digital information-sharing and communication enables increased vertiport automation for efficiency in negotiating use of vertiport resources, servicing, vertiport configurations, and arrival and departure timing.

One or more TLOF pads will support arrivals and departures at each vertiport, with designated parking and charging stations for transient and fixed-base aircraft, although these vertiport capabilities are not required in Use Case 3. The increase in operational tempo requires a greater level of automation than Use Case 2, to include fully automated multicast or network sharing of vertiport pad status, increased efficiency in communications with PSUs and between PSU Networks, and issuing, communicating, and negotiating surface trajectories (latitude, longitude, and time). The vertiport will manage surface movement by providing navigational information to the aircraft and flight crew to traverse from pad to destination within the vertiport. It is important to note that aircraft will be equipped with detect and avoid (DAA) capabilities for obstacle avoidance when following the 4D surface trajectory.

Figure 5: Urban Air Freight Visualization[4]

[3] Operational tempo for UMLs 1 to 3 were derived by scaling from current state operations to the envisioned high-density UML-4 operational tempo of 80 to 120 operations per hour.
[4] "Urban Air Mobility (UAM) Market Study" NASA Urban Air Mobility.

1.3.4 Use Case 4: Urban Passenger Air Metro

Description: Air metro services between urban and suburban vertiports use highly automated aircraft to transport four to six passengers at a time in performance-based high-density routes on predetermined routes.

Traffic density in the airspace will be as high as hundreds of aircraft at a time, driving individual vertiport operations to as high as 80 to 120 operations per hour. Vertiports in Use Case 4 are large multi-landing locations with a parking capacity of approximately 12 aircraft and may offer extensive service support capabilities such as refueling or charging, vendor services, and long- and short-term parking for aircraft. Although vertiports in urban centers are not likely to have the space needed to offer extended services, high service vertiports may be located in the periphery of urban centers, including at airports. Aircraft tempo and turnaround time will tend to drive vertiport sizing requirements, the number of final approach and takeoff (FATO) zones, the number of parking spots, and service offerings. Achieving the high operational tempo drives the need for vertiport automation to manage dynamic resource scheduling and assure safety and security of operations. Airspace complexity is increased, with multiple vertiports serving aircraft approaching and departing in the same geographic region. Automation is highly integrated into vertiport operations management, with limited human intervention in routine operations. The role of the human operator shifts to oversight as in human-over-the-loop, handling off-nominal scenarios with contingency or emergency procedures and direct human-to-human communications as needed. All information is shared digitally at an appropriate pace for different consumers in the PSU Network, and the network of operations is highly efficient and predictable in timing.

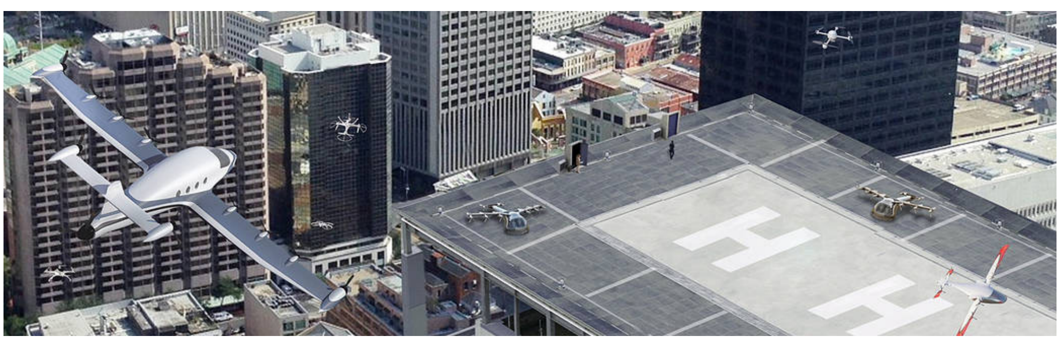

Figure 6: Urban Passenger Air Metro Visualization[5]

Table 1 summarizes the use cases.

[5] "Air Traffic Management – eXploration (ATM-X)," https://www.nasa.gov/aeroresearch/programs/aosp/atm-x/atm-x-project-description.

Table 1: UML-Use Cases Qualitative Descriptions

	Utility Inspection	AAM Medical Delivery	Urban Air Freight	Urban Passenger Air Metro
UML	UML-1	UML-2	UML-3	UML-4
Reasoning for Selection	Represents an early adopter of civilian UAS technology. Also provides an enhanced business use case incorporating BVLOS automated operations.	Provides additional business applications, introduces advanced, automated eVTOL aircraft, more automation.	Represents a significant increase in density, complexity, and pace of operations due to the integration of automation.	Introduces high traffic density, mixed VTOL traffic, multiple vertiport variants, and some autonomy in aircraft and vertiport operations.
Metropolitan Airspace Density	1 - 10 simultaneous operations.	10 - 50 simultaneous operations.	50 - 100 simultaneous operations.	100 - 1,000 simultaneous operations.
Surface Movement	Limited surface movement, predominantly isolated to landing and takeoff from TLOF pad.	Manual generation and communication of surface trajectories, surface navigational aids at vertiport, pilot visual navigation or pilotless aircraft sensor-based navigation.	Automated generation and communication of surface trajectories to multiple locations on vertiport surface, capable of supporting multiple vertiports in vertiplex, aircraft sensor-based navigation.	Additional automation of conformance monitoring, anomaly detection, and surface trajectory replanning for off-nominal or contingency scenarios.
Vertiport Operations Complexity	A manual operation assisted by various unintegrated digital and non-digital applications. A USS may be in place for UAS operations.	Provides more complex operational scenarios with aircraft piloting mix, automated monitoring of vertiport infrastructure, introduces information sharing with PSUs and fleet operators, standard VFR and IFR procedures. Likely single PSU operation, limited route structure between limited points.	Increased responsibility of automation system, capable of determining throughput and turn-around time based on payloads and characteristics of aircraft for a single type of operation, managing several independent vertiports in vertiplex. Multiple PSU operations, moderate route structure, VOAs and VPVs at high-density vertiports.	Support for multiple similar operations, capable of determining throughput and turn-around time based on not just the aircraft and payloads, but also other factors, such as weather, automation of support monitoring functions such as conformance. Multiple PSUs, multiple high-density vertiports, high-density route structure, VOAs and VPVs at vertiports.
Vertiport Automation and Capabilities	Manual ground operations with a small number of landing spots (1-4), and a network of aircraft occupying vertiports, some with multiple aircraft, some automated self-monitoring of resources, central management of the network.	A small number of landing spots and parking positions (1-4), automated self-monitoring (open pad status, charging station status), some communicated allocation with PSU of landing and takeoff slots.	A growing number of landing spots (3-10), increasing ratio of landing spots to parking positions, automated broadcast of vertiport status, increased communicated allocation with PSU of landing and takeoff slots.	Active urban vertiport and vertiport network serving high-density operations, automated status, automated collaboration, allocation of landing and takeoff slots.

1.4 Operational Stakeholder Descriptions

Table 2 summarizes the operational stakeholder roles mentioned and referenced throughout this ConOps.

Table 2: Operational Stakeholder Summary and Role Description

Stakeholder	Role
Federal Aviation Administration (Regulatory Role)	Create standards for vertiport design, vertiport operations, fleet operations, PSUs, the PSU Network, and flight critical SDSPs, and oversee UOE airspace.
Air Navigation Service Provider (ANSP)	For the purposes of this ConOps, the ANSP role is to receive and provide relevant information for AAM flight operations. In the U.S., the FAA serves in the ANSP role in addition to its regulatory role.
Vertiport Manager	Manage operations at one or multiple vertiports and support the safe takeoff, landing, and surface operations of each incoming and outgoing flight.
Fleet Operator	Manage the aircraft fleet, supporting personnel, and negotiations for moving people or cargo from point-to-point.
Flight Crew and Aircraft	Piloted, remotely piloted, or remotely supervised aircraft and the individuals onboard or offboard the aircraft who perform the appropriate checks, communicate information to the necessary stakeholders, navigate during flight and on the surface, monitor aircraft health status, etc.
Provider of Services to Urban Air Mobility	Manage flights using a cooperative data exchange platform that provides a common operating picture and shared situational awareness for subscribed fleet operators and schedules aircraft in-and-out of UAM airspace using volume reservations.
Provider of Services to Urban Air Mobility Network	Fully integrated system consisting of multiple participating PSUs servicing the same metropolitan area and sharing resource information across all stakeholders.
Supplemental Data Service Provider	Data service providers supporting fleet operators, PSUs, vertiport managers, and/or the PSU Network in providing information for the management, coordination, and scheduling of flight operations.
State and Local Government	State or local regulators create regulatory standards that may impose environmental, infrastructure, and operational limitations which the vertiport manager must monitor and comply with.

2 Current State

2.1 Description of the Current State

This section provides an overview of current-state operations as a basis for projecting how future vertiport concepts will evolve from existing infrastructure, processes, and systems. According to 14 CFR § 157.2, "airport" means any airport, heliport, helistop, vertiport, gliderport, seaplane base, ultralight flightpark, manned balloon launching facility, or other aircraft landing or takeoff area., while "heliport" means any landing or takeoff area intended for use by helicopters or other rotary wing type aircraft capable of vertical takeoff and landing profiles.

Heliports and airports are briefly described, as well as innovative concepts for vertiports. Selected examples of current helicopter operations and a general overview of aircraft designed with AAM in mind provide additional context.

2.1.1 Heliports

A heliport is an area of space intended for the takeoff and landing of helicopters. Heliports vary in complexity; most are simple designs with a TLOF pad surrounded by a FATO zone and safety area. FAA heliport design standards assume there will never be more than one helicopter simultaneously within any one FATO zone and its associated safety area. In today's environment, heliports are selectively charted on the low altitude sectional charts published by the FAA. Helicopter Route Charts, also published by the FAA depict heliports; however, the FAA publishes these charts only for the following locations:

1) Baltimore Washington
2) Boston
3) Chicago
4) Dallas Ft Worth
5) Detroit
6) Houston
7) Los Angeles
8) New York
9) Gulf Coast

Heliports are the most analogous current-state model for vertiports of the future. Today, the United States has a total of 5,918 heliports on record in the FAA airport master record database, and 58 are listed as public use.[6] The FAA provides recommendations for the design specifications of heliports in a 2012 Advisory Circular (AC) 150/5390-2C, but these specifications are enforceable only if the heliport receives federal grants through the Airport Improvement Program (AIP) or if the state or local municipality requires them.[7] Further FAA guidance for heliport oversight and inspection is provided in Flight Standards Information Management System (FSIMS) Order 8900.1.[8] Additionally, the FAA stipulated the use of Heliport AC 150/5390-2C for Instrument Flight Rule Operations (IFR) at Visual Flight Rule (VFR) heliports.[9] Code standards covering building standards promulgated by the National Fire Protection Association, as well as the International Fire Code, also apply to heliports. Additional regulations levied on heliports include individual state regulations, some of which adopt FAA AC 150/5390-2C as well as the building and fire code standards. As is the case with state governments, many cities and municipalities adopt standards that range from minimal to very stringent. Also, several independent accreditation standards organizations develop criteria for heliports. For example, the Commission on Accreditation of Medical Transport Systems (CAMTS) develops standards for the helicopter air ambulance industry.

More than 90% of heliports are of the single-aircraft variety, with no additional parking, fuel, or services.[10] Many of these heliports, some of which are in highly desirable urban locations, are now considered inactive and are used only in case of an emergency. For example, San Francisco has several heliports atop high-rise buildings that are inactive due to local ordinances governing noise levels. These facilities are not to be confused with sites originally designated as emergency helicopter landing facilities (EHLF), which are emergency evacuation sites required by building and fire codes and are not required to be evaluated by the FAA. Indianapolis Downtown Heliport (8A4), New Orleans Downtown Heliport (7N0), and West 30th Street Heliport (KJRA) in New York are the only true heliports in the United States that have ever received AIP funding. From 1996 to 2019, only $2.7 million was spent on those three heliports, while $51.3 billion was spent on airports during the same period. Of the AIP funding spent on airports, $44 million was used for installing or upgrading helicopter infrastructure, such as lighting, markings, and ramp space, at 51 public use airports. For example, Indianapolis Downtown has self-service Jet A refueling, minor airframe and engine repair capabilities, an Automated Weather Observing System (AWOS), a

[6] "Developing Sustainable Urban Air Mobility Infrastructure that is Efficient, Safe and Regulatory Compliant," Vertical Flight Society, https://vtol.org/store/product/developing-sustainable-urban-air-mobility-infrastructure-that-is-efficient-safe-and-regulatory-compliant-16408.cfm

[7] "Will the FAA Have Authority over Vertiports for High-Volume Air Taxi Operations?" Aviation Today, https://www.aviationtoday.com/2020/03/13/will-faa-authority-high-volume-air-taxi-operations/

[8] FAA Order 8900.1, CHG 140 (3/3/11), Volume 8: General Technical Functions, Chapter 3: Miscellaneous Technical Functions, Section 3 Evaluation and Surveillance of Heliports

[9] FAA/DOT Order 8260.42B, Appendix A. Conditions and Assumptions for IFR to VFR Heliport (IVH) (Proceed Visually) Approach Procedures

[10] "Heliports: 25 Frequently Asked Questions and Answers," HeliExperts International, https://heliexpertsinternational.com/heliport-safety-educational-and-regulatory-information/heliports-25-frequently-asked-questions-answers/

Pulse Light Approach Slope Indicator (PLASI), instrument approach procedures, and parking and tiedown capabilities, as well as noise abatement procedures for the approach.

Under current operations, a helicopter flying under an IFR flight plan in controlled airspace would generally conduct a point-in-space (PinS) instrument approach procedure to a VFR heliport under ATC. This procedure continues until the helicopter either enters visual meteorological conditions (VMC) conditions for a proceed-VFR procedure or has visual contact with the landing environment upon reaching the decision height for a visual landing. Today, there are no operational civil heliports in the United States with instrument equipage, excluding those collocated at airports; any heliport that has an instrument procedure is classified as a VFR heliport.[11] However, the U.S. military has some non-precision and precision approach procedures to IFR heliports. Most instrument procedures are PinS, which are established in special instrument flight procedures laid out by the FAA.[12]

If the airspace around the heliport is controlled Class B, C, D, or E airspace, and the pilot can see the heliport and safely land the helicopter under VMC, the pilot will cancel the IFR flight plan with ATC and land the helicopter. Alternatively, if the airspace surrounding the heliport is Class G, the pilot will cancel the IFR flight plan when leaving ATC-controlled airspace, and the pilot will complete the mission under VFR. Heliports collocated at controlled airports are under the control of ATC. ATC in controlled airspace would come from a tower in Class D airspace, from a Terminal Radar Approach Control (TRACON) facility in Class B, C, or E airspace, or from an Air Route Traffic Control Center (ARTCC) in Class E airspace. The decision height for helicopters is typically 500 feet above ground level (AGL) or higher for a proceed-VFR procedure. If the pilot conducting a proceed-visual procedure in controlled airspace does not have visual reference of the landing environment when reaching the decision height, the pilot must execute a missed approach. This discussion is specific to heliports; the approaches for helicopters into normal traffic flows into airports is covered next.

2.1.2 Airports

An airport is an area designated for the takeoff and landing of aircraft, along with the surrounding facilities. The facilities could include refueling, an ATC tower, maintenance, cargo handling, and other capabilities. Airports range in size, uses, and capabilities, and they are classified based on the types of operations they support. Commercial service airports serve aircraft that provide scheduled passenger service, and cargo service airports serve only cargo-carrying aircraft. There are other types of airports as well, such as

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[11] FAA-H-8083-16B; Chapter 7, IFR Heliports, page 7-17.
[12] “Special Instrument Flight Procedures”, FAA, https://www.faa.gov/air_traffic/flight_info/aeronav/aero_data/Flt_Procedures_Data/

reliever airports, which relieve overcrowded airports, and general aviation airports, which support general aviation.

Airports are either towered or non-towered, and both types have procedures to maintain safe operations. Towered airports have air traffic controllers and require two-way radio contact with ATC to obtain landing, taxi, and takeoff clearances. If a flight originates from a Class B or C airport, the aircraft must be equipped with a Mode C transponder.[13] , Automatic Dependent Surveillance-Broadcast (ADS-B) Out is also required within the Mode C veil, currently surrounding all primary Class B airports. Pilots follow the procedure laid out by ATC and need to be flexible to deal with changing conditions on the ground that may result in a last-minute swap to another runway. Non-towered airports are the more common type and have unique procedures to maintain safe operations. Right-of-way rules apply, and deconfliction, collision avoidance, and sequencing are handled by the pilots, typically via the common traffic advisory frequency (CTAF).[14]

Current airport operations differ from what is seen with heliports. At larger airports, the physical infrastructure is separated from other transportation methods, and passengers and aircraft flow in and out through a highly controlled environment. Terminal approach procedures at some airports are not based on the short urban flights envisioned in the AAM concept; rather, they are designed to support conventional fixed wing aircraft operations. Airports allow for helicopter operations provided that pilots use the approach and departure procedures for fixed wing aircraft if conducting IFR operations, and pilots approaching to land avoid the flow of fixed wing traffic if conducting VFR operations. These flights typically require ATC clearance to enter the airspace and they are required to be equipped with the proper radio and radar tracking equipment.[15] Inclement weather causes lengthy delays and may require that operations take place in higher-altitude airspace than is practical for UAM aircraft on shorter trips.[16]

2.1.3 Vertiports

Vertiport is a collective term referring to areas designed specifically for UAM aircraft to take off and land. FAA AC 150/5390-3 issued in 1991 provided guidance on vertiport design.[17] The AC was cancelled in 2010, but the term *vertiport* still appears in 14 CFR 157.[18] Vertiports will vary in levels of complexity, size, automation, and capabilities to enable high-density operations.[19] An early, potentially UML-1, example of

[13] "Operations at Towered Airports", Air Safety Foundation, https://www.aopa.org/-/media/files/aopa/home/pilot-resources/asi/safety-advisors/sa07.pdf
[14] "Operations at Nontowered Airports", Air Safety Foundation, https://www.aopa.org/-/media/Files/AOPA/Home/Pilot-Resources/ASI/Safety-Advisors/sa08.pdf
[15] "Helicopter Operations", San Francisco International Airport, https://www.flysfo.com/community/noise-abatement/helicopter-operations
[16] "Advancing Aerial Mobility", The National Academies Press, https://www.nap.edu/catalog/25646/advancing-aerial-mobility-a-national-blueprint
[17] "AC 150/5390-3 Vertiport Design", FAA, https://www.faa.gov/regulations_policies/advisory_circulars/index.cfm/go/document.information/documentID/23096
[18] "14 CFR 157", FAA, https://www.govinfo.gov/content/pkg/CFR-2012-title14-vol3/pdf/CFR-2012-title14-vol3-chapI-subchapI.pdf
[19] "NASA AAM Vertiport Automation Trade Study - Final Draft", Deloitte, Currently Unreleased

a vertiport could be a current heliport outfitted with automated sensing and direct human-to-human communications capabilities for weather, wind, and visibility data. While no vertiport exists and operates today, several developers are presenting concepts for vertiports as unique entities separate from heliports and airports. These concepts are designed to support VTOL aircraft, promote urban integration, and emphasize collaboration within the future AAM ecosystem.

For example, Volocopter, based in Germany, is developing a complete AAM ecosystem, including aircraft, ground infrastructure, and ATM systems. The VoloPort, a proposed vertiport design, is one part of the developing ecosystem. A VoloPort prototype, currently being developed in Singapore, is designed to be a testing ground to demonstrate that a vertiport can support AAM operations. According to Volocopter, the VoloPort will have planned customer services such as pre-flight checks and boarding procedures alongside ground services such as battery swapping, charging, and maintenance.[20] VoloPorts are designed with modularity in mind, able to fit into a wide range of urban locations ranging from rooftops to parking lots.[21] Volocopter is looking to transition from the prototype stage to fully operational service at the end of 2022 or the beginning of 2023.[22]

Like Volocopter, Lilium is developing their own vehicles and vertiport designs. Lilium's vertiport design is modular and scalable, based on a core set of modules. A key detail of Lilium's design is the emphasis on "plug-and-play" solutions for charging equipment and digital surveillance tools to create a scalable solution.[23] In September 2020, Lilium partnered with Düsseldorf and Cologne/Bonn Airports to establish regional air mobility as a new mode of transportation in the North Rhine-Westphalia region by 2025. Both airports are large intermodal hubs with access to air, rail, and road traffic, making them ideal locations for the incorporation of "networked mobility," including air taxi operations.[24] Lilium recently partnered with Tavistock Development Company, a design agency located in Orlando, Florida, and the City of Orlando to launch their first hub location to support AAM operations in the area.[25] An additional partnership with Ferrovial, an infrastructure operations group, was formed building off of Lilium's existing plans with the goal of developing 10 or more new vertiport sites across the state of Florida.[26]

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[20] "The VoloPort", Volocopter, https://www.volocopter.com/en/voloport/
[21] "VoloPort", Skyports, https://skyports.net/projects/volo-port/
[22] "Trends: Urban Air Mobility", Inside Unmanned Systems, https://insideunmannedsystems.com/trends-urban-air-mobility/
[23] "Designing a Scalable Vertiport", Lilium, https://lilium.com/newsroom-detail/designing-a-scalable-vertiport
[24] "Lilium Agrees Partnership with Dusseldorf and Cologne/Bonn Airports", Lilium https://lilium.com/newsroom-detail/lilium-partnership-dusseldorf-cologne
[25] "Lilium partners with Tavistock development and City of Orlando to establish first region in the US", Lilium, https://lilium.com/newsroom-detail/lilium-partners-with-tavistock-and-orlando
[26] "Lilium to Expand Planned Florida eVTOL Network", AINonline, https://www.ainonline.com/aviation-news/business-aviation/2021-01-28/lilium-expand-planned-florida-evtol-network

Skyports, based in London, Los Angeles, and Singapore, supports vertiport development and operation through local partnerships enabling site acquisition, cost-effective and vehicle-agnostic designs, and managing both airside and landside operations. Skyports played a key role in developing Volocopter's prototype VoloPort in Singapore, described above.[27]

ILandMiami designs and builds innovative helicopter landing platforms and is beginning to support eVTOL aircraft. ILandMiami is interested in marine landings, with the goal to maximize community acceptance and safety of operations using water-based vessels for takeoffs and landings. The company's core offering is based on its Marine Utility Vessel (MUV), which allows helicopters to land on watercraft rather than using valuable urban real estate. The company is promoting a concept for a modular version of the MUV, which would allow the attachment of multiple MUVs to provide a larger landing pad. The MUV is designed for transient use and VFR operations only when in an undocked configuration.[28] Due to MUV weight limitations, in the current state MUVs would not be able to serve as an equivalent to a full-service vertiport with charging infrastructure and support facilities.

Another vertiport concept being explored is integration into existing transportation infrastructure such as cloverleaf exchanges.[29] Multiple factors make cloverleaf exchanges attractive areas for a vertiport, including the existing level of noise, public ownership of land by federal or state governments, considerable number of exchanges and national distribution of the interchanges, and proximity to existing ground infrastructure to support intermodal travel. On the other hand, use of cloverleaf exchanges poses multiple problems for ground traffic, including the difficultly of merging traffic from the highways with traffic to and from the vertiport and lack of access for pedestrians on foot or on bicycles or scooters. These problems may be exacerbated during rush hour traffic. Other drawbacks include the possibility of distracting drivers and the proximity of flight paths to nearby buildings and other obstacles.

2.1.4 Operations

The examples that follow represent current helicopter operations in the United States that could be considered near-UML-1 vertiports. Advances such as automated data management and additional weather data collection capabilities are needed to transition to a UML-1-ready vertiport. Currently, it is unclear if the following operations have plans for expansion or intent to support UAM aircraft.

One example of a current low-density and low-complexity operation is the air care service at the University of Mississippi Medical Center (UMMC). This operation employs four helicopters capable of

[27] "Landing Infrastructure," Skyports, https://skyports.net/landing-infrastructure/
[28] "Will your future eVTOL aircraft land on a boat?", eVTOL, https://evtol.com/features/will-your-future-evtol-aircraft-land-on-a-boat/
[29] "Silicon Valley as an Early Adopter for On-Demand Civil VTOL Operations", NASA, https://ntrs.nasa.gov/citations/20160010150

supporting IFR operations, allowing the pilots to complete flights during some marginal weather conditions. All UMMC aircraft feature autopilot systems, color weather radar, and anti-collision instruments to increase pilot awareness and enhance safety.[30] The heliport (4MS6) includes two rooftop TLOF pads at the hospital, with one permanently assigned to the UMMC aircraft and the other for transient aircraft.[31]

Atrium Health's heliport (34NC), consisting of three separate TLOF pads located atop the Carolinas Medical Center, is used to transport injured or critically ill patients to the nearby hospital. A peak day sees 50-60 take offs and landings, or about 5-6 operations an hour. Prior authorization, obtained by contacting Atrium's Communications Center, is required before landing at any of the three pads. The heliport is located within Class B airspace, requiring clearance from the Charlotte ATC TRACON prior to departure.[32] MedCenter Air operates the helicopter bases serving the Atrium network, all of which operate year-round. MedCenter uses IFR-capable helicopters that can operate within a 150-mile radius, are satellite tracked, and have night vision goggles onboard. The crew is highly trained, and a web-based Global Positioning System (GPS) location tool assists the dispatch team with tracking and supporting operations.[33]

Another current operation is Vertiport Chicago Heliport (43IL), a full-service heliport managed by a fixed-base operator (FBO) and a hub for emergency medical service (EMS). FBO typically refers to a commercial business that is permitted by the airport or heliport to provide services such as parking, fueling, maintenance, repair, and towing. The heliport has one TLOF pad, two approach and departure routes, and eight parking spots. The heliport provides various navigation aids (NavAids), including landing direction lights, TLOF and FATO perimeter in-surface lighting, taxiway centerline lights, a lighted windsock, and a rotating beacon. The facility, including the refueling station, operates all day. Inbound aircraft must contact Vertiport Chicago when no less than five miles out and are assigned a parking location on arrival. Pilots are required to manage taxiing and sequencing the aircraft into and out of the heliport.[34]

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[30] "Department of Helicopter Transport", The University of Mississippi Medical Center, https://www.umc.edu/UMMC/Outreach-Programs/MS-Center-for-Emergency-Services/Critical-Care-Transport/AirCare-Home/Department-of-Helicopter-Transport-Home.html

[31] "Helipad Policy", The University of Mississippi Medical Center, https://www.umc.edu/UMMC/Outreach-Programs/MS-Center-for-Emergency-Services/Critical-Care-Transport/AirCare-Home/Aircraft/helipadpolicy.pdf

[32] "Helipads" Atrium Health, https://atriumhealth.org/medical-services/specialty-care/other-specialty-care-services/medcenter-air/for-providers/helipads

[33] "MedCenter Air", Atrium Health, https://atriumhealth.org/medical-services/specialty-care/other-specialty-care-services/medcenter-air

[34] "Vertiport Chicago Flight Procedures", Vertiport Chicago, https://www.vertiportchicago.com/wp-content/uploads/2018/07/Vertiport-Chicago-Flight-Procedures_2018_.pdf

2.1.5 Air Traffic Management and Unmanned Aircraft System Traffic Management

ATM, another essential aspect of the vertiport concept, is designed to be a coordinated response or systems approach to managing traffic and disruptions in the National Airspace System (NAS).[8] This function, requires consideration of the events in the airspace and who is impacted by them to enact a coordinated effort focusing on managing traffic amid changing conditions and demand in the NAS. The process emphasizes safety, efficiency, and equity in the delivery of air traffic services.[35] One aim of the ATC System Command Center (ATCSCC), which oversees traffic management in the NAS, is to prevent localized traffic delays from cascading across the country.

Traffic management is divided into tactical and strategic management.

Tactical management is a reactionary process where impacts of disruptions (weather conditions as a primary example) are managed locally to minimize delays. Planning is typically within the next two hours after a weather event is identified.

Strategic management is a longer-range planning effort to reduce or remove the demand on the airspace entirely when, for example, a weather event is forecasted.[20] The planning is typically at a regional or national level, and between two and eight hours are generally allocated for planning.

The type of management used depends on the scale of the weather event and the time that is available to react. Collaborative decision making (CDM) aims to improve air traffic flow management by supporting an increase in information exchange between the ANSP, which is the FAA in the United States, and the system participants.[36] CDM focuses on providing more accurate, precise, and relevant information to support proper decision making, with the objective of giving flight operators and ANSPs the proper tools and procedures to respond properly to rapidly changing conditions in the NAS.

Although the focus of this document is not on small UAS (sUAS), parts of the UTM model are applicable to the AAM vision. The FAA will not provide positive ATC services, rather, it will provide operational constraints that the operators will manage themselves. The vision for UTM is to manage both VLOS and BVLOS sUAS operations without the direct involvement of ATC services. UTM promotes real-time cooperation between various operators and the FAA to determine airspace status.[37] Stakeholders will use automated systems connected by application programming interfaces (API) to support communication and coordination.

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[35] "Traffic Management Overview", Federal Aviation Administration, https://www.faa.gov/nextgen/programs/weather/tfm_support/overview/
[36] "CDM Home", FAA, https://cdm.fly.faa.gov/
[37] "Unmanned Aircraft System Traffic Management (UTM)", FAA, https://www.faa.gov/uas/research_development/traffic_management/

2.1.6 Aircraft

Today, most civilian VTOL operations use helicopters for vertical flight. First responders, charter flight providers, and the news media are some of the major entities using helicopters for daily operations. Helicopters are typically fueled by Jet A, allowing them to use the same refueling facilities as jet aircraft. Pilots must be certified to fly a helicopter, with requirements varying according to the certification needed by the pilot.

For AAM, electric and hybrid-electric VTOL concepts are leading in the global push to support sustainable aviation. The Vertical Flight Society (VFS) maintains a *World eVTOL Aircraft Directory* that lists 395 aircraft placed in multiple categories, including the configurations below, with reference pictures shown below some of the descriptions. [38]

Vectored Thrust (*137 aircraft*): These aircraft orient their thrusters for lift and cruise based on the phase of flight.

Lift and Cruise (*56 aircraft*): These aircraft have separate thrusters for cruise and lift. They do not have any thrust vectoring.

Wingless or Multicopter (*106 aircraft*): These aircraft have multiple rotors (typically more than two). And thrusters used only for lift.

Electric Rotorcraft (*23 aircraft*): These aircraft use a rotor and operate as an electric helicopter.

Hover Bikes or Personal Flying Devices (*73 aircraft*): These wingless aircraft are designed for use by a single person and are not intended for commercial service. These aircraft are not considered in this analysis since they are not expected to operate at vertiports under this concept.

Figure 7: Example Vectored Thrust[39], Lift and Cruise[40], and Multicopter[39] Aircraft

These approximately 400 designs come from over 200 different sources ranging from student design teams to well-funded companies already in the process of flight testing for certification.[41] Multiple designs

[38] "eVTOL Aircraft Directory", VFS, https://evtol.news/aircraft
[39] "Advanced Air Mobility Mission Overview," NASA, https://www.nasa.gov/aam/overview/
[40] "Advanced Air Mobility," NASA, https://www.nasa.gov/aeroresearch/programs/iasp/aam/description/
[41] "VFS World eVTOL Aircraft Directory now at 300 entries", VFS, https://evtol.com/news/vfs-evtol-directory-300-aircraft/

in the directory are listed as “defunct,” and it is unknown how many innovative designs will be developed in the future. It is also unclear how many of these designs will complete the certification process and be used in AAM operations.

There are multiple reasons for the shift away from typical rotorcraft, as seen by the presence of only 23 rotorcraft out of 395 total designs, toward distributed electric propulsion for AAM operations. Lower levels of noise, lower direct operating costs, and zero “tailpipe” emissions are the main reasons advocates support distributed electric propulsion.[42]

What role hydrogen fuel cells will play in powering UAM aircraft is unknown, but supporters believe the greater lifespan and energy density make them the right choice. Hydrogen fuel cells may prove more suitable for longer-distance flights, but the increased weight and volume of the fuel system associated with using hydrogen may be a drawback for an aircraft designed for short-range urban flights.

To enable the projected growth of numbers of aircraft in operation as part of the AAM vision, stakeholders are looking into solutions for a potential pilot shortage for these new aircraft. A sizeable portion of developers are looking to automation and autonomy to either support a single pilot on board the aircraft or move the pilot off the aircraft entirely. This level of automation will require stricter certification processes for these aircraft, and the additional expectations on the aircraft could also result in additional certification and licensing requirements for pilots.

2.2 Advanced Air Mobility Vertiport State-of-the-Art Assessment

This section examines state-of-the-art technology and automation, providing a general description, with standout examples, of aircraft equipage and ground infrastructure at heliports and airports, as well as technology and automation used by the flight crew, FOCC, and ATC. This description of the current state establishes a basis to determine technology developments that may be applied in future operations.

2.2.1 Aircraft and Flight Crew

Projecting high-density vertiport operations of the future must consider both current and future aircraft capabilities. This section covers the capabilities of current aircraft, with a specific focus on helicopters, but it also briefly addresses technologies in development that may be used in future UAM aircraft.

[42] “Charging Forward New eVTOL Concepts Advance”, eVTOL News, https://vtol.org/files/dmfile/eVTOLConcepts-KenSwartz2.pdf

2.2.1.1 Communications, Navigation, Surveillance, and Information Technologies

Communications capabilities on aircraft are primarily handled through very high frequency (VHF) or radio links augmented by data-based communications. Aviation has relied on VHF analog radios for decades, and, over time, advancements in electronics permitted a significant increase in the number of usable frequencies.[43] For example, the Aircraft Communications Addressing and Reporting System (ACARS), [44] a character-based messaging service that transfers data between onboard aircraft systems and ground networks, has evolved significantly over its lifespan, from its original use by ATC to issue pre-departure clearances to its current capability to support satellite communications.[45] Additionally, ACARS permits transmitting from an aircraft information such as local weather, aircraft health, and in-flight positioning. Aviation is beginning to shift toward internet protocol (IP) based communications, with a global effort to use internet protocol suite (IPS) for air communications. The goal of IPS is to support datalink communications such as ACARS. It is expected that IPS will serve as a new tool to support greater situational awareness capabilities, rather than replacing ACARS. IPS will allow aircraft to become "flying nodes," capable of sharing data with other aircraft, thereby allowing collection and distribution of more precise weather and turbulence information.[46]

Multiple navigation instruments are required for helicopter operations under 14 CFR Part 27.1303. In addition to common instruments such as a clock, airspeed indicator, and altimeter, operations in instrument meteorological conditions (IMC) require various indicators for magnetic direction, free-air temperature, rate-of-climb, and other data. Some warning and redundant systems, such as a speed warning device and an alternate static pressure source, are also required if the helicopter is configured for single pilot operation, although two pilots are typically required for Part 135 operations.

ADS-B is designed to enhance the safety and efficiency of operations in the NAS, providing direct benefits to all parties involved in airspace operations. This system is the foundation for the FAA's Next Generation (NextGen) Program, shifting to tracking via satellite signals instead of traditional ground-based radar and NavAids. The FAA provides ADS-B equipped aircraft with traffic information on other aircraft through traffic information service – broadcast (TIS-B), as well as weather, terrain, and other important aeronautical information through flight information system – broadcast (FIS-B) using the universal access transceiver (UAT) datalink. ADS-B In cockpit displays that show the location of aircraft and equipped

[43] "Aircraft Communications", Aviation Pros, https://www.aviationpros.com/aircraft/article/10381753/aircraft-communications
[44] "How ACARS Will Evolve, Not Disappear, With Transition to IPS", Aviation Today, https://www.aviationtoday.com/2018/06/12/acars-will-evolve-not-disappear-transition-ips/
[45] "The Evolution of ACARS Series with Rockwell Collins' Dan Pendergast", Connected Aviation Today, https://connectedaviationtoday.com/evolution-acars-series-rockwell-collins-dan-pendergast/#.X8ezgM1KhPZ
[46] "The move to IP-based communications in aviation", Aerospace Testing International, https://www.aerospacetestinginternational.com/features/the-move-to-ip-based-communications-in-aviation.html

ground vehicles on airport surfaces also reduce the risk of runway incursions.[47] This capability even functions at night or during heavy rainfall, and applications are in development to alert pilots of potential collisions.

As of January 1, 2020, ADS-B Out has been required for helicopters to fly in the following types of controlled airspace:[48]

1) Flying in Class A airspace at any altitude.
2) Flying in Class B airspace from surface to 10,000 feet MSL, including the airspace from portions of Class B that extend beyond the Mode C Veil up to 10,000 feet above mean sea level (MSL), as in LAX, LAS, and PHX controlled airspace.
3) Flying in Class C airspace from surface up to 4,000 feet MSL, including the airspace above the horizontal boundary of the airspace up to 10,000 feet MSL.
4) Flying in Class E airspace above 10,000 feet MSL over the Contiguous United States (CONUS), excluding airspace at and below 2,500 feet AGL.
5) Flying in Class E airspace over the Gulf of Mexico at and above 3,000 feet MSL within 12 nautical miles of the coastline of the United States.

2.2.1.2 Operations

Helicopters require a licensed and certified pilot on board who has up to date training. Several types of helicopters may require special certifications and require the pilots to have additional training. If a helicopter is operating outside of Class G airspace, it is typically equipped with VHF radios and VHF omnidirectional range (VOR) equipment, although VOR is being gradually phased out and replaced with GPS.

A flight plan must be filed for IFR operations, and communication with ATC is required for helicopters entering controlled airspace. In the case of an in-flight emergency resulting from inadvertent flight into instrument meteorological conditions (IIMC) while operating VFR, the pilot may attempt to reverse course and exit the IIMC, or, prior to entering IMC, the pilot may land where they are. If the helicopter is IFR equipped and the pilot has the proper training, it is recommended that the pilot request an IFR clearance and proceed through the IMC. However, in other than an emergency, if an IFR clearance is not issued by ATC, the flight crew are not legally allowed to fly IFR. In cases where weather conditions cannot support VFR minima, the pilot may request special VFR (SVFR).

Some helicopters can perform instrument approaches and departures in IFR conditions. Helicopters capable of instrument landing system (ILS) approaches can take advantage of precision NavAids at airports that have them. In some air ambulance operations, helicopters are kept at airport facilities that

[47] "ADS-B Frequently Asked Questions", FAA, https://www.faa.gov/nextgen/programs/adsb/faq/
[48] "Equip ADS-B, Airspace", FAA, https://www.faa.gov/nextgen/equipadsb/research/airspace/

support IFR operations, rather than at the medical facility's heliport, so that the aircraft's departure is not restricted by IMC.

Heliport operations are manually controlled in the current state of operations. There are some tracking capabilities, with ADS-B equipage becoming more standard over time. Most approaches to heliports in IFR conditions are non-precision, but precision approaches are available at airports for appropriately trained flight crews in equipped helicopters. Near the heliport, pilots deconflict their flights through voice radio. At an uncontrolled airport, helicopters should, but are not necessarily required to, announce their position and intentions when flying into the airport. Depending on the airport, helicopters may fly the same pattern as fixed wing aircraft, or they could follow an opposite-direction traffic pattern. If the helicopter is not capable of ground taxiing it may land on a dolly or a portable landing pad for ground handling operations. Heliports currently lack automated, or information technology (IT) based allocation and scheduling systems, and the processes are generally human operations, such as call-ahead reservations, or simply first-come, first-served operations.

2.2.2 Heliports, Airports, and Vertiports

This section discusses key infrastructure and technology at heliports and airports to provide insight into how this infrastructure will apply to UML-4 operations in the future. Vertiports, as addressed in this section, comprise two distinct categories: the first group is analogous to heliports but chooses to use the title "vertiport" in their name, while the second group of vertiports consists of newer designs and prototypes that focus on UAM aircraft and operations. Examples of both groups are described in Sections 2.1.1 and 2.1.3.

2.2.2.1 Communications, Navigation, Surveillance, and Information Technologies

At more sophisticated airports, helicopters can take advantage of precision NavAids if they are capable of ILS approaches. ILS, in combination with high-intensity lighting arrays, allows for safe landing of IFR-capable aircraft during IMC. The main components of ILS are the localizer, which provides lateral guidance, and the glide slope, which provides vertical guidance. Airports that support ILS approaches at runways include a separate ILS for each runway direction. An example is Chicago O'Hare, which has separate ILS coupled with Distance Measuring Equipment (DME) on each runway end.[49]

Ground-Based Augmentation System (GBAS) is an alternative to ILS. GBAS has multiple advantages over ILS, including simplified airport infrastructure, steadier approach guidance, and fewer required flight inspections. One GBAS station can support multiple runway ends, allowing the airport to reduce space

[49] "Chicago O'Hare INTL", Federal Aviation Administration, https://nfdc.faa.gov/nfdcApps/services/ajv5/airportDisplay.jsp?airportId=ORD

used by navigation infrastructure and to decrease required maintenance by minimizing physical infrastructure.[50]

Larger airports typically use an AWOS or an Automated Surface Observing System (ASOS) to collect data in real time on current airport weather conditions. AWOS, which is highly configurable, collects data on barometric pressure, wind speed and gusts, wind direction, temperature, dew point, visibility, runway surface conditions, and other parameters.[51] With the use of additional sensors, AWOS can also detect thunderstorms via a lightning detector and freezing rain via a freezing rain sensor.[51] ASOS, which is more sophisticated than AWOS, is capable of tracking wind shifts, peak winds, rapid pressure changes, and amount of accumulated precipitation, in addition to the capabilities of AWOS.[51] Airport Surveillance Radar (ASR), specifically the most common ASR-9, also has weather sensing capabilities. Additionally, ASR-9 employs a dual-beam antenna and advanced digital processing, enabling detection of smaller aircraft or other targets in cluttered and low-visibility airspace.[52] Airport Surface Detection System – Model X (ASDE-X) reduces runway incursions by notifying air traffic controllers of conflicts on runways and taxiways. ASDE-X relies on multiple data sources, including ADS-B, ASR-9, and multilateration (MLAT) to identify aircraft and ground vehicles while also determining their position on or near the airport movement area.[53]

The FAA's Next Generation Air-to-Ground Communications Program (NEXCOM) supports air-to-ground (A/G) communications equipment used by air traffic controllers and pilots for radio communications. NEXCOM, which operates continuously within all regions in the NAS, also affords ground-to-ground communications needed when servicing airfield equipment and provides key communications infrastructure for all phases of flight.[54] Another communications solution is Aeronautical Mobile Airport Communication System (AeroMACS), which supports a wide range of applications, increases security capabilities, and optimizes ATM.[55] AeroMACS is internationally standardized and validated by the European Organization for the Safety of Air Navigation (EUROCONTROL), the FAA, and the International Civil Aviation Organization (ICAO).

Smaller, less-trafficked airports typically coordinate with nearby ATC and TRACONs to issue advisories to pilots rather than issuing direct clearance. While a few heliports have a collocated AWOS, most have a low level of equipage, potentially offering only a windsock and lights for night operations. In certain cases,

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[50] "GNSS Frequently Asked Questions - GBAS", Federal Aviation Administration, https://www.faa.gov/about/office_org/headquarters_offices/ato/service_units/techops/navservices/gnss/faq/laas/#:~:text=Unlike%20ILS%20%2D%20which%20requires%20one,ILS%20is%20unable%20to%20support.&text=The%20GBAS%20approach%20guidance%20is%20steadier%20than%20ILS%20approach%20guidance.

[51] "Automated Weather Observing System (AWOS)", Skybrary, https://www.skybrary.aero/index.php/Automated_Weather_Observing_System_(AWOS)#Automated_Surface_Observing_System_.28ASOS.29

[52] "Airfield Surveillance Radar ASR 9", Radartutorial, https://www.radartutorial.eu/19.kartei/03.atc/karte003.en.html

[53] "Airport Surface Detection Equipment, Model X (ASDE-X)," FAA, https://www.faa.gov/air_traffic/technology/asde-x/

[54] "NEXCOM Program Description", FAA, https://www.faa.gov/about/office_org/headquarters_offices/ang/offices/tc/library/storyboard/detailedwebpages/nexcom.html

[55] "AeroMACS", WimaxForum, https://wimaxforum.org/Page/AeroMACS

heliports can take advantage of infrastructure of nearby airports, such as precision NavAids, AWOS, or ASOS.

2.2.2.2 Operations

At controlled airports, aircraft are issued a specific taxi route by ATC. Taxiing is typically carried out with two-way voice communications over radio and directional signs installed at the airport. The airport manager is responsible for establishing the proper signage as laid out in A/C 150/5300-13, Airport Design; A/C 150/5340-1, Standards for Airport Markings, and A/C 150/5340-18, Standards for Airport Sign Systems.

At heliports and uncontrolled airports, helicopters will typically hover or ground taxi from their landing site to their final spot. While hover taxiing (movement 25 feet or less above the vertiport surface) is possible, it may not be used if there is a potential risk of rotor wash damaging parked aircraft or if there is loose equipment in the area. When greater distances on airport surfaces need to be traversed, helicopters may also employ air taxi movement (more than 25 feet above the surface). Pilots use signage and other passive NavAids to guide them around the heliport or airport, and they are expected to self-separate and follow the rules of the facility.

2.2.3 Air Traffic Management and Fleet Operational Control Center

This subsection summarizes the technology and involvement of ATM and FOCCs, primarily focused on the communications with aircraft and flight crew.

2.2.3.1 Communications, Navigation, Surveillance, and Information Technologies

Controllers at airports have traditionally used voice communications via radio to provide pilots with flight information and to issue clearances. However, voice communications are a manually operated time consuming process that limits operational efficiency. Additionally, voice communications can lead to “talk back, read back” errors between pilots and controllers.[56] The FAA is implementing data communications (DataComm), which allows controllers and pilots to transmit a variety of messages with the touch of a button. DataComm supports transmission and electronic display of flight plans, clearances, instructions, advisories, flight crew requests, reports, and other messages.[56] These capabilities can cut down on delays by allowing the flight crew to accept a new flight plan sent by a controller without lengthy two-way voice communication. DataComm’s increased bandwidth enables enhanced use of digital messaging and automated procedures to further reduce communication times and errors.

Traffic flow management (TFM) as a part of ATM manages the flow of aircraft in the NAS by balancing airspace capacity and demand. The FAA Air Traffic Control System Command Center (ATCSCC) manages the flow of aircraft in the NAS by implementing traffic management programs, monitors the impacts of traffic management initiatives and weather, and serves as the central and final authority for

[56] “Fact Sheet – Data Communications (Data Comm)”, FAA, https://www.faa.gov/news/fact_sheets/news_story.cfm?newsId=21994

inter-facility traffic management. TFM uses the FAA's Common Support Services – Weather (CSS-Wx) and Common Support Services – Flight Data (CSS-FD) to develop strategic plans for a given day. The Collaborative Convective Forecast Product (CCFP), a forecast produced by the National Weather Service (NWS), aircraft operators, ARTCC weather units, and the meteorological service of Canada, is the primary weather planning tool used by traffic management personnel to make decisions during periods of inclement weather.[57]

A FOCC is required for helicopter air ambulance operations when operating 10 or more helicopters. The fleet FOCC is required to provide two-way communications with pilots, provide current and forecasted weather briefings along the planned route of the flight, monitor the progress of the flight, and participate in the pre-flight risk analysis.[58] FOCC communication is typically via radio, but in some cases, it is via telephone or onboard satellite phone.

2.2.3.2 Operations

Multiple ongoing efforts aim to increase efficiency of operations in the current NAS. Airspace Technology Demonstration-Two (ATD-2), a solution developed by NASA, the FAA, and industry partners, integrates arrival, departure, and surface concepts to enhance operational efficiency.[59] ATD-2 incorporates concepts from three major FAA operational support system technologies:

Traffic Flow Management System (TFMS): provides multiple capabilities, such as arrival management, airborne metering, and departure scheduling, to reduce delays, travel time, and fuel burn.[60] TFMS embraces the joint CDM initiative described in Section 2.1.

Time-Based Flow Management (TBFM): serves as a trajectory modeler to enhance efficiency, optimize capacity, minimize environmental impact, and increase operational predictability.[61]

Terminal Flight Data Manager (TFDM): improves the exchange of flight data to streamline the flow of departures and improve CDM capabilities.[62]

ATD-2 demonstration at Charlotte Douglas International Airport in 2017 to 2020 showed significant reduction in delay. Additionally, ATD-2 will enable flights to absorb their delays at the gate, making operations more environmentally friendly.[59] While the benefit mechanisms for a high-density vertiport will

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[57] "Traffic Flow Management in the National Airspace System", FAA, https://www.fly.faa.gov/Products/Training/Traffic_Management_for_Pilots/TFM_in_the_NAS_Booklet_ca10.pdf
[58] "14 CFR § 135.619 – Operational control centers", Legal Information Institute, https://www.law.cornell.edu/cfr/text/14/135.619
[59] "Airspace Technology Demonstration 2 (ATD-2)", NASA, https://aviationsystems.arc.nasa.gov/research/atd2/index.shtml
[60] "Traffic Flow Management System (TFMS)", FAA, https://www.faa.gov/about/office_org/headquarters_offices/ang/offices/tc/library/storyboard/detailedwebpages/tfms.html
[61] "Time Based Flow Management", FAA, https://www.faa.gov/nextgen/cip/tbfm/
[62] "Terminal Flight Data Manager (TFDM)", FAA, https://www.faa.gov/air_traffic/technology/tfdm/

be different than for a large commercial aviation hub airport, ATD-2 is an example of the benefits of coordinated and automated arrival, departure, and surface operations.

One older effort of interest is Digital taxi (D-Taxi) clearances. D-Taxi enables ATC to give departure clearances to aircraft equipped with datalink capabilities. Experiments on D-Taxi's impact on ATC found that it reduced voice communications when at least 75% of the aircraft have datalink capabilities without increasing workload on controllers.[63]

2.3 Vertiport Challenges and Barriers

A variety of challenges and barriers need to be addressed to advance the state of the art from current heliport operations to integrated vertiports in the AAM ecosystem. For this ConOps, the primary focus on needed changes is from the perspective of the vertiport manager. Comparison of envisioned AAM traffic volume with the number of conventional aircraft operations illustrates the magnitude of the challenges involved. The FAA reports that in 2019 there were 16,404,606 IFR flights and 11,277,851 VFR flights in the NAS, with as many as 5,000 IFR flights in the air during peak times.[64] In contrast, AAM business projections range as high as millions of operations daily.[65]

This section discusses challenges and barriers related to 10 key functions involved in vertiport operations.

2.3.1 Communications

UAM operations have various communications barriers requiring solutions for high-density operations. In urban environments, multipath interference, various line of sight issues, and co-channel interference caused by the increased density of operations will limit effective use of voice communications. Additionally, available aviation spectrum concerns surrounding communications required to support UAM operations including aircraft-to-aircraft, aircraft-to-vertiport, command and control, remote identification, and aircraft-to-fleet operator or PSU must be addressed.

DataComm methods and standards must be established to enable cooperation among the vertiport, PSU, fleet operator, flight crew, and aircraft. Currently, data models such as the Aeronautical Information Exchange Model (AIXM), the Weather Information Exchange Model (WXXM), and the Flight Information Exchange Model (FIXM) along with the Flight and Flow Information for a Collaborative Environment (FF-ICE) are used by the FAA and industry stakeholders for data exchange. The National Academy of Sciences suggests that data will be diverse in content, size, and real-time update requirements, and DAA capabilities for UAS will require a common geospatial framework for updates on aircraft condition and

[63] "Digital Taxi Clearances in Airport Traffic Control Towers - Interface Design and Results From a High-Fidelity Simulation Experiment" , FAA, https://www.researchgate.net/profile/Todd_Truitt/publication/233903743.pdf
[64] "Air Traffic by the Numbers", Federal Aviation Administration, https://www.faa.gov/air_traffic/by_the_numbers/media/Air_Traffic_by_the_Numbers_2020.pdf
[65] "Enabling Autonomous Flight and Operations in the NAS", NASA Aeronautics Research Institute, https://nari.arc.nasa.gov/aero-autonomy

communication of intent.[16] Given these considerations, we assume that the vertiport will need to have the necessary infrastructure to support the level of data communications required for its operations.

2.3.2 Navigation

Precise airspace and surface navigation capabilities are necessary to enable sequencing, precise scheduling, and operational safety. GPS has varying levels of accuracy based on multiple factors, including satellite geometry, signal blockage, atmospheric conditions, and receiver quality.[66] Obstructions such as buildings and bridges will impact GPS accuracy in UAM flights. Recent FAA data shows that 95% of the time GPS receivers attain an accuracy within 6.2 feet.[66] Implications of this accuracy are in the realm of surface movement and other ground operations. Using dual frequency receivers can boost GPS accuracy to enable real-time positioning within a few centimeters, and incorporating other augmentations, such as GBAS or ILS, can provide further enhancements. GBAS provides corrections to aircraft around an airport to improve the accuracy of the GPS position of the aircraft.[67] GBAS could also be used as a redundant system to ensure integrity of position data. ILS has wide international acceptance and is accurate, reliable, and easy to maintain. The primary issue facing dual frequency GPS, GBAS, and ILS is the associated costs. GBAS and ILS will require significant investment and maintenance for infrastructure at a vertiport, while dual frequency GPS will require the proper equipage on aircraft.

2.3.3 Surveillance

Surveillance and sensing capabilities will be needed around the vertiport for automated data collection and monitoring of available resources. Aircraft and ground vehicle surface tracking is necessary. Additionally, takeoff and landing pad availability, parking spot availability, charging and refueling availability, and other data will need to be monitored by the vertiport and reported to the PSU or to the aircraft directly in case of an emergency. The vertiport will need to monitor non cooperative aircraft, potential sUAS intruders, and the presence of birds and other wildlife to guarantee a safe operating environment. Technologies such as MLAT and millimeter wave radar may be applicable for vertiport surveillance.

2.3.4 Information Storage and Processing

Increasing levels of automation from UML-1 to UML-4 will increase data storage requirements at the vertiport. The various challenges include, but are not limited to, a wide variety of data being received from multiple sources at varying update rates, the complexity of managing and ensuring data quality, and the security and privacy implications associated with the information sources. However, the use of edge, fog, and cloud computing (or any combination of the three) may reduce expected data storage capacities at a

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[66] "GPS Accuracy", GPS.gov, https://www.gps.gov/systems/gps/performance/accuracy/
[67] "Satellite Navigation – GBAS – How It Works, Federal Aviation Administration, https://www.faa.gov/about/office_org/headquarters_offices/ato/service_units/techops/navservices/gnss/laas/howitworks/

vertiport. Data from aircraft operating in and out of the vertiport will be stored to train machine learning (ML) algorithms and enable artificial intelligence (AI) capabilities. ML and AI training will become crucial in the transition from UML-2 to UML-3 when the UAM aircraft operating in the NAS begin to incorporate increasing levels of automation.

2.3.5 Ecosystem Integration

The vertiport may need to be integrated to varying degrees with the surrounding AAM ecosystem, depending on the use case or business model. If the vertiport operation is vertically integrated – i.e., aircraft, vertiport, and PSU all operated by the same entity – the vertiport may be isolated and might not interact with other AAM entities. In contrast, a public vertiport with multiple operators, PSUs, and types of operations will need modularity in infrastructure and operational design. Infrastructure modularity refers to the compatibility of equipment at the vertiport for operations such as charging and refueling or ground taxiing. Operational modularity refers to the compatibility of approach and departure paths with many existing aircraft types, along with hover-hold time limits and other attributes. A vertiport cannot realistically be expected to be compatible with every possible aircraft, and some classes of aircraft may be excluded from operating at certain vertiports based on their performance capabilities or other requirements. The implication is the need to codify aircraft and vertiport capabilities to ensure that when a flight plan is filed, the vertiport is capable of supporting the aircraft.

2.3.6 Operational Tempo

Operational tempo at a vertiport, although not necessarily a barrier itself, will reveal other barriers. Both high and low operational tempos will require automation at the vertiport to maintain safety and to either increase efficiency in high-tempo operations or reduce personnel costs in low-tempo operations. At higher operational tempos, vertiports will have decreased resilience to off-nominal conditions. potentially resulting in cascading delays and congestion in the vertiport's schedule.

2.3.7 Charging and Refueling

Another operational barrier the vertiport will need to overcome is refueling infrastructure for aviation fuel, electric, and, potentially, hydrogen-powered aircraft. As stated earlier in this section, over 90% of current-state heliports do not support refueling of any sort. Aircraft in future vertiport operations are projected to rely on electric, hydrogen, or hybrid propulsion energy, and thus will not be able to rely on the 10% of heliports that currently offer refueling services. The new infrastructure cannot simply just replace the existing refueling infrastructure, since conventional helicopters are likely to still be in operation in some capacity in UML-4. Additionally, charging and refueling infrastructure is costly and will take up valuable space in urban vertiports, which may result in vertiports providing either refueling or recharging, but not necessarily both services.

2.3.8 Weather

One environmental barrier is the impact of weather on vertiport operations. As of April 2019, 61.9% of flight delays were caused by weather-related events.[65] Thunderstorms, fog, and icing will all restrict vertiport operations unless addressed by appropriate capabilities. Different weather events have different implications for ground and air operations. For example, icing around a vertiport will impact ground taxiing of aircraft as well as takeoff and landing procedures. Adverse weather conditions are currently mitigated by either rerouting flights to another airport or introducing delays such as vectors, speed reductions, and holding. However, these techniques will not necessarily be available for UAM, since a weather-related delay at one vertiport will likely cause delays at other vertiports in the operating zone.[68] Rerouting passengers to vertiports outside of the operating zone would result in longer ground travel times, impacting the time saving goal of UAM. Current UML-4 throughput projections result in time slots being as short as 30 seconds, as opposed to 15 minutes in traditional aviation. Smaller buffer times and shorter flight times will result in weather impacts cascading delays across numerous flights.

Highly dynamic replanning of flight plan and resource allocation at the vertiport will be required to minimize the impact of weather on UAM operations. Freezing weather will impact the performance of batteries and will need to be monitored to ensure safe vehicle operations and compliance with required FAA fuel reserves.[69] The effects of wind and turbulence around the vertiport and in other operational areas must be considered, and micro-weather sensing and prediction capabilities may be needed to ensure safe operations. The availability of weather data must also be considered, as the current infrastructure might not be sufficient. The United States is covered by a network of weather radars known as Next-Generation Radar (NEXRAD), which consists of 157 sites operated mostly by the NWS.[70] NEXRAD is augmented by the 45 Terminal Doppler Weather Radar (TDWR) units operated by the FAA to serve aviation requirements such as wind-shear readings. One of the key issues with this system is the current lack of low-level coverage provided. While there are few areas with no coverage, much of the coverage is above 3,000 feet AGL, posing a major barrier to helicopter and UAM operations that will most often occur below this altitude.[70]

2.3.9 Security

Both physical and cybersecurity are needed to assure safe operations and to protect passengers and physical assets. Vertiport operations will need to support an optimal mix of pre-flight, technology-enabled screening with sensible on-the-ground security parameters to efficiently assure a safe travel experience.[68] In the context of vertiport management, cybersecurity capabilities are also vital to ensure safe operations

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[68] “Fast-Forwarding to a Future of On-Demand Urban Air Transportation,” Uber Elevate, https://www.uber.com/elevate.pdf
[69] “In-time System-wide Safety Assurance (ISSA) Concept of Operations and Design Considerations for Urban Air Mobility (UAM)”, NASA Aeronautics Research Institute, https://nari.arc.nasa.gov/sites/default/files/attachments/ISSA.Conops.Final_.20.07.01.pdf
[70] “Examining the weather radar issues behind the Survival Flight crash”, Vertical Mag, https://verticalmag.com/news/survival-flight-crash-weather-radar-issues/

around a vertiport. The FAA UTM ConOps states that threats can range from a misinterpretation of data to intentional spoofing of the navigation systems.[69] Industry will also need to identify cybersecurity risks and how they will be assessed and mitigated.

2.3.10 Noise

Noise created by helicopter operations prevents the use of many existing urban heliports and potential heliport locations. These urban heliports are highly sought after for future UAM operations due to their integration in the urban core. To take advantage of existing heliports for UAM, provisions must be made to comply with local ordinances on noise levels and procedures for noise abatement. Some larger heliports have noise abatement procedures in effect that may scale to high-density UAM operations. Vertiport Chicago's approach and departure corridors are located above the Global I Intermodal Facility, minimizing noise impact on the surrounding community. Incorporating vertiports into locations that already have elevated levels of ambient noise, such as inside cloverleaf exchanges, discussed in Section 2.1, will minimize public discontent from noise. Additionally, manufacturers can focus on minimizing the air vehicle source noise to comply with the various noise ordinances that restrict helicopter operations today.

3 Desired Changes

This section of the ConOps describes the shortcomings of the current system or situation that motivate development of a new system or modification of an existing system. This discussion bridges the focus from Section 2, describing the current system, to Section 4, describing the proposed future-state system.

3.1 Rationale for Changes

The NASA vision for AAM is to help emerging aviation markets to safely develop an air transportation system that moves people and cargo between places previously not served or underserved by aviation – local, regional, intraregional, or urban – using revolutionary new aircraft that are only now becoming possible[71]. As described in Section 2, a current system for envisioned AAM operations does not now exist. No VTOL aircraft other than rotorcraft are certified by the FAA; although the FAA is processing four initial applications for certification of innovative VTOL aircraft and expects to issue type certificates (TC) by 2022.[72]

AAM is currently most closely represented by helicopter operations in the NAS. While the term vertiport is often used synonymously with heliport, the vertiport described in this ConOps fulfills different requirements. Current heliports provide for helicopter arrivals and departures, just as vertiports will support novel VTOL aircraft, but there are several differences.

Current heliports lack automation for management of traffic and heliport resources such as landing pads and parking pads. In some cases, heliports experience demand that exceeds their capacity for arrival and parking of helicopters. While some busy heliports request advanced notification of arrival traffic, there is little or no management of heliport resources in advance of helicopter arrivals.

The traffic demand for heliports today is an order of magnitude less than that expected for vertiports in the UML-4 timeframe. The physical infrastructure available for vertiports will be limited, especially in urban areas where large open areas are minimally available and real estate is scarce. Thus, vertiport resources will be a constraining issue in meeting expanded demand, and management of these scarce resources will require vertiport automation with the ability to plan and schedule resources in real time. The management of passenger and cargo traffic at high-density vertiports will also require a systematic process and automation to accommodate the high tempo and substantial number of operations.

3.2 Description of Desired Changes

This subsection describes the evolution and changes needed to enable the concept presented in Section 4. Each part begins with a concise overview of the current state, then transitions to providing some details

[71] "Advanced Air Mobility Mission Overview," NASA.gov, https://www.nasa.gov/AAM
[72] Earl Lawrence, FAA Director of Aircraft Certification, ATCA Technical Symposium September 16, 2020

about the intermediate state. The end state for this ConOps – operations under the conditions of UML-4 – is described in Section 4.

Many current vertiport equivalents are heliports except for a difference in nomenclature. During the transition period, vertiports are expected to come into their own and begin to form a unique identity around AAM operations. Initial vertiports will take a form such as the concepts and prototypes created by companies such as Lilium, Volocopter, and Skyports, discussed in Section 2. Vertiport systems will sense and broadcast availability of resources such as parking spots and charging and refueling equipment. Additionally, vertiports may begin ingesting data on weather conditions on the surface or in the nearby airspace. Charging infrastructure will be developed and installed, with potential efforts to standardize equipment across the industry to promote compatibility. Refueling equipment will not be phased out during this time since conventional helicopters will still be in operation in UML-4. However, charging equipment will start to become more prevalent than refueling equipment in the urban core. Although charging equipment in urban areas (such as rooftops) could strain existing electrical infrastructure in the building and surrounding area, transporting Jet A to rooftops is a significantly harder logistical task.

Operationally, initial vertiports will function similarly to current heliports. Most operations will be charter flights and medevacs, but initial stages of AAM air freight and passenger air metro will also develop. In early cases. These operations may still be performed with helicopters; the primary difference will be potential sensing of pad status (occupied, available, or obstructed) and efforts to digitize the communications from pilot to pilot, pilot to FOCC, pilot to vertiport, and pilot to PSU. Voice communications will not be phased out, but digital communications may be used in certain operations, depending on the need. Pilot certification and licensing requirements will change as more systems on the aircraft become automated. The pilot may be aboard the aircraft, operating remotely, or supervising the operation of autonomous aircraft. In the last case, in this intermediate state the pilot will exercise control by closely monitoring the aircraft and actively applying control only as necessary. Advancements in automation may reduce the vigilance required by the remote pilot in future states, as well as enabling the monitoring of multiple aircraft simultaneously.

The PSUs and SDSPs for various applications are expected to phase in over time. PSUs will manage flights from subscribed fleet operators, and SDSPs will provide data and efficiency services to fleet operators, PSUs, and vertiport managers. Various SDSPs with information on weather will be critical to providing localized weather at vertiports. Service providers for communications, navigation, and surveillance will develop business models around providing infrastructure and capabilities to vertiports and performing the necessary maintenance on provided infrastructure. Service providers will not prevent more-developed vertiports from owning, using, and maintaining their own equipment, but they may enable less-developed vertiports to provide more operational support than what is seen today in heliports.

Helicopter operations are a manual, human centric operation today. In the initial stages, automation efforts may focus on relieving portions of the workload on human operators, potentially taking the form of an automated alert system to increase situational awareness. Over time, this capability may develop into a system not reliant on having a human in the loop, with automated sensing of weather conditions, takeoff and landing pad status, charging station status, and other parameters. A gradual increase in automation, as public confidence in automated systems is built up through a proven record of safety, is critical to enabling the UML-4 concept.

4 Future State Concept of Operations

4.1 Description of the Proposed System

The VAS is a dynamic software capability that supports the scheduling, management, communication, alerts, and resource assignments at the vertiport. The VAS is a System of Systems (SoS), defined as multiple, dispersed, and independent systems as part of a larger, more complex system. The independent systems are referred to as services, which combine to form the VAS. This SoS approach provides the vertiport manager the flexibility to add different services or to scale capabilities as needed to match the business needs at that vertiport. The SoS approach also promotes interoperability among the diverse services in a plug-and-play approach, allowing for modular customization of the VAS depending on needs.

4.1.1 Operational Viewpoint

The Operational Viewpoint-1 (OV-1) diagram is a high-level operational concept graphic that describes a mission by showing the foremost operational concepts and unique aspects of operations. The interactions between the VAS and the environment are depicted at a high-level.[73]. The OV-1 diagram in Figure 8 represents multiple vertiports within a metropolitan area, with aircraft flowing in and out via a high-density route. This perspective illustrates the vertiports' role in the larger metropolitan area and the VAS interactions with stakeholders in the geographic region. The diagram in Figure 9 zooms in on an individual vertiport to better depict the operations at and around the vertiport.

[73] DoDAF Viewpoints and Models, DoD Chief Information Officer, https://dodcio.defense.gov/Library/DoD-Architecture-Framework/dodaf20_ov1/

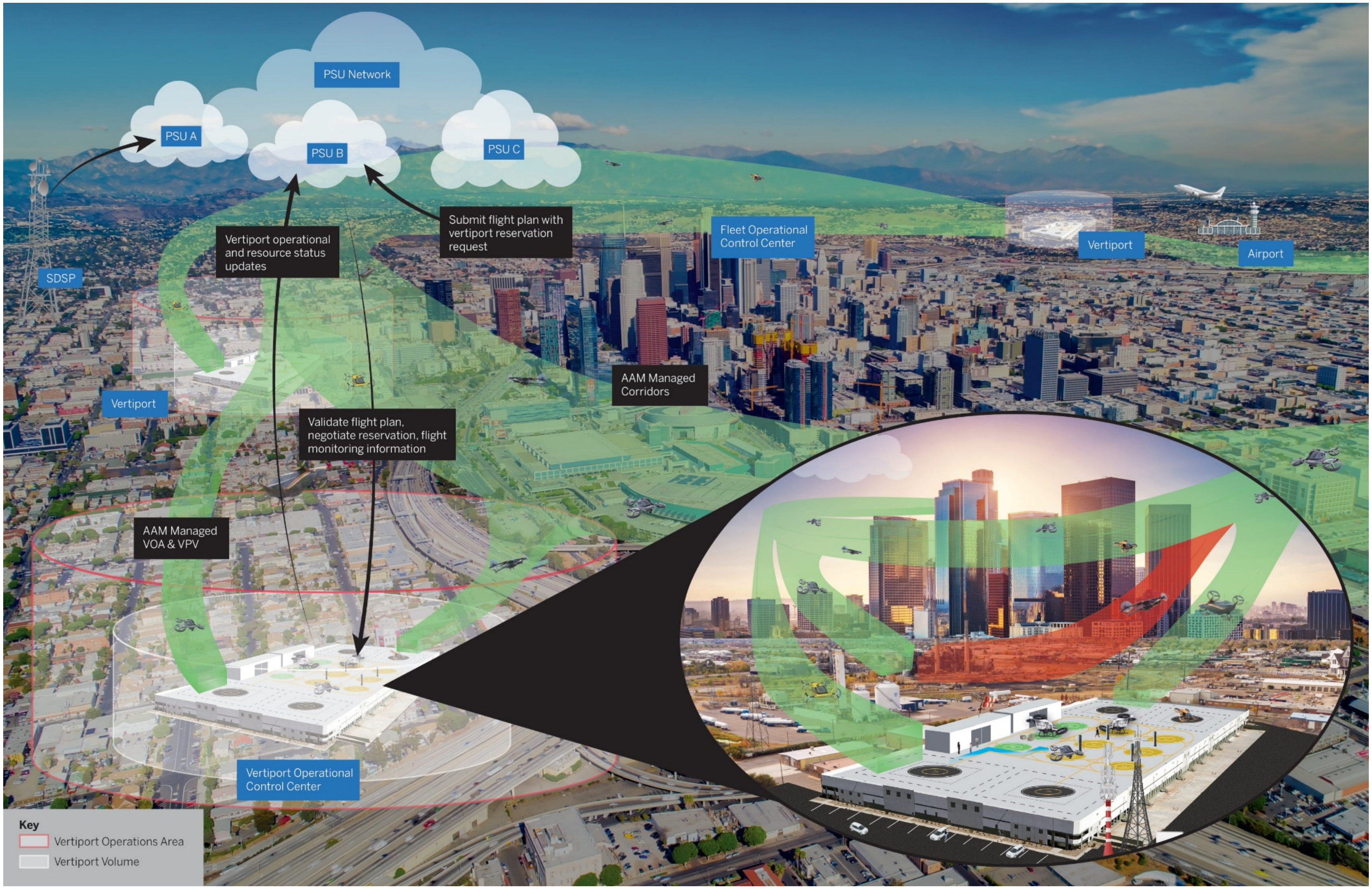

Figure 8: Vertiport Automation System (VAS) Airspace OV-1 Diagram

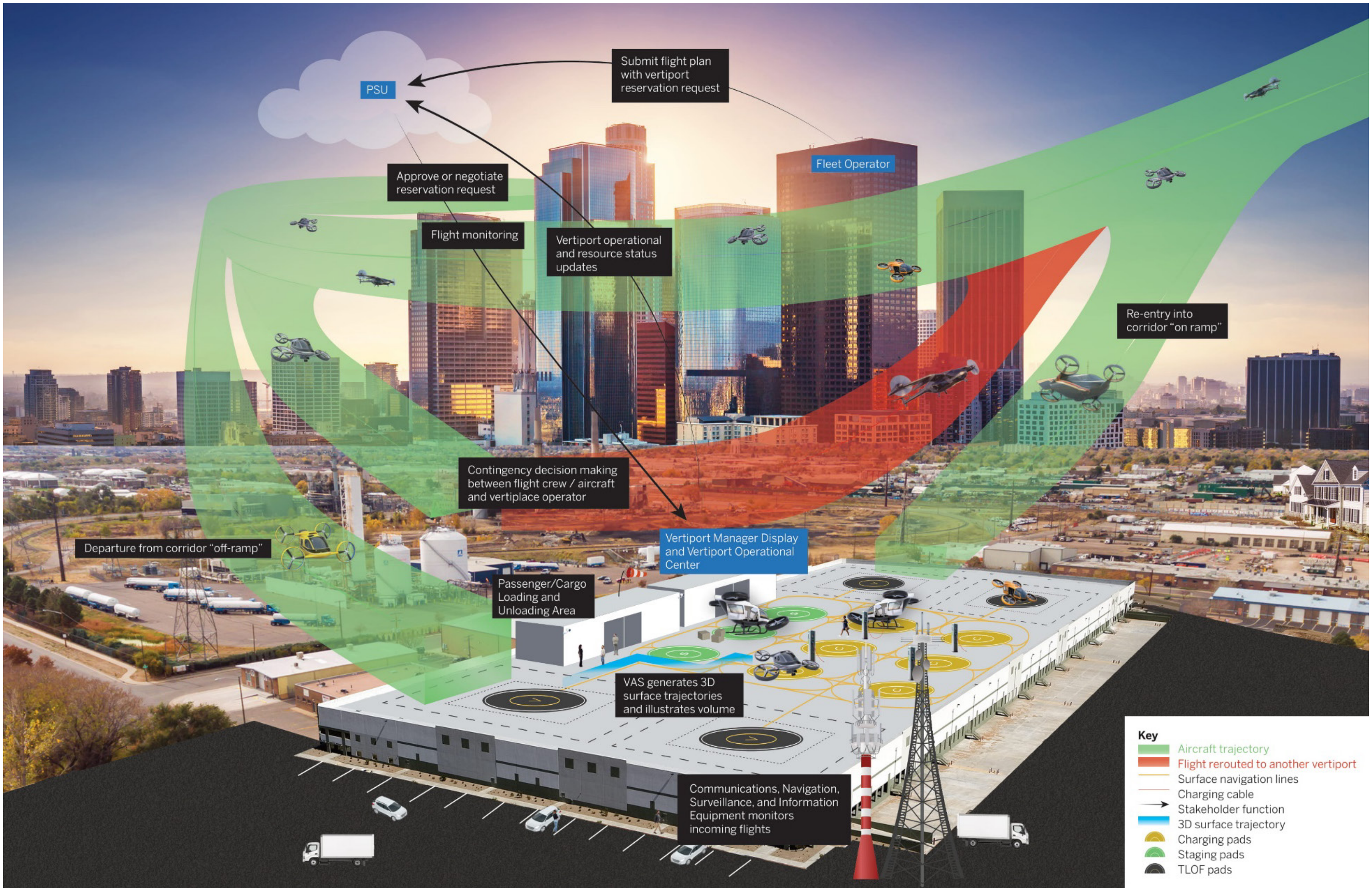

Figure 9: Vertiport Automation System (VAS) Vertiport OV-1 Diagram

4.2 Operational Environment

The UOE is defined in NASA's UML-4 ConOps[74] as a flexible airspace designated for areas of high UAM activity. UOEs could be volumes (corridors) surrounding high-density routes or evolve to being areas of multiple high-density routes, and thus high-density UAM activity in close proximity. Typically, UOE airspace (or corridors) will be within a Metropolitan Statistical Area (MSA), which is defined as including one urbanized area with a minimum population of 50,000 people. For a particular MSA, the FAA determines UOE locations and performance-based route attributes; the UOE routes are managed by PSUs in the PSU Network. The main purpose of the UOE is to enable establishment of performance-based criteria which aircraft must satisfy to render the airspace "cooperative." Aircraft intending to operate in a UOE must be subscribed to a PSU to manage the flight through that airspace, in the same way as if an AAM aircraft intended to fly through ATC-managed airspace. Most often the UOE airspace will be static and would appear on aeronautical charts detailing the volume of airspace with associated requirements, but the FAA can modify the UOE as needed, including modifying boundaries, adding Temporary Flight Restrictions (TFRs), or suspending the UOE.

Two volumes of airspace associated with vertiports are the VOA and VPV, illustrated and defined in Section 1. One could think of the VOA and VPV as being UOEs. The VOA is the first in the series of volumes that arriving aircraft enter as they approach the vertiport. For both the VOA and VPV, we assume that the FAA or the community will establish requirements to determine process, procedures, and equipage for operations in the two volumes of airspace. In any case, the complexity of the airspace and the potential traffic volumes around a vertiport will require charting for navigational purposes. Additionally, equipage restrictions within the airspace near a vertiport will need to be promulgated and "charted" in terms of requirements to enter the vertiport's proximate airspace.

The VOA is a construct to ensure the safety of high-density flight operations around vertiports. With safety assurance as the top priority, the VOA imposes several requirements that must be met to operate in that volume of airspace. Where the high-density route or UOE feeds traffic into the VOA and VPV, aircraft are already subscribed to a PSU to receive flight management services. In other cases, the aircraft operating outside the VOA through see-and-avoid or DAA procedures or under ATC control must subscribe to a PSU before entering the VOA. To ensure adequate levels of safety, prior to departure or contingency redirect the PSU verifies the aircraft CNSI capabilities to accomplish the intended arrival and departure operations. An example could be verifying a 5G network communication link with a redundant 5 GHz line-of-sight radio frequency (RF) link. Another example could be verifying navigational signal and strength in the VOA. A vertiport may have multiple established approach and departure fixes available, depending on

[74] "UAM ConOps Overview Feedback", NASA, https://nari.arc.nasa.gov/sites/default/files/attachments/ConOps%20Overview%20Feedback%20slides%202020.07.15.pdf

aircraft and flight crew capabilities. Prior to a flight's entrance into the VOA, the PSU will select the most appropriate fixes according to pad allocation, timing, and aircraft performance.

When the aircraft enters the VOA of the arrival vertiport, the vertiport manager freezes surface resource assignments, such as a specified landing pad, and will indicate to the PSU that the resource assignments will not be modified for arrival. Other requirements for operation in the VOA may include increased frequency of communications, dynamic mapping for potential hazards, in-depth micro-weather forecasts and real-time weather updates, and GPS validation and verification. Within the VOA aircraft are independently tracked by the vertiport; bidirectional communication with the vertiport is established; independent high frequency localization is provided; vertiport status information, hazards, and established procedures are provided; TLOF pad assignments are provided; and clearances to land are issued. Vertiports may play a role in providing these additional services or pairing with third party service suppliers to meet the imposed requirements or exceed them to attract potential clients.

The VPV is tightly coupled with the vertiport's geographic location, and traffic cannot flow through the VPV unless the flight has been cleared with the vertiport manager. The objective of limiting the traffic flow is to reduce the risk of aircraft collision near the vertiport and provide the vertiport manager with additional control capabilities to manage and optimize use of surface resources. This additional control contrasts with the operation in the VOA, wherein aircraft can travel through whether or not they intend to arrive at or depart from a vertiport. The VPV is important to PSUs since they cannot route non-participating traffic or trajectories through that volume of airspace while the vertiport is active. The vertiport manager must verify that the conditions needed to enter the VPV are satisfied prior to entry of a flight, such as ensuring that the intended pad is not occupied or checking for the presence of foreign object debris (FOD) that may damage the aircraft and onboard payload. Requirements for aircraft entry into the VPV may include more frequent information sharing, trusted and reliable ground-based navigational aids, and highly accurate positioning of the aircraft relative to the vertiport.

Inside the VPV will be a single vertiport that may contain several FATO zones. These vertiports may come in several configurations and sizes, which may be categorized as vertihubs, vertiports, and vertistops, as described below and illustrated in Figure 10:[19]

Vertihub: A vertiport with infrastructure for maintenance, repair, and overhaul (MRO) operations for the fleet, parking spaces for longer-haul vertical takeoff and landing (VTOL) aircraft, and a centralized operations control system.

Vertiport: An identifiable ground or elevated area, including any buildings or facilities thereon, used for the takeoff and landing of VTOL aircraft and rotorcraft.

Vertistop: A vertiport intended solely for takeoff and landing of VTOL aircraft and rotorcraft to drop off or pick-up passengers or cargo.

Figure 10: Vertiport Configurations (Vertihub, Vertiport, Vertistop)[19]

The surface configurations of vertiports will result in different throughput, safety, and noise levels, along with implications for the total size and cost of the vertiport. This section describes three general models of surface configurations and their individual properties. A brief high-level overview of the three designs is followed by a more in-depth analysis. The graphics in this section are informed and inspired by the report "Analysis of Alternate Vertiport Designs" by Megan Taylor, Asya Saldanli, and Andy Park of George Mason University.[75]

4.2.1 Single Pad Design

The first, and least complex, design is a single TLOF pad surrounded by a FATO zone, as depicted in Figure 11. This design will have the lowest throughput, cost, and physical footprint of the three designs. Any available charging, maintenance, or other capabilities will be available at the pad without a need for the aircraft to taxi. A single-pad surface configuration will be common at smaller vertistops. The low cost and small footprint will be favorable in urban environments, where space is limited, and the cost of land is generally much higher than in suburban or rural regions.

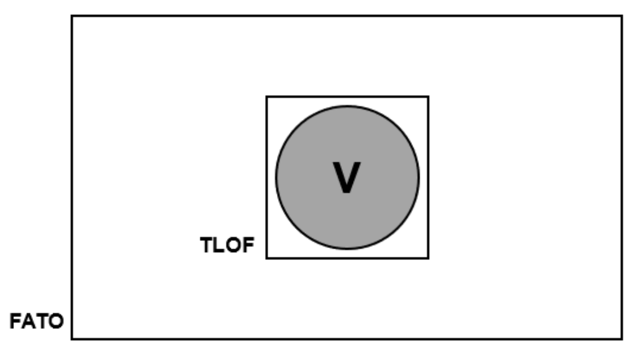

Figure 11: Example Single Pad Surface Configuration

[75] "Analysis of Alternate Vertiport Designs", George Mason University, https://catsr.vse.gmu.edu/pubs//IEEEConferencePaper_AnalysisAlternateVertiportDesignsICNS.pdf

4.2.2 Hybrid Design

The second design has a larger footprint than the first, with one TLOF pad and multiple staging areas, illustrated in Figure 12. Staging areas are outside of the FATO perimeter to allow for services such as parking, refueling, and maintenance in addition to passenger and cargo loading and unloading. Aircraft must taxi from the TLOF pad upon arrival or to it for departures at the vertiport.

This hybrid configuration increases throughput by allowing aircraft to taxi from the pad for turnaround. However, the use of staging areas results in an increased cost and physical size compared to the single-pad configuration. A small hybrid design, with only two staging areas, would reduce cost and footprint but would sacrifice the throughput of hybrid designs with more staging areas. Hybrid configurations will be common at medium-sized vertiports near urban cores – for example, operations within medical networks moving patients, equipment, and personnel across the region.

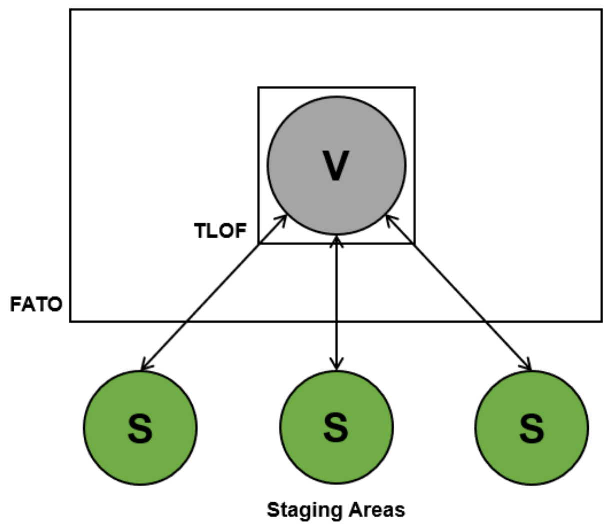

Figure 12: Example Hybrid Surface Configuration

4.2.3 Linear Process Design

The largest design is the linear process configuration, shown in Figure 13. Aircraft land at an arrival TLOF pad on one side, taxi to the staging areas for servicing, then taxi to another TLOF pad intended for departure from the vertiport. The linear process design supports the highest throughput of the three configurations and has the highest associated cost and physical footprint. Linear process configurations will be used for vertihubs on the urban periphery that are capable of moving copious quantities of passengers and cargo.

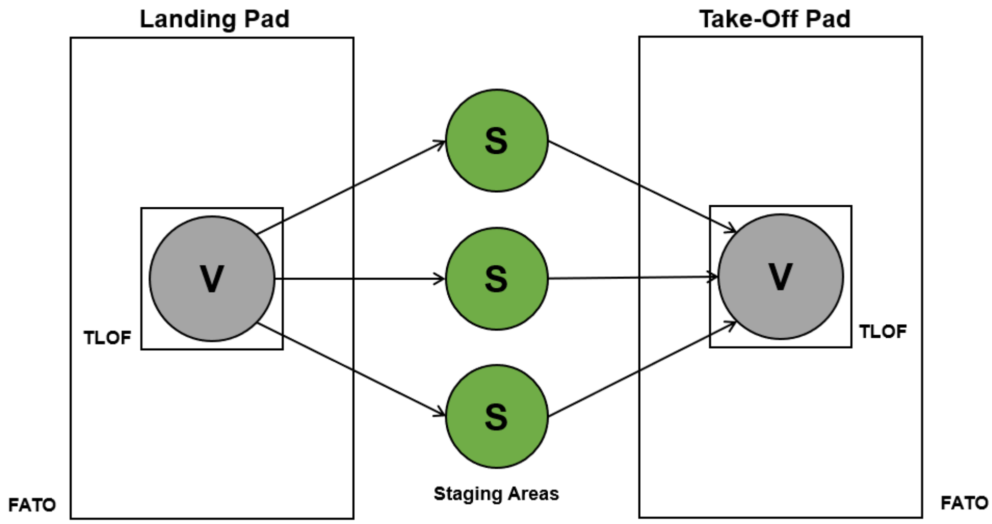

Figure 13: Example Linear Process Configuration

4.2.4 Vertiport Area Arrival and Departure

Figure 14 provides a geographic view of the vertiport area illustrating: the VOA and VPV; arrival and departure fixes; arrival, departure, and transition surfaces; and the associated FATOs and TLOFs. Aircraft will exit the high-density routes and begin descent into the VOA airspace starting at the initial approach fix (IAF). From the IAF, aircraft will continue their approach to the vertiport on the pre-defined pathway to the intermediate fix (IF) and on towards the final approach fix (FAF). The FAF leads to the decision point, otherwise referred to as point-in-space (PinS), where the aircraft will either enter the “visual segment” of the approach or execute a missed approach. Multiple FAFs will converge at the PinS for a single stream of traffic that is entering the VPV. The “visual segment”, or “vertiport segment”, is a portion of the approach where the vertiport has secured navigation and communication with the arriving aircraft, ensuring a safe approach to the vertiport. Methods for the assurance of navigation and communication are not specified in this document, but could include the usage of pilots, onboard sensors, or ground-based equipment. From the PinS, aircraft will follow the pre-determined landing procedures to the designated vertipads and complete the landing sequence. The PinS approach was taken as reference because it used for existing helicopter operations, can be charted, and is rigid while allowing for some flexibility in arrival or departure procedure definition. The authors recognize that with charting, performance-requirements may be imposed for vertiport arrival and departure operations therefore limiting which aircraft may be able to operate at the respective vertiport. Further research is required to determine the number of PinS approaches for the vertiport, one PinS approach is notionally depicted in the diagram.

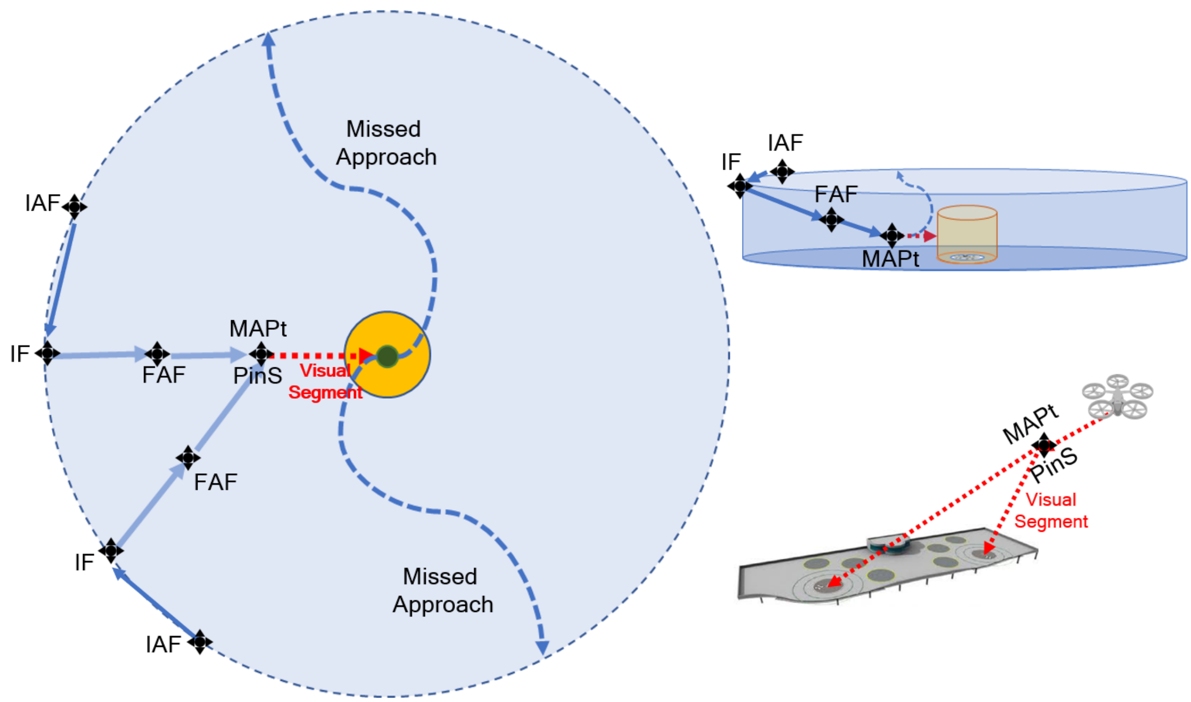

Figure 14: Geographic View of the Vertiport Area

4.3 Operational Stakeholders

This subsection describes the roles and responsibilities of the various stakeholders engaged with the operational environment, vertiport manager, and VAS.

4.3.1 Federal Aviation Administration

The FAA establishes rules, regulations, and policies for the airspace and the stakeholders involved in public flight operations. With respect to the role of the vertiport manager, the FAA will establish new standards for vertiports of varying sizes (vertihubs, vertiports, vertistops) or modify existing 14 CFR Part 139 Airport Certification standards. Previously, the FAA administered ACs applicable only to heliports that received AIP funding, which proved to be limited. Having regulations applicable to public vertiports will help to gain trust that public vertiports meet adequate safety standards. The FAA will also establish areas of high-density UAM operations (e.g. high-density routes/corridors, UOEs if necessary) and create the rules for operating in those environments. The FAA will approve the management of the airspace operations by UAM participants using federated PSU support. The VAS concept is not dependent upon the airspace structure. The FAA retains its authority for the airspace and may make changes to the airspace at any time with timely notice.

4.3.2 Vertiport Manager

The vertiport manager, a public or private operator of a vertiport, is responsible for managing ground-to-air operations at the vertiport, ranging from landside management to monitoring vertiport airside surface conditions. In the context of this ConOps, the vertiport manager manages the VAS via the Vertiport Manager Display and supervises the overall status, services, and connectivity to the PSU Network in addition to overseeing arrival, surface taxi, departure, parking, and other vertiport services on the airside. The vertiport manager under UML-4 will most often serve as a supervisor of the VAS and associated services, using the Vertiport Manager Display to monitor contingency or off-nominal scenarios when hazards arise and to respond appropriately. The vertiport manager also may need to step in for communications with aircraft, flight crews, PSUs, or fleet operators on an ad hoc basis if equipment at the vertiport or on aircraft is not operating as expected, or if communication is time-critical to diverting an aircraft.

4.3.3 Fleet Operator

At the fleet level, the fleet operator is a 14 CFR Part 121 or Part 135 FAA-certified operator responsible for the fleet and individual aircraft management who manages the schedule of resources and negotiates with vertiport managers to schedule payload-carrying flights from point to point. At the individual aircraft level, the fleet operator ensures that each aircraft is safe for flight operations, keeps up to date with maintenance standards, and performs routine upkeep on a need or time basis. The fleet operator is responsible for monitoring the aircraft position, timing, and health status of the fleet and communicating that information to PSUs. The fleet operator must subscribe to a PSU, which serves as the broker or ANSP, to provide traffic management services for aircraft in its fleet. The fleet operator may subscribe to any number of PSUs within a geographic region to satisfy business objectives. Aircraft in the fleet may be manned, remotely piloted, or remotely supervised; in any case, the fleet operator will manage the fleet from a hub or distributed FOCC, with supporting personnel and automated tools. The fleet operator also maintains a fleet operator station at a vertiport to connect fleet operations with vertiport surface activities such as passenger or cargo loading, passenger movement, aircraft servicing, or other operational support.

4.3.4 Flight Crew and Aircraft

The flight crew and aircraft are categorized together as a single stakeholder because, depending on the automation capabilities of the aircraft; in some instances, the aircraft may have flight crew members perform activities onboard, whereas in other cases the aircraft may be remotely piloted or remotely supervised. In either scenario, a flight crew manages the aircraft from gate to gate. The role of the flight crew and aircraft is to safely prepare for and execute the intended mission for an individual aircraft. Duties involved include preparing the aircraft through pre-flight checks, loading or unloading payload, briefing passengers, monitoring the performance and health status of the aircraft, performing flight maneuvers and safe navigation, executing tactical maneuvers, and requesting appropriate clearances. These duties may be distributed between the flight crew and aircraft, as determined by the fleet operator.

4.3.5 Provider of Services to Urban Air Mobility

The PSU provides strategic and tactical conflict management services to UAM aircraft. Multiple PSUs, approved by the FAA to provide services, may serve a geographic region. The PSU is the broker between different stakeholders, such as the fleet operator and vertiport manager, connecting resource supply with demand. The PSU will help the fleet operator to achieve the user-preferred trajectory and desired timing while ensuring that the flight plan meets required performance standards of the UOE. The PSU will provide 4D (longitude, latitude, altitude, and time) flight trajectories for individual aircraft and will monitor adherence to that trajectory and to performance standards during all phases of flight. Vertiport managers will provide resource availability to PSUs related to the business objectives of the vertiport manager, meaning increased availability can be provided to specific fleet operators, PSUs, and air charter brokers, depending on the business model. Any aircraft operating in the UOE, including aircraft operating in the VOA or VPV, must be subscribed to a PSU. The PSUs adhere to FAA standards on data exchange, data logging, and adjusting flight trajectories based on issued UOE airspace changes.

4.3.6 Provider of Services to Urban Air Mobility Network

The PSU Network is the collection of PSUs for a particular geographic region providing discovery services to stakeholders in the ecosystem. PSUs will share information among one another in addition to FAA-provided data such as changes to UOEs, Notices to Airmen (NOTAMs), TFRs, or other airspace-related publicly available information that can be accessed by stakeholders. The PSU Network, comprising the PSUs serving a geographic region, relies on a digital backbone that connects PSUs to enable safe, efficient, and scalable airspace operations. The digital infrastructure connecting PSUs provides visibility into 4D airspace operational intent across the network to strategically deconflict air traffic. Individual PSUs can thus ensure that a flight plan requested from the fleet operator can be successfully accomplished within airspace limitations and restrictions across affected PSUs.

4.3.7 Supplemental Data Service Provider

SDSPs may take various forms, but their fundamental purpose is to provide supplemental data to support air and surface operations. Traditional functions served by the FAA or other government agencies, such as broadcast of weather observations and forecasts, will be performed by third-party organizations providing data as a service. FAA approval may be necessary for SDSPs that provide flight-critical information to a fleet operator, PSU, or vertiport manager. SDSPs may also provide non-flight-critical data services to those stakeholders as a potential for add-on fees or additional marketing to attract customers. Examples of SDSP functions could include providing validated micro-weather data, dynamic mapping of geographic volumes, surveillance at low altitudes, and information downlink and uplink. SDSPs may plug in directly to the vertiport manager’s VAS to support airside management.

4.3.8 State and Local Government

State and local governments may impose local restrictions on environmental impact, noise, timing of operations, energy usage, zoning, or land use to include vertiport locations and uses, or other locally regulated issues. These restrictions may limit vertiport operations and thus need to be input into the VAS to bound the services. The requirements would be tracked by the vertiport manager through the VAS and monitored to notify or alert the manager when operations breach the specified boundaries, such as exceeding the noise threshold. The vertiport will be tightly integrated with local communities, and the operator will need to closely monitor adherence to local policies or restrictions to gain community buy-in. The VAS can provide operational data to the state and local government and general public for transparency and compliance with locally imposed constraints.

Table 3 presents a summary of the various stakeholders' responsibilities corresponding to the phase of flight. The phases of flight comprise several activities that may take place during each phase, since stakeholders may perform multiple functions in each phase. The table provides a high-level perspective of the allocation of responsibilities among the stakeholders considered.

Table 3: Stakeholder Responsible, Accountable, Consulted, and Informed (RACI) Matrix for Nominal Phases of Flight

Phase of Flight	Flight Crew and Aircraft	Fleet Operator	Vertiport Manager	Monitoring PSU	FAA, State and Local Government
Pre-Flight	R	A	I	C	I
Emplane	R	A	C	I	I
Taxi	R	A	C	I	I
Takeoff	R	A	C	C	I
Climb	R	A	I	C	I
Cruise	R	A	I	C	I
Approach	R	A	C	C	I
Land	R	A	C	C	I
Taxi	R	A	C	I	I
Deplane	R	A	I	I	I
Post-flight	R	A	I	C	I

4.4 Vertiport Automation System Services[76]

4.4.1 Vertiport Automation Supplemental Data Service Provider (VA-SDSP) Interface

The VA-SDSP Interface is a standardized interface allowing stakeholders to make representational state transfer (RESTful) API calls to the VAS and to use subscription as a means of direct communications to and from the VAS deployed at the vertiport. While VAS, the engine for vertiport operations, can be customizable to serve flexible vertiport manager business models, industry consensus standards will be needed for the VA-SDSP Interface and data.

A common standard for the VA-SDSP Interface is essential for scalability at UML-4 and to enable interoperability for stakeholders performing operations at vertiports managed by different organizations. The common standard ensures consistent methods for external stakeholders to make RESTful API calls to separate vertiports, thus avoiding the need for fleet operators to support different data formats and messaging paradigms when operating at different vertiports. The VA-SDSP Interface also plays a key role in assuring the safety and security of data flowing into and out of the VAS. The RESTful Interface allows stakeholders to receive vertiport resource information such as pad availability at a particular time, provides stakeholders a channel to update arriving or departing flight status, and affords a method for reservation requests. The VA-SDSP Interface is accessible via traditional ground-based communication networks, but it also provides a direct wireless communication link connecting the VAS to individual aircraft near the vertiport. The wireless communication supports sharing of critical information that needs to be directly exchanged or requires low latency as aircraft approach or depart the vertiport.

4.4.2 Vertiport Resource Management and Scheduling Service

As the core element of the VAS architecture, the Vertiport Resource Management and Scheduling Service is responsible for determining vertiport configurations, implementing business rules, enforcing community and government-imposed requirements, and responding to resource requests to strategically allocate and assign vertiport resources. Resources includes TLOF pads, long- and short-term parking, charging services, or any other surface resource available to fleet operators. The vertiport manager monitors the scheduling prioritization algorithm that uses business rules programmed by the vertiport manager to automate resource allocation. The vertiport manager also configures the decision-making criteria to tailor the highly automated resource negotiations with PSUs and fulfill fleet operator requests based on their business objectives. Managers of private vertiports could provide favorable preference to certain partners based on established partnerships. For example, as with gates at conventional airports, specific staging areas and charging stations could be owned, leased, or reserved for specific operators to guarantee high

[76] This ConOps is a living document that is the basis for derivation of software requirements. The descriptions in this ConOps represent the services as envisioned at the time of publication but are subject to change as software requirements are further defined and when prototype software is developed and tested.

operational tempo in day-to-day business operations. Conversely, public vertiport managers will have equity built in to ensure equitable resource allocation without bias.

The Vertiport Resource Management and Scheduling Service communicates information through the VA-SDSP Interface where PSUs pull resource availability information and match it against flight plans submitted by fleet operators. The service also pushes information such as responses to requests, status information, pad allocations, vertiport operational status, resource status, or infrastructure health status for external stakeholder awareness.

4.4.3 Vertiport Manager Display

Vertiport managers will facilitate ground-to-air operations, manage vertiport configurations, and monitor resource status, infrastructure health, risks, schedule, anomalies, VOA airspace, and all other VAS services. These functions will be automated for each of the VAS services, with the vertiport manager placed on or over the loop to step in during off-nominal conditions. The Vertiport Manager Display will be a physical user interface (UI) that describes the current state of vertiport operations and provides sufficiently detailed information to adjust business objectives and configuration settings and help clear operational anomalies and hazards. The display will use advanced human-machine teaming techniques to place the vertiport manager in the best position to maintain safe, consistent, and profitable operations. While many of the routine tasks are automated by VAS services, the vertiport manager will maintain a presence on site to manage the vertiport and to respond quickly during emergency situations. Low-operation-tempo vertiports near a vertihub could perhaps not require an on-site vertiport manager presence.

Surface resource constraints and contingency scenarios are likely to occur frequently, considering the high resource usage at the targeted throughput rates. The Vertiport Manager Display will be alerted of any automated responses to off-nominal scenarios, positioned to adjust resource scheduling while not impacting the higher-level flow of operations. The vertiport manager will oversee mitigation response efforts and step in the loop as needed.

4.4.4 Surface Trajectory Service

When aircraft land at a pad at the vertiport, the Surface Trajectory Service will retrieve information from the Vertiport Resource Management and Scheduling Service to determine taxiway and gate availability and update a nominal or pre-planned 4D surface trajectory (latitude, longitude, height above vertiport surface, and time) for aircraft surface movement. Surface trajectories are essential to efficiently move aircraft from point-to-point on the vertiport surface while staying clear of other ground traffic and ground support vehicles. High-density vertiport surface movement will require strategically coordinated surface taxiing for collision avoidance, identification of the optimal path, and limiting departure queuing. To support efficiency, the Surface Trajectory Service will use predictive analytics to model the most efficient route based on current conditions. Although the Surface Trajectory Service generates and communicates the 4D surface trajectory to the aircraft, it is the responsibility of the aircraft and flight crew to follow the provided trajectory and avoid passing surface traffic. It is expected that a set of community-based rules (CBRs) will detail surface taxi requirements for the aircraft and flight crew to follow when tactical deconfliction is required.

Passengers and cargo will require guidance to navigate from point to point on the vertiport surface. The Surface Trajectory Service provides navigation for automated systems moving payloads and triggers sensory cues to direct the flow of passenger traffic. Passenger and cargo flow management, albeit highly automated during nominal conditions, will require vertiport manager intervention during off-nominal conditions when passengers or cargo are unaccounted for, equipment fails, or other non-predictable situations arise.

4.4.5 Aircraft Conformance Monitor

Aircraft conformance is monitored both on the surface and within the surrounding VOA for compliance with scheduled arrival and departure operations. The scope of monitoring aircraft conformance includes both the nearby airspace and surface to ensure that operations will not conflict and that, with the current timing, adequate separation is maintained between sequenced aircraft. Surface monitoring includes aircraft adherence to provided 4D surface trajectories, pad occupation status, vertiport servicing updates, aircraft health status, and appropriate clearances. VOA monitoring includes aircraft adherence to PSU-provided arrival or departure information, surveillance of non-cooperative traffic, aircraft health status, and appropriate clearances. Impacts to the flight plan, either early or delayed, may affect the sequencing of traffic, depending on surface traffic congestion and resource availability. An aircraft delay, for example, could propagate throughout the stream of air traffic, impacting many aircraft in the process. The Aircraft Conformance Monitor will identify these issues in advance and provide the necessary data to other services to respond appropriately and mitigate schedule-related issues.

4.4.6 Risk Assessment Service

The Risk Assessment Service supports the vertiport Safety Management System (SMS) program by automating parts of the Safety Risk Management process through estimating pre-identified hazard risks. SMS activities evaluate the effectiveness of safety procedures, identify any hazards, determine the associated risks, evaluate mitigations implemented by the operations team, and promote continued use of the safety program. NASA's In-time Aviation Safety Management System (IASMS) with its monitor-assess-mitigate capabilities is an example of an evolving concept that may perform these functions.[77] Risk information is provided to the Vertiport Manager Display for further review and analysis. Additionally, the Risk Assessment Service supports the SMS Safety Assurance program through the continual monitoring of established risk mitigation strategies and generation of reports detailing their effectiveness.

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[77] Ellis, Kyle K. et al, "A concept of Operations (ConOps) of an In-time Aviation Safety Management System (IASMS) for Advanced Air Mobility," AIAA 2021-1978, AIAA SciTech 2020.

Other functions include providing access to safety policy documentation such as the Emergency Response Plan, which can be automatically triggered when needed. Input data includes vertiport infrastructure sensor information, resource availability, and aircraft conformance status; with output being level of risk and safety status.

4.4.7 Hazard Identification Service

The Hazard Identification Service receives anomaly alerts from the Aircraft Conformance Monitor and Software Monitoring Service, detects anomalies using vertiport infrastructure sensors, identifies hazards from those anomalies, and sends identified hazards to the Risk Assessment Service. Hazards identified include contingency or off-nominal situations, which then trigger the Risk Assessment Service to provide safety alerts to affected stakeholders. Examples of anomalies for which the Hazard Identification Service will monitor include FOD, non-cooperative traffic, vertiport resource availability, and external data that could affect the safety of vertiport operations. The inputs and outputs of the Hazard Identification Service and the outputs from the Risk Assessment Service are analyzed for adaptive purposes. Additionally, the vertiport manager can define the categorization of identified hazards that are output for risk analysis as a mechanism to indicate the severity of the hazard. ML using historical data improves anomaly detection and hazard identification capabilities over time, enabling more effective identification of issues affecting the safety of the vertiport.

4.4.8 Infrastructure Data Connectors

4.4.8.1 Weather Service

The Weather Service collects raw sensor data from the distributed weather sensors at the vertiport and transforms that data into information ingestible by the Data Management System for distribution to VAS services. Weather information is collected locally for key parameters (e.g., visibility, winds) requiring precise measurements at the vertiport surface and relevant for vertiport operations. This service is separate from the Weather SDSP, which will provide a more comprehensive weather outlook for geographic regions.

4.4.8.2 Foreign Object Debris Detection Service

The FOD Detection Service leverages specialized sensors capable of identifying objects contaminating surface taxi pathways or pads, potentially impacting arriving and departing traffic. FOD data is stored in the Data Management System and distributed to relevant VAS services, such as the Risk Assessment Service and Hazard Identification Service, which will use that data to appropriately identify risks and notify the affected stakeholders.

4.4.8.3 Surveillance Service

The Surveillance Service receives raw surveillance data from local airspace and surface surveillance sensors. The raw data is processed into information that is provided to the Data Management System for distribution to appropriate VAS services, such as the Vertiport Manager Display, for vertiport management visualization. Surveillance sensors analyze both the VOA and surface for redundancy in aircraft position information in the air and enhanced ground monitoring capabilities. Cooperative traffic may be verified through low-altitude surveillance sensors, and non-cooperative traffic can be identified in time to respond appropriately. Surface traffic surveillance data is ingested by the Aircraft Conformance Monitor to track aircraft as they progress along the provided surface trajectory and enables additional visualizations to help the vertiport manager make effective decisions.

4.4.8.4 Charging Service

The Charging Service receives data from the electric charging stations, transforming the data into information that is suitable for use by other VAS services. This information is used to monitor data for resource scheduling, including aircraft charging status, availability of charging infrastructure, average charging time, remaining charging time, and equipment health status.

4.4.8.5 Noise Service

The Noise Service receives noise data from sensors placed across the vertiport and transforms the noise data into information to be consumed by compliance monitoring services. CBRs or government-imposed noise restrictions on certain fixes and at certain times of the day may require data to be stored for historical access to verify compliance.

4.4.8.6 Communications Service

The Communications Service identifies the health and status of communications infrastructure to ensure that safe and reliable communications are available for the vertiport. The Communications Service will identify relevant attributes of communications signals, strength, bandwidth, and latency, and it will store that information to help inform the VA-SDSP Interface in selecting communications channels. The service also performs RF monitoring to try to identify frequencies that are saturated and recommend alternative frequencies to use to reduce RF congestion.

4.4.8.7 Resource Service

The Resource Service receives raw sensor data used to actively monitor the current status of vertiport resources, such as landing pads, and transforms that data into a useful format for use by VAS services. Conformance monitoring and resource scheduling are examples of VAS services that rely on this service.

4.4.9 Common Software Infrastructure

4.4.9.1 Data Management System

The Data Management System manages data across the VAS and serves as the central repository and database manager, ensuring that each service has access to the right data at the right time. Each VAS service produces and consumes data for use by internal services and external stakeholders. Acting as the hub for all VAS data exchanges, the Data Management System performs the common functions of data transformation, mediation, and filtering according to a common well-defined schema. A key feature of the Data Management System is the matching of flight data from multiple sources to individual flights by use of a Globally Unique Flight Identifier (GUFI). With the GUFI as the key, VAS services can obtain all information for an aircraft generated by many different sources conflated into a single object. This service greatly simplifies the process of combining flight information from different sources as the aircraft progresses from pre-flight to arrival.

Depending on their needs, VAS services can conduct ad-hoc queries or establish a subscription to receive an asynchronous stream of data tailored to their needs. By operating in the same environment as the VAS services, the Data Management System can provide access with low latency and high reliability. Data generated from internal services and externally from stakeholders and collected by the Data Management System is initially stored in an active data repository in support of ongoing operations. Once this information is no longer needed it is transferred to a historical archive. These historical archives are valuable for use in post-operations analysis, accident investigations (National Transportation Safety Board and FAA), training of ML models, investigation of past events, and other applications. High input-output (IO) operations are supported and can scale automatically as needed to match demand.

4.4.9.2 Cybersecurity Service

Cybersecurity must be implemented in depth across all services in the VAS to secure operations against potential cyberattacks. The first layer of cybersecurity is the VA-SDSP Interface, which authenticates external users accessing the RESTful interface, and validating their authorization using User-Based Access Controls (UBAC) to respond to each request and enable the appropriate level of access to VAS data and functionality. Data submitted by external stakeholders is inspected to ensure adherence to the established interface format and detection of malicious or corrupted data. The Cybersecurity Service will also validate internal service requests to the VA-SDSP Interface when asking to retrieve external stakeholder data, and it will validate internal service requests for data from the Data Management System. In addition to validation, the Cybersecurity Service also monitors for anomalies in VAS services and networks for indications of security breaches. Any indication of a security incident is communicated to the Vertiport Manager Display and automatic countermeasures are deployed to stop and contain the threat. Data encryption will be used to secure network traffic and data at rest, ensuring security even in the event of a compromise. Since cyber disruptions have significant propagated effects, cybersecurity will play a critical role in standardizing the VA-SDSP Interface and assuring network stability for fleet operators across geographic regions.

4.4.9.3 Software Monitoring Service

The Software Monitoring Service ensures that each service is behaving as expected and provides an assessment of operational status for each service. The Software Monitoring Service aggregates the software health reports and logs of each service and feeds this information to a dashboard on the Vertiport Manager Display for quick diagnosis of VAS issues. The vertiport manager is thus able to respond appropriately if a service is not functioning as expected or has degraded. The Software Monitoring Service also ensures that data is flowing appropriately between the different services and that all services are functionally connected with no loss of data.

4.5 Vertiport Automation System Relationships

4.5.1 Internal Relationships

Although VAS services are independent of one another, they rely on each other to provide value to the vertiport manager and successfully execute operations. All data must flow through the Common Software Infrastructure, internal or external, which allows the independent services to retrieve the information required to perform service-specific functions. Table 4 is a matrix of VAS transmitting services (rows) and the flow of outgoing data from those services to the receiving services (columns). The matrix represents the interaction of output data from the transmitting to receiving services and illustrates the relationship between services. Each service may provide output data to a few or many services, depending on the functions of the transmitting and receiving services. The VA-SDSP Interface is not included in the matrix because it is the method by which data is exchanged between external stakeholders and the VAS, and thus acts as middleware in the data flow. Likewise, the Common Software Infrastructure is not shown in the matrix because its services are in the middle of the loop.

Table 4: Vertiport Automation System Service Data Flow: Transmitting Service to Receiving Service

		Receiving Services						
	Service Output Matrix	Vertiport Management and Scheduling	Vertiport Manager Display	Surface Trajectory Service	Aircraft Conformance Monitoring	Risk Assessment Service	Hazard Identification Service	Infrastructure Data Connectors
Transmitting Services	Vertiport Management and Scheduling		X	X	X			
	Vertiport Manager Display	X				X	X	
	Surface Trajectory Service		X		X			
	Aircraft Conformance Monitoring	X	X			X	X	
	Risk Assessment Service	X	X	X				
	Hazard Identification Service	X	X	X		X		
	Infrastructure Data Connectors	X	X	X	X	X	X	

4.5.2 External Relationships

Figure 15, the OV-2 diagram, illustrates the nodes involved in the operation of a vertiport. Each node is served by Operational Need Lines, which depict resources that flow between operational nodes. The flows depicted are logical paths and do not represent the physical connection paths between nodes. For example, flight plan information flows from the FOCC to the PSU and then to the VOCC. However, there are changes made to the flight plan information at the PSU, and once the flight plan is approved by the PSU, the approved flight plan information flows from the PSU to the VOCC. In other cases, such as the Weather SDSP, the logical path for this information is between the Weather SDSP and the VOCC.

Within the vertiport, each fleet operator using that vertiport would have a station that is responsible for ground servicing and passenger loading and unloading of the operator's flights serving that vertiport. The station provides resources for ground crews and information to serve the operator's flights, and the operator's station is the center of information for the operator at the vertiport. The operator's station thus provides and consumes information as depicted on the OV-2 diagram.

There is also a need to provide and consume information directly between the aircraft and the VOCC. while aircraft are operating near and on the surface of the vertiport, and local government rules and regulations may be imposed on the operations at the vertiport.

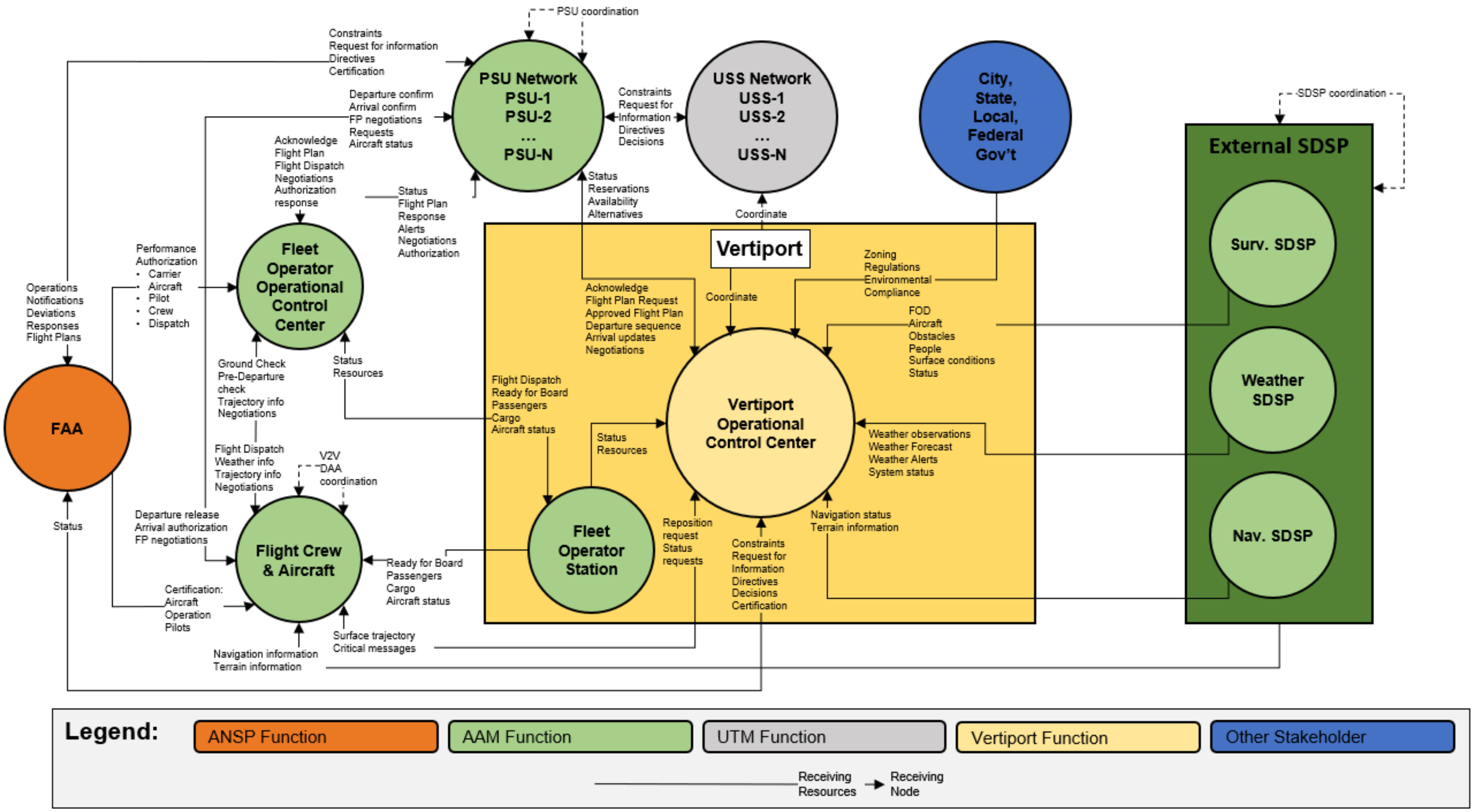

Figure 15: Vertiport Automation System (VAS) OV-2 Diagram

4.6 Configuration Decisions

Early decisions for the VAS configuration will affect the foundational elements of how the services interact, types of information shared, and capabilities that can be supported by the vertiport manager. The following subsections discuss important delineations that affect the VAS configuration.

4.6.1 Private or Public

What is the targeted business model, and which type of fleet operators does it support? For private vertiports, operations do not have to fit the needs of a wide breadth of airspace users, fleet operators, or even PSUs. The vertiport manager has flexibility to adapt to business partnerships and relationships to fit the needs of the vertiport operations business model. The information shared to PSUs or fleet operators can be tailored based on those partnerships to provide additional benefits or more opportunity for fleet operators with established relationships. An example could be exclusive contracting with one fleet operator and serving as a hub location for that operator to house their operations. Public vertiports, on the other hand, will accommodate a variety of fleet operators and PSUs and must be equitable for all airspace users. Partnerships and assigned spaces may apply to the public model, but all users of the airspace must have the opportunity for access. Public vertiport managers may also face needs for additional regulatory compliance imposing a tighter set of rules to align with and accommodate a broad diversity of aircraft configurations.

4.6.2 Single or Multiple Fleet Operators

Another configuration discriminator for the VAS is whether the vertiport will accommodate single or multiple fleet operators. For the single operator case, the vertiport can tailor operations to that operator and can tightly couple vertiport operations with their objectives. With a single fleet operator, there is no consideration of equity because there is no competition between fleet operators making resource requests at that vertiport. When the fleet operator is the same organization as the vertiport manager, information can be shared freely within the enterprise to increase operational efficiency; this case would be a private vertiport offering exclusive rights to a particular fleet operator. A private vertiport can also decide to accept multiple fleet operators operating in-and-out of the vertiport, creating some competition for resources on the vertiport. Multiple fleet operators may operate the same or different aircraft configurations, and each will share information about resources with the VAS.

4.6.3 Piloted and/or Optionally Piloted and/or Unpiloted Aircraft

This ConOps assumes that at UML-4 there will be a mix of piloted, optionally piloted, and unpiloted aircraft operating in a UOE, all properly equipped, that may operate at vertiports. Depending on their risk tolerance and business model, vertiport managers may opt to accommodate a mixed traffic flow or impose limits based on piloting type (e.g., onboard pilots, remote pilots, unpiloted). Although the processes and procedures will be standardized for all piloting types, each has certain limitations that the vertiport manager will consider. For example, if operating with mixed traffic, certain pads may have to be allocated solely for piloted aircraft vice unpiloted aircraft. Another example could be increased separation requirements for a flow of mixed traffic, considering uncertainty of mixed operations. Operations involving a mixture of piloted and unpiloted aircraft is an area ripe for research and will impact vertiport configuration decisions.

4.6.4 Passengers and/or Cargo

Vertiports will be designed to handle cargo, passengers, or a mixture of both, depending on the business model and geographic location of the vertiport. Although passenger and cargo operations do not differ much from an airspace and traffic management perspective, the supporting ground operations may vary. For a passenger oriented vertiport, appropriate navigation is required for passenger movement and signage to direct passengers to the appropriate gates, pads, and aircraft. For a cargo oriented vertiport, ground handling equipment and built-in cargo handling must integrate tightly with the aircraft operations. In the case of mixed passenger and cargo operations, passengers must not wander into cargo-dedicated areas and need to be kept clear of cargo handling equipment or vehicles. Cargo would also have to move seamlessly on the surface to sorting facilities and between aircraft without interfering with passenger foot traffic and other vertiport operations.

4.6.5 Visual Flight Rules and/or Instrument Flight Rules

The flight standards applicable to aircraft arriving and departing at a vertiport will affect the requirements to support those flight operations. For VFR, or adaptation using a DAA system, tactical separation is an aircraft function and strategic separation is managed at the PSU level. VFR could also apply to manned aircraft, with the pilot onboard manually flying the aircraft down to the pad. IFR procedures currently require expensive ground infrastructure to provide accurate position information and validation for low-visibility conditions. Aircraft will have to be able to operate in low visibility, and AAM businesses may not survive without IFR-capable flights. An SDSP may provide adequate resources and information to support IFR flights with distributed ground-infrastructure throughout a geographic area, or the vertiport may add additional capabilities to support low-visibility flights. Within the UML-4 time frame, a set of digital flight rules would place the burden on individual aircraft to maintain strategic routing and cooperative self-separation from other air traffic on user-preferred trajectories, but only in PSU-managed airspace (i.e., high-density routes) where all participating aircraft are capable of digital information exchange.

4.6.6 Community Integration

Local or state-level regulations or community restraints may impact operations at given times of the day or year and may pose additional requirements on vertiport operations. Examples could include not operating at certain times during the evening or adhering to noise regulations on the ground. The vertiport will be a part of the local community, and it must demonstrate utility to that community to support adoption. Noting those community-imposed restraints from the outset and on a continual basis will help the VAS configuration to mitigate future problems and enhance community buy-in.

4.6.7 Quantity and Type of Vertiport Staff

While VAS services will be highly automated, humans will still be required to oversee day-to-day management of the facility and must be present to manage off-nominal or contingency situations. In those cases, automation will alert the vertiport manager that intervention is required for a particular situation. The services may be designed with human-machine teaming to alert, advise, assist, or respond. The degree of oversight will depend on the governing business model, size, and location of the vertiport, as well as complexity of intended operations. More staff will be required for more complex models at a large facility to oversee the numerous services and to be able to quickly respond in case of emergency situations.

4.6.8 Vertiplex

A vertiplex is defined as a central vertiport digitally managing several facilities in a geographic region. The VOCC will be centrally located at a hub vertiport that also manages several vertiports along its periphery. The central vertiport can flexibly allocate resource among the various vertiports, and its actions may reallocate traffic, in conjunction with the PSU Network, to any of the vertiports that are under its management. The VA-SDSP Interface can leverage the vertiports under management to strategically provide resource information to fleet operators and PSUs to fulfill the business objectives of the vertiport manager. Equipment placed at one vertiport may be shared with other vertiports for uses such as communications, navigation, or surveillance, or the technology could be proprietary to a particular vertiport manager.

4.6.9 Other Configuration Decisions

The layout of the vertiport, resources available, and flow of passengers and cargo will play a key role in informing VAS services of capabilities and limitations. Vertiport designs and configurations could take various forms, and the VAS should be able to accommodate a diversity of pad, gate, and taxiway orientations. Aircraft landing at the vertiport may have skids rather than wheels, and a tug-and-dolly system or hover taxi is required to move the aircraft to another location on the vertiport surface. Servicing may be done entirely at the pad or at the gate or at a parking spot. The ramifications of these variabilities in configuration must be considered in detail and may affect operator aircraft requirements for operations at some vertiports. Other potential considerations include passenger flow through physical security, intermodal integrations, locations and types of MRO service offerings, assigned fleet operator or aircraft locations, and capabilities for emergency response.

5 Operational Scenarios

A scenario is a step-by-step description of how the proposed VAS should operate and interact with its users and its external interfaces under a particular set of circumstances. Scenarios help the readers of a ConOps document understand how all the pieces interact to provide operational capabilities.

5.1 Base Nominal Scenarios

Baseline nominal scenarios for this ConOps consist of one master scenario that reflects a gate-to-gate passenger flight (Section 5.1.1), with variations presented for cargo (Section 5.2.1) and mixed passenger and cargo (Section 5.3.1) gate-to-gate flights. Variations of these baseline scenarios are presented at the end of each section.

Sequence diagrams are illustrated at the end of the passenger gate-to-gate sections to summarize external stakeholder interactions with the departure and arrival VAS.

5.1.1 Passenger Gate-to-Gate

All fleet operators must receive a performance authorization from the FAA to operate in a UOE. The performance authorization covers specific aircraft, flight crews, and flight operations. Once authorized, the fleet operator is obliged to stay within the bounds of what has been authorized.

5.1.1.1 Pre-flight

1) Initially at the start of the day of operations, and thereafter whenever a change occurs, the VAS confirms vertiport safety, resource availability, and operational status and shares that information with all stakeholders via the PSU Network through the VA-SDSP Interface.
    a) Fleet operators and PSUs acknowledge receipt of the message from the VAS to confirm that they possess the safety, resource availability, and operational status of the vertiport prior to beginning operations.
2) The fleet operator files the flight plan, a 4D flight trajectory for the flight operation, with the PSU.
    a) With respect to the departure and arrival vertiport operations, the flight plan contains an Estimated Arrival Time (ETA), a description of what services the flight needs and has arranged through the appropriate service provider, how long it will stay at the vertiport, and an Estimated Departure Time and the planned departure direction.
    b) The PSU checks the flight plan for accuracy, content, and feasibility in the airspace traffic flow based on the published vertiport resource availability. The PSU submits the flight plan to the departure and arrival VAS to verify if the requested vertiport resources are available.
        i) If the requested departure and arrival vertiport resources are available, then:
            (1) The departure VAS responds to the PSU with an affirmative availability for aircraft departure.
            (2) The arrival VAS responds to the PSU with an affirmative availability for aircraft arrival.

ii) If the requested departure or arrival vertiport resources are not available as requested, then:
(1) In the case of a departure, the departure VAS responds to the PSU indicating the lack of availability as requested, signifying a change from the last published resource availability.
(2) In the case of an arrival, the arrival VAS responds to the PSU indicating the lack of availability as requested, signifying a change from the last published resource availability.
(3) The departure or arrival VAS may inform the PSU of suggested alternatives to the requested resource availability.
(4) The PSU communicates the responses to the unapproved submitted flight plan and the vertiport resource availability to the fleet operator, along with any alternatives that were identified. The fleet operator (with its own automation) probes alternative departure and arrival availability until a resolution is achieved.

c) When the flight plan is approved, after all required resources are verified as available, each VAS reserves the required vertiport resources for the designated flight operation, each VAS publishes an update to their resource availability, and the PSU:
i) Approves the flight plan via data exchange ("handshake") with the fleet operator, and
ii) Makes the flight plan available to the FAA and the PSU Network, as well as the departure and arrival VAS.

3) Ground and flight crews perform a visual aircraft check.
a) A pre-flight check is performed by the fleet operator's station ground crew and the flight crew, or by the aircraft if the aircraft is automated, to ensure that the aircraft is airworthy. The pre-flight check results are sent to the fleet operator station at the vertiport, which may forward them to the FOCC for review and action, if required.
b) Any cold-start procedures for the aircraft would be performed as required.

4) As personnel and passengers arrive at the vertiport, they are processed through ticketing by the fleet operator station staff at the vertiport and appropriately screened by vertiport security personnel, and passengers are directed to further processing (queuing) prior to boarding.
a) Once the passengers are in the boarding area, the fleet operator gate agents provide the passengers with a full boarding safety briefing prior to their boarding the aircraft. Once passengers are boarded on the aircraft, a pre-flight safety briefing is provided, either fully automated through a video or supported by a flight crew member if one is onboard.

5) The flight crew (or automated aircraft systems) performs a final inspection of the aircraft and confirms with the departure VAS and the fleet operator that the aircraft is ready for boarding. The fleet operator ground crew safely guides passengers to the aircraft. In a more automated operation, when the aircraft is ready for boarding the fleet operator automation will open the departure gate and activate signage or lighting to direct passengers to the proper aircraft, and the VAS will update the flights status to boarding when the gate is opened.
a) If an anomaly with the aircraft is detected, the flight crew or aircraft will contact the VAS, PSU, and fleet operator station to inform them that the aircraft is not available for flight at this time.

i) Through discussions with the fleet operator, the flight crew will determine a course of action to restore the aircraft to operational status, the fleet operator will advise the PSU that a maintenance plan is being executed, and the fleet operator will withdraw or amend the filed flight plan, as required.

ii) Since the aircraft is located at the departure vertiport, the fleet operator's ground crew, in consultation with the FOCC, will negotiate with the departure VAS to either move the aircraft or keep it in place for maintenance and fault correction, as required.

6) With the passengers onboard, the flight crew addresses any passenger questions or additional needs, either in person or remotely.

7) The aircraft and flight crew perform a system check and send a confirmation, as well as continual updates, of the estimated off-block time (EOBT), estimated take-off time (ETOT), estimated landing time (ELDT), and estimated in-block time (EIBT) to the departure VAS and fleet operator, who will verify the system check that the aircraft is ready for departure.

8) The fleet operator authorizes and dispatches the flight and informs the aircraft, flight crew, departure and arrival VAS, and PSU that the flight is authorized.

Figure 16 presents a sequence diagram for pre-flight activities that are described in Section 5.1.1.1.

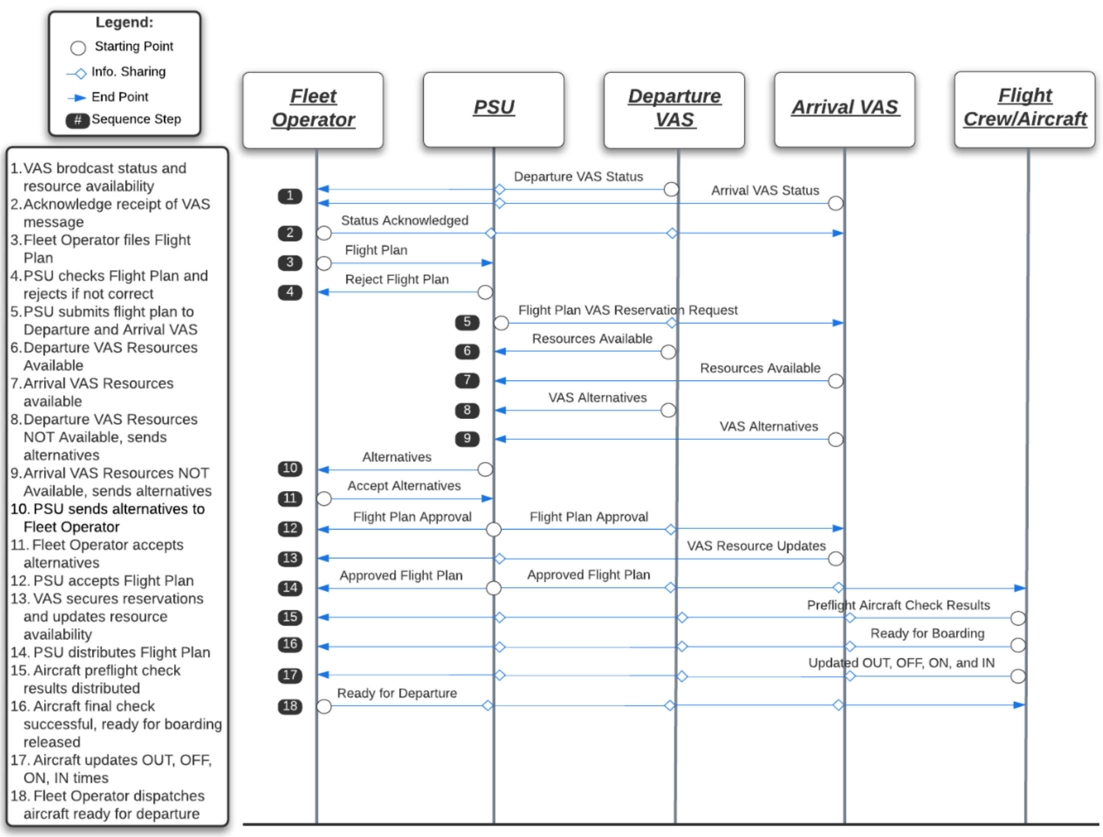

Figure 16: Pre-Flight Sequence Diagram

5.1.1.2 Taxi for Takeoff

1) The PSU assigns a takeoff time slot in coordination with the departure VAS and initiates departure sequencing. The departure VAS confirms the departure pad.
   a) Once departure sequencing is determined and communicated across the vertiport to all vertiport aircraft (incoming, at the gate, and taxiing), flight crew, and fleet operators, the departure VAS gives the final all-clear for aircraft taxi, issues the taxi trajectory to the aircraft (or flight crew, if manned), and informs the PSU and fleet operator that the aircraft is in taxi mode.
      i) The PSU will have provided the aircraft with a full flight trajectory clearance (departure pad to arrival pad) prior to taxi commencement.
   b) The aircraft, remote flight crew, or onboard flight crew then executes the vertiport surface trajectory and maintains V2V and V2I data exchange and tactical deconfliction with other aircraft and obstacles encountered along the path.
   c) The VAS at the departure vertiport (departure VAS) continuously monitors the vertiport surface for FOD and any obstacles incorrectly placed on the vertiport surface.
      i) Departure VAS monitors the progress of the departing aircraft on the vertiport surface as the aircraft taxis from the gate to the designated departure pad.
      ii) Departure VAS will alert the departing aircraft and flight crew of any detected anomalies or FOD along the path, and departure VAS will provide a resolved surface trajectory to the aircraft to avoid any ground collision with other aircraft or obstacles. If the aircraft itself has a surface detection capability (for objects and/or other aircraft) and detects an anomaly, an electronic negotiation between the VAS and the aircraft takes place to create a resolution trajectory. There may be cases where an immediate action must be taken by the aircraft to avoid conflict; these actions will likely be governed by CBR, and the departure VAS will monitor and adjust the overall surface operation, as required.
      iii) The aircraft or flight crew, either in person or electronically, keeps passengers informed of updates before the aircraft leaves the gate and when the aircraft is cleared for takeoff.
   d) Departure VAS continues to track the aircraft's progress on the surface until the aircraft arrives at the departure pad and is ready to depart. The tracking includes updates to the aircraft EOBT, ETOT, ELDT, and EIBT, which are shared with the arrival VAS through the PSU Network.
2) The aircraft or flight crew indicates to the departure VAS and the PSU that the aircraft is in position for departure.
3) The PSU assumes management of the aircraft and links communications directly with the aircraft.
4) The PSU determines that the departure slot time is still valid, and that the aircraft trajectory is strategically separated as it enters the VPV and VOA and transitions to downline airspace (most often AAM high-density routes in urban airspace), and that the VAS at the arrival vertiport (arrival VAS) has validated the required availability of vertiport resources.

a) The PSU provides a departure clearance to the aircraft and departure VAS and the aircraft departs.
b) The PSU and departure VAS monitor the aircraft takeoff and climb after departure to assure that the aircraft is fully airborne and outside of the VPV and that the aircraft does not require an immediate return to base.
c) Once the departing aircraft is clear of the VOA, the departure VAS ceases to monitor the departure flight.
d) Departure VAS releases the departure pad for further use after it determines the departing aircraft has exited the VPV.

Figure 17 presents a sequence diagram for taxi and departure activities that are described in Section 5.1.1.2.

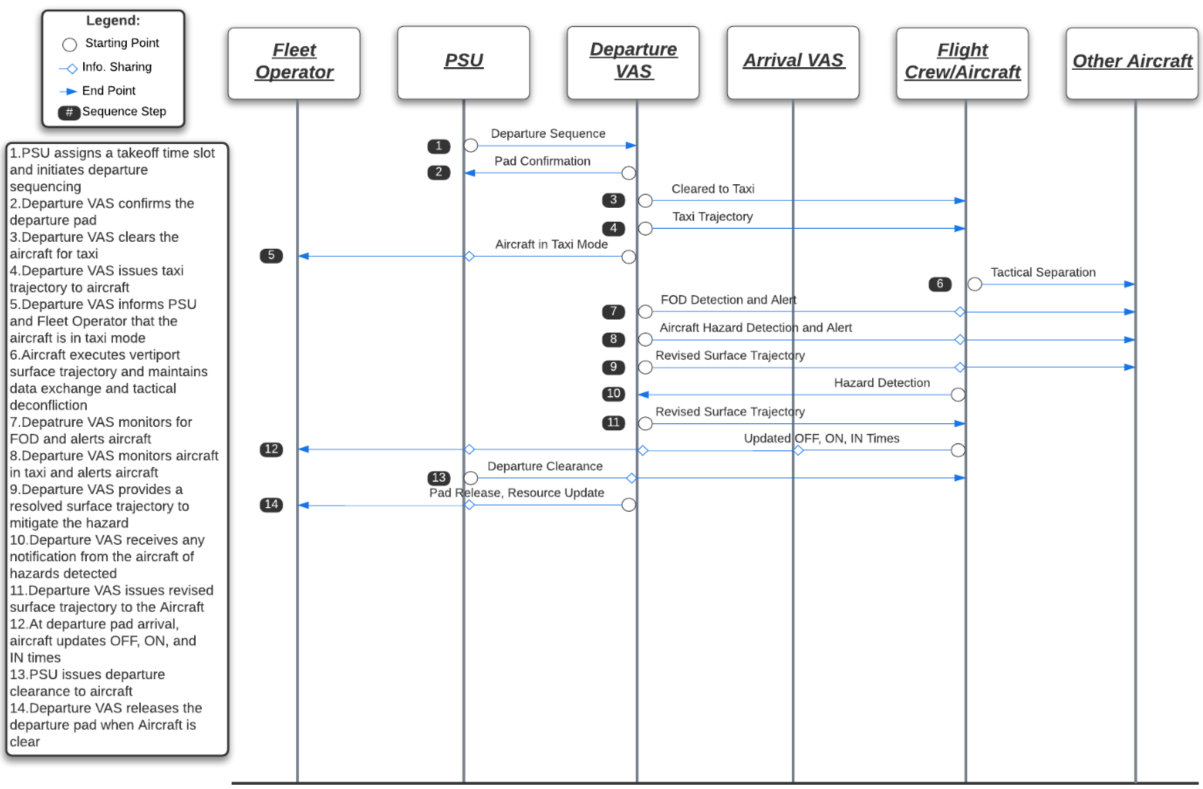

Figure 17: Taxi and Departure Sequence Diagram

5.1.1.3 Climb and Cruise

1) After takeoff, the PSU assures strategic separation for the aircraft within AAM high-density routes downline. If the flight plan takes the aircraft through controlled airspace, it must follow the rules for flight within that regime.

2) The aircraft executes the climb and cruise procedures in accordance with its approved flight plan, maintains V2V and V2I data exchange, and executes tactical deconfliction as necessary using onboard DAA capabilities.
3) Throughout the flight, the aircraft monitors onboard systems and pushes health status to the fleet operator.
   a) If the monitoring produces system anomalies, the fleet operator notifies the PSU of the issue and the potential impact to the aircraft trajectory.
   b) If maintenance is required on landing, the fleet operator arranges for that maintenance directly with the MRO provider at the arrival vertiport.
      i) If there is no MRO provider at the arrival vertiport, the fleet operator needs to produce an alternative.
   c) Once a course of action is determined by the fleet operator and negotiated with the PSU, the flight plan is updated by the fleet operator and the PSU informs the arrival VAS of any perturbation to the aircraft's airborne trajectory, as well as the need to taxi to the MRO provider at the arrival vertiport, if appropriate.
4) The fleet operator monitors conformance of the internal aircraft parameters within the context of the current flight plan, aircraft energy management and reserves, and real-time flight status, to determine any potential issues in advance. The fleet operator shares this flight status information with the PSU.
   a) The arrival VAS is notified through the PSU of any changes to the flight plan based on the aircraft internal monitoring status.
5) The arrival VAS updates its resource plan accordingly and advises the PSU of any issues that would affect the arrival reservation.
   a) If any time-critical issues arise, the arrival VAS may alert the aircraft first and subsequently notify the PSU.
6) PSUs, fleet operators, and aircraft continuously access en route and arrival weather data from the various Weather SDSPs, as required.
7) Aircraft and flight crews are kept informed by fleet operators of any forecasted weather conditions that could impact the flight, and the aircraft or flight crew provides that information to passengers.
   a) The PSU continues to track aircraft conformance and alerts the fleet operator if the aircraft is not conforming.
   b) The PSU and fleet operator track updates from SDSPs, including weather-related events. Dynamic UOE airspace changes made by the FAA are tracked by the PSU, and the PSU informs the aircraft and fleet operator of any airspace changes, as required.
   c) The PSU exchanges updates to the flight plan with other PSUs on the PSU Network when necessary, including sequencing, reroutes, and weather deviations.
      i) The fleet operator, aircraft, flight crew, and arrival VAS are notified as appropriate.
      ii) The aircraft or flight crew updates the passengers, as required.

d) As the aircraft proceeds according to its flight plan (as amended), when necessary, the aircraft executes rerouting based on information received from the PSU. The arrival VAS monitors the status of arriving flights through the PSU Network and communicates updates of resource availability to the PSU.

   i) The PSU communicates the availability updates to the fleet operator, aircraft, and flight crew, as required.

Figure 18 presents a sequence diagram for climb and cruise activities that are described in Section 5.1.1.3.

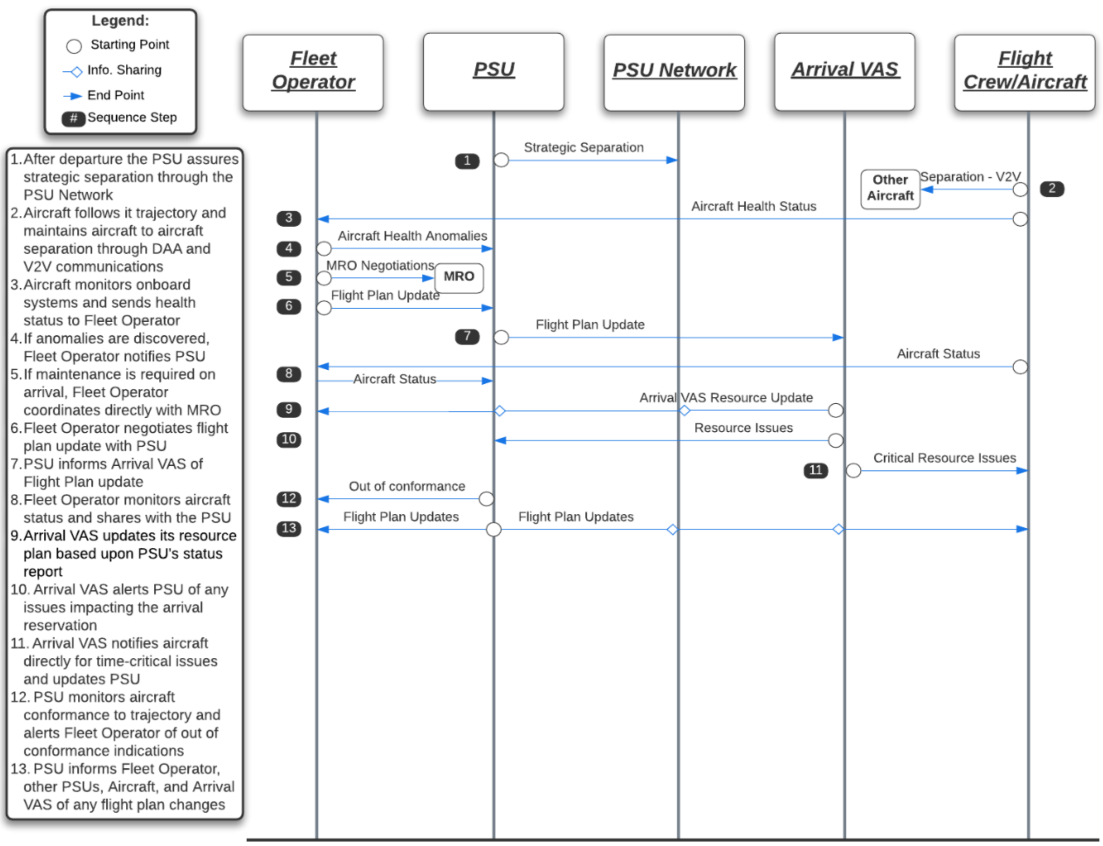

Figure 18: Climb & Cruise Sequence Diagram

5.1.1.4 Approach

1) The arrival VAS monitors the aircraft flight status and determines when the aircraft is in range of the vertiport's arrival pad.
2) As the aircraft begins its approach to the arrival vertiport and is approaching the VOA, the arrival VAS independently monitors the aircraft, reconfirms that the vertiport is clear for aircraft landing, finalizes the allocation of the landing pad, and shares that information with the PSU and fleet operator ground crews, as appropriate.

a) If flight delays or other circumstances on the arrival vertiport have negated the arrival reservation, the arrival VAS advises the PSU that the reservation is no longer valid.
b) If the notification is time-critical to the flight, the arrival VAS will directly notify the aircraft and expect execution of a published procedure missed approach. The arrival VAS will monitor the aircraft to ensure that a missed approach is in progress and will confirm with the PSU that the aircraft is executing a missed approach.
    i) After the aircraft executes the missed approach, the arrival VAS may offer possible alternatives to continue the flight operation to the intended vertiport, adjusting the prior reservation in accordance with the current vertiport status.
        (1) The PSU, aircraft or flight crew, and fleet operator can accept one of the alternatives offered, propose a new alternative for this arrival vertiport, or choose to land the aircraft at an alternate destination.
        (2) The flight plan will be amended in accordance with the resolution and the aircraft will execute a missed approach and follow its new flight plan and trajectory.

3) Based on the current aircraft ELDT, the PSU, coordinating with the PSU Network, determines arrival sequence and landing information and communicates any updates to the arrival VAS, fleet operator, and aircraft or flight crew, as appropriate.
4) The fleet operator continuously monitors internal aircraft parameters in the context of the current flight plan and reports the status through the PSU and directly to the aircraft.
5) The PSU tracks aircraft conformance along its trajectory, alerts the aircraft and fleet operator of any non-conformances to the flight plan, and requests the ready-to-land notification from the fleet operator, aircraft, or flight crew. The fleet operator, aircraft, or flight crew confirms that the aircraft is ready to land and shares that information with the PSU.
6) The PSU notifies the aircraft or flight crew and the arrival VAS that the aircraft is cleared to land.
7) As the aircraft approaches the VPV, the VAS confirms that it is ready for landing and assumes control of the aircraft within the VPV.
8) The arrival VAS continuously monitors the trajectory of the arriving aircraft and ensures that the designated arrival pad is clear of any debris and other aircraft. If a hazard is detected, arrival VAS commands a missed approach to the aircraft and notifies the PSU accordingly.
9) The aircraft or flight crew informs the passengers of the planned landing. The aircraft executes the approach procedure and sequencing and maintains V2V and V2I data exchange as necessary to execute tactical deconfliction using onboard DAA capabilities as it approaches the arrival vertiport.

Figure 19 presents a sequence diagram for approach activities that are described in Section 5.1.1.4.

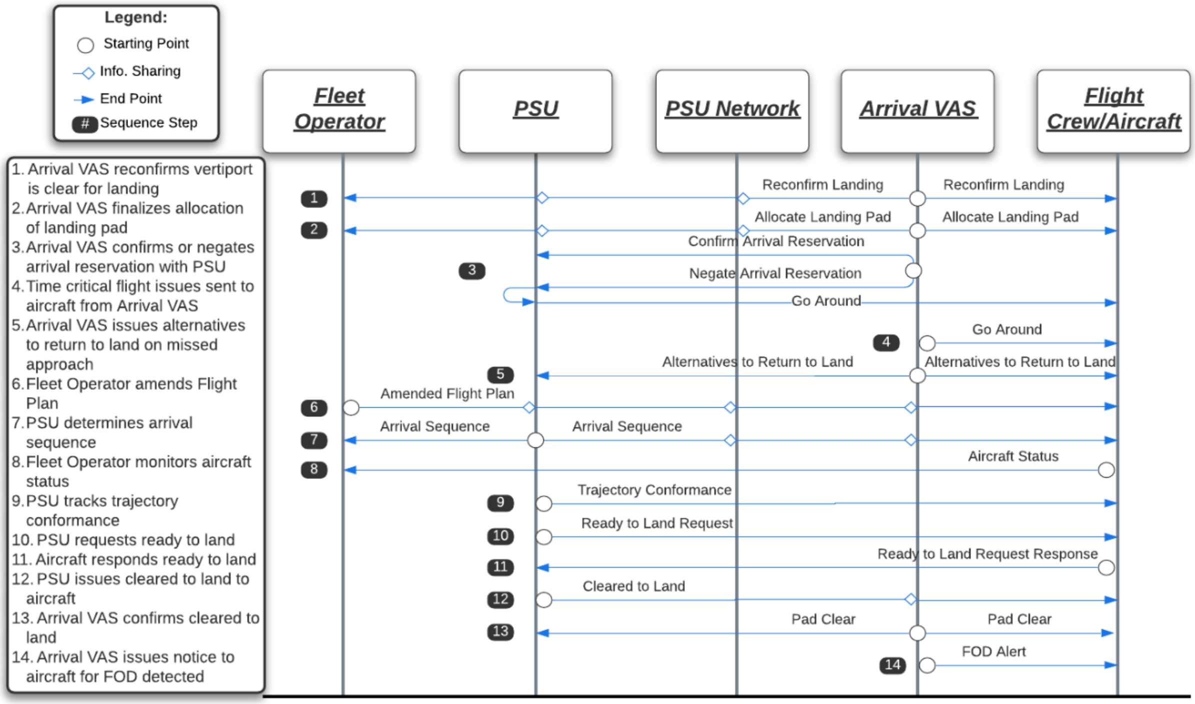

Figure 19: Approach Sequence Diagram

5.1.1.5 Land, Taxi, and Deplane

1) During the final phase of flight, the PSU and fleet operator track aircraft progress, and the aircraft and flight crew are responsible for navigating the approach and remaining clear of all other air traffic down to the landing pad.
    a) The arrival VAS confirms that a landing pad on the vertiport is clear and is ready for the arrival aircraft to land, and VAS provides this information to the PSU, fleet operator, aircraft, and flight crew.
    b) The PSU confirms to the aircraft that it is cleared for landing.
    c) Once cleared for landing, the aircraft or flight crew conducts a short safety briefing and confirms that the aircraft is ready for landing.
    d) The aircraft, flight crew, and VAS scan the landing area to confirm that there are no hazards.
    e) The aircraft and flight crew conduct a final system check and execute the landing.
2) The aircraft informs the arrival VAS, their fleet operator ground crew at the arrival vertiport, and the fleet operator when the landing is complete (wheels down or skids on a dolly).
    a) On arrival at of the aircraft at the landing pad, the arrival VAS sends a 4D surface trajectory to the aircraft for it to follow from the landing pad to the intended vertiport surface destination (gate, pad, charging station, or other designated parking area).

    i) The aircraft and flight crew then execute the arrival vertiport surface trajectory and maintain V2V and V2I data exchange and tactical deconfliction with other aircraft and obstacles encountered along the path.

b) The arrival VAS continuously monitors the vertiport surface for FOD, ground vehicles, ground personnel, and any other obstacles located on the vertiport surface.
    i) The arrival VAS monitors the aircraft taxi from the landing pad to the arrival vertiport destination, advising the aircraft of any issues that arise along the trajectory.

c) The arrival vertiport fleet operator ground crew assists the passengers as they deplane and ensures that they are safely distanced from the active areas on the vertiport.
    i) The passengers are safely guided into the terminal area, or, in the case of an automated operation, the aircraft doors are opened, and the passengers are instructed to follow the signage and lights for guidance into the terminal area.

d) The flight crew informs the arrival VAS that the aircraft is deplaned, and the arrival VAS coordinates the servicing of the aircraft with the ground crew through the MRO provider.
    i) If the aircraft requires repositioning on the vertiport surface for any of these services, the arrival VAS will issue a surface trajectory to the aircraft for the repositioning.
    ii) The aircraft and flight crew then execute the vertiport surface trajectory and maintain V2V and V2I data exchange and tactical deconfliction with other aircraft and obstacles encountered along the path.
    iii) The aircraft arrives at its desired location on the vertiport, and notifications are sent to VAS Data Management Service and to any city, state, or local officials requiring notification.

Figure 20 presents a sequence diagram for land, taxi, and deplane activities that are described in Section 5.1.1.5.

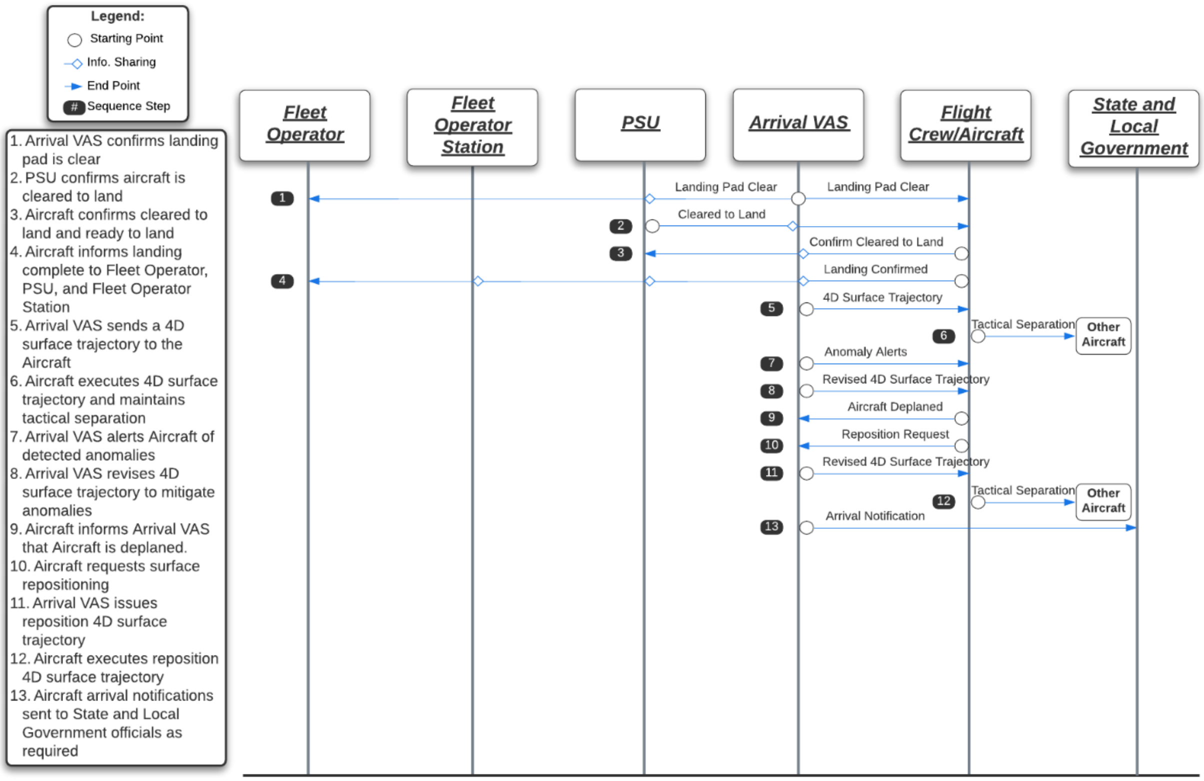

Figure 20: Land, Taxi, and Deplane Sequence Diagram

5.1.1.6 Variations of Nominal Passenger Scenario

5.1.1.6.1 Maintenance Required on Arrival

If an arriving aircraft requires maintenance on arrival, in general the passengers would be deplaned at the arrival gate and brought into the terminal as normal. Thereafter, the following would occur:

1) In the case of minor maintenance issues, the passengers would be processed at the gate, and the enplaning passengers would be held in the terminal until the maintenance activities are completed. Subsequently, the passengers would board as normal, and the flight would proceed to depart as described in the nominal scenario.
2) More substantial maintenance issues would require the aircraft to reposition to the maintenance hangar or facility on the vertiport (if available). The aircraft would be designated as out of service and would remain out of service until the required maintenance is performed and the aircraft is returned to service. The out-of-service time carries uncertainty, depending on the maintenance requirements.
   a) If a substitute aircraft is available for the next flight leg of the arriving aircraft, the new aircraft would be located at a gate awaiting passenger boarding, and the flight would continue as scheduled.
   b) In the absence of a substitute aircraft, the subsequent flight operation is cancelled, and the passengers would be redirected to other flights or transportation modes.

3) If there is no maintenance facility available at the vertiport, the aircraft would be repositioned from the gate to a parking pad or ramp until on-call maintenance personnel arrive to perform the requisite maintenance. The aircraft is designated out of service and would remain in that state until returned to service post maintenance.

5.1.1.6.2 Vertiport Aircraft Repositioning

As described in the case for aircraft maintenance, and as applicable for a variety of other events, the arriving aircraft, or any aircraft located on the vertiport surface, may require movement to another area of the vertiport. In this case:

1) The aircraft, flight crew, or the fleet operator's ground crew sends a request to the VAS to reposition the aircraft from its original position on the vertiport surface to another vertiport location.
2) Since this move is local to the vertiport, the PSU is not notified unless the aircraft had filed an operating plan for departure and that plan is cancelled.
3) The VAS checks the request and develops a trajectory for the movement of the aircraft on the surface. The trajectory may reflect an alternate time, depending on the requested start time for the movement and traffic conditions at the vertiport at the time of desired movement.
    a) If the movement is of an urgent nature, that condition would be contained in the request and the VAS would accommodate the urgency based on the priority assigned.
4) The surface trajectory is sent to the aircraft using a standardized format, and the aircraft follows the trajectory to its destination on the vertiport surface.
    a) If the aircraft can move under its own power, it will navigate the trajectory and the VAS will monitor the movement for conformance to the trajectory.
    b) If the aircraft is not capable of movement under its own power, a tug will be dispatched, connected to the aircraft if it is wheeled, and the VAS will send the trajectory to the tug and to the tug operator (if so configured). The VAS will monitor the movement of the tug and aircraft for conformance to the trajectory. If the aircraft has skids rather than wheels and is incapable of executing a hover taxi, the aircraft will require a motorized or towable dolly for movement on the vertiport surface. The motorized dolly will function like the robotic tug.

5.1.1.6.3 Long- or Short-Term Parking

If the arriving aircraft with passengers does not choose to arrive at a passenger gate, but seeks long- or short-term parking at the vertiport, then:

1) The initial operating plan filed by the FOCC or aircraft operator would have contained the request for long- or short-term parking, including estimated parking duration, and that request would have been considered by the VAS in approving the arrival reservation.
2) The trajectory provided by the VAS on arrival of the aircraft would indicate the designated long- or short-term parking pad as the vertiport destination for the aircraft, and the aircraft would follow that surface trajectory (generated by the Surface Trajectory Service) as described in the nominal scenario.

5.1.1.6.4 Refueling or Charging Request on Arrival

If an arriving aircraft requires refueling or charging, this service request would be present in the initial or amended flight plan filed for the arrival flight and approved and reserved by the vertiport, including the duration of the refueling or charging service to be provided. The vertiport may be configured in two ways, such that:

1) The fueling or recharging service can be performed at the gate or parking destination on the vertiport.
   a) In this case, the aircraft would not require repositioning, and the service would be performed in situ. The duration of the service would be accounted for in the reservation.
2) The aircraft must be repositioned to avail itself of the refueling or charging services.
   a) In this case, the aircraft would be repositioned as described above, and the duration of both the repositioning and fueling service would be considered in the aircraft's reservation at the vertiport.

5.1.2 Cargo Gate-to-Gate

All fleet operators must receive a performance authorization from the FAA to operate in a UOE. This performance authorization covers specific aircraft, flight crew, and operations. Once authorized, the fleet operator stays within the bounds of what has been authorized under an honor system arrangement.

In the case of cargo operations, all operations, including the aircraft, fleet operator, cargo facility at the vertiport, fleet operator's ground crew (cargo handlers) at the vertiport, and the vertiport manager, must abide by the Federal Hazardous Materials Regulations (49 CFR Part 171 through 180) for any cargo containing hazardous materials for transportation by aircraft.

This section follows the Passenger Gate-to-Gate scenario presented in Section 5.1.1, describing only steps in the scenario that are different for cargo operations. All other steps are the same as those identified in Section 5.1.1.

5.1.2.1 Pre-flight

Steps 1 to 3 are identical to the Passenger Gate-to-Gate scenario presented in Section 5.1.1.1.

4) As cargo arrives at the vertiport, it is processed through the vertiport cargo operation, appropriately screened by vertiport security personnel, checked for proper shipping documentation and packaging, and checked for Hazmat contents before being moved to the cargo loading area. For particularly hazardous material, the VAS ensures that the aircraft has additional separation and is routed away from the passenger terminal to a parking location that is safe for hazmat handling.

   a) Once the aircraft is in the cargo loading area, the cargo facility's agents provide the cargo manifest to the fleet operator's agents and the flight crew, and an aircraft loading plan is generated prior to any cargo being loaded onto the aircraft. Once the agents and flight crew approve the loading plan and verify that cargo documentation meets regulations, the cargo is loaded onto the aircraft.

Step 5 is identical to the Passenger Gate-to-Gate scenario presented in Section 5.1.1.1.

6) With the cargo onboard, the flight crew addresses any issues or needs either in person or remotely and advises the fleet operator's agents and the cargo agents as to the disposition of the cargo during the maintenance operation. The cargo handlers will offload the cargo if it needs to be offloaded.

Steps 7 and 8 are identical to the Passenger Gate-to-Gate scenario presented in Section 5.1.1.1.

5.1.2.2 Taxi for Takeoff

All steps are identical to the Passenger Gate-to-Gate scenario presented in Section 5.1.1.2.

5.1.2.3 Climb and Cruise

All steps are identical to the Passenger Gate-to-Gate scenario presented in Section 5.1.1.3.

5.1.2.4 Approach

Steps 1 to 7 are identical to the Passenger Gate-to-Gate scenario presented in Section 5.1.1.4.

8) The aircraft executes the approach procedure and sequencing. maintaining V2V and V2I data exchange as necessary to execute tactical deconfliction using onboard DAA capabilities as it approaches the arrival vertiport,

5.1.2.5 Land, Taxi, and Unload

Step 1 is identical to the Passenger Gate-to-Gate scenario presented in Section 5.1.1.5.

2) The aircraft informs the arrival VAS, the fleet operator's ground crew at the arrival vertiport, and the fleet operator when the landing is complete.
    a) On arrival of the aircraft on the landing pad, the arrival VAS sends a surface trajectory to the aircraft for it to follow from the landing pad to the intended vertiport surface destination (gate, pad, charging station, or other parking designated area).
        i) The aircraft, remote flight crew, or onboard flight crew then executes the arrival vertiport surface trajectory and maintains V2V and V2I data exchange and tactical deconfliction with other aircraft and obstacles encountered along the path.
    b) The arrival VAS continuously monitors the vertiport surface for FOD and any obstacles incorrectly located on the vertiport surface.
        i) The arrival VAS monitors the aircraft taxi from the landing pad to the gate (arrival vertiport destination), advising the aircraft of any issues that arise along the trajectory.
        ii) The arrival vertiport manager, the fleet operator ground crew, or the air cargo ground crew review the cargo manifest and the ground crew unloads the cargo from the aircraft to the cargo area on the loading dock or within the cargo building.
        iii) The aircraft has been unloaded of its cargo and may now be loaded with new cargo or dispatched to another location, as required.

c) The aircraft and flight crew inform the arrival VAS that the aircraft is unloaded, and the arrival VAS coordinates the servicing of the aircraft with the ground crew through the MRO provider.

   i) If the aircraft requires repositioning on the vertiport surface for any of these services, the arrival VAS will issue a surface trajectory to the aircraft for the repositioning.

   ii) The aircraft and flight crew then execute the vertiport surface trajectory and maintain V2V data exchange and tactical deconfliction with other aircraft and obstacles encountered along the path.

3) The aircraft arrives at its desired location on the vertiport.

5.1.2.6 Variations of Nominal Cargo Scenario

5.1.2.6.1 Maintenance Required on Arrival

If an arriving aircraft requires maintenance on arrival, the following will occur:

1) In the case of minor maintenance issues, cargo would be processed at the cargo ramp, and the cargo may be held on the aircraft or unloaded, depending on the nature of the cargo and the maintenance required, until the maintenance activities are completed. Additional cargo could then be loaded as normal, and the flight would proceed to depart as described in the nominal scenario.

2) More substantial maintenance issues would require the aircraft to reposition to the maintenance hangar or facility on the vertiport (if available). The aircraft would be designated as out of service and would remain out of service until the required maintenance is performed and the aircraft is returned to service. The out-of-service time carries uncertainty, depending on the maintenance requirements.

   a) If a substitute aircraft is available for the next flight leg of the arriving aircraft, the new aircraft would be located (or relocated) at the cargo ramp awaiting the loading of cargo, and the flight would continue as scheduled.

   b) In the absence of a substitute aircraft, the subsequent flight operation is cancelled, and the cargo load would be redirected to other flights or transportation modes.

3) If there is no maintenance facility available at the vertiport, the aircraft would be unloaded and then repositioned from the cargo ramp to a parking pad or ramp until on call maintenance personnel arrive to perform the requisite maintenance. The aircraft is designated out of service and would remain in that state until returned to service post maintenance.

5.1.2.6.2 Vertiport Aircraft Repositioning

As described in the case of passenger aircraft maintenance, and as applicable for a variety of other events, the arriving aircraft, or any aircraft located on the vertiport surface, may require movement to another area of the vertiport. The scenario for this movement follows that of a passenger aircraft as described in Section 5.1.1.6.2.

5.1.2.6.3 Long- or Short-Term Parking

If the arriving aircraft with cargo does not choose to arrive at the cargo terminal, but seeks long- or short-term parking at the vertiport, then:

1) The initial operating plan filed by the FOCC or aircraft operator would have indicated the request for long- or short-term parking, including an estimated parking duration, and that request would have been considered by the VAS in approving the arrival reservation.
2) The trajectory provided by the VAS on arrival of the aircraft would indicate the designated long- or short-term parking pad as the vertiport destination for the aircraft, and the aircraft would follow that trajectory as described in the nominal scenario.

5.1.2.6.4 Refueling or Charging Request on Arrival

If an arriving aircraft requires refueling or charging, this service request would be present in the initial or amended flight plan filed for the arrival flight and approved and reserved by the vertiport VAS Vertiport Resource Management and Scheduling Service, including the duration of the refueling or charging service provided. The vertiport may be configured in two ways, such that:

1) The fueling or recharging service can be performed at the cargo ramp or parking destination on the vertiport.
    a) In this case, the aircraft would not require repositioning, and the service would be performed in situ. The duration of the service would be accounted for in the reservation.
2) The aircraft must be repositioned to avail itself of the refueling or charging services.
    a) In this case, the aircraft would be repositioned as described above, and the duration of both the repositioning and fueling service would be considered in the aircraft's reservation at the vertiport.

5.1.3 Mixed Passenger and Cargo Gate-to-Gate

In this scenario, the aircraft carry a mixed load consisting of passengers and cargo. The air medical business case is a typical example, where medical personnel and medical equipment or other medical related cargo are transported from one medical facility to another. In the case of any medical cargo operations, all operations including the aircraft, fleet operator, cargo handling at the departure and arrival vertiports, and vertiport manager and its employees must abide by the Federal Hazardous Materials Regulations (49 CFR Part 171 through 180) for handling any cargo containing hazardous materials (dangerous goods) for transportation by aircraft.

All fleet operators must receive a performance authorization from the FAA to operate in a UOE. This performance authorization covers specific aircraft, flight crew, and operations. Once authorized, the fleet operator stays within the bounds of what has been authorized under an honor system arrangement.

This section follows the Passenger Gate-to-Gate Scenario presented in Section 5.1.1, describing only steps in the scenario that are different for cargo operations. All other steps are the same as those identified in Section 5.1.1, as noted in each subsection.

5.1.3.1 Pre-flight

Steps 1 to 3 are identical to the Passenger Gate-to-Gate presented in Section 5.1.1.1.

2) As personnel and passengers arrive at the vertiport, they are processed through pre-boarding by the fleet operator’s staff and appropriately screened by vertiport security personnel. Passengers are directed to further processing (queuing) prior to boarding. In the case of a medical use case or any other intra-company transfer of people and goods, the passengers’ company identification is scanned to ensure that they have proper credentials to travel on the flight. Any cargo for the flight would have been either loaded prior to passenger boarding, or carried on board by one or more passengers, or loaded after passengers are boarded. It is expected that the cargo requirements would not necessitate loading at a cargo terminal and then relocation of the aircraft to a passenger terminal for passenger boarding. However, that scenario can be accommodated if necessary.
    a) Once in the boarding area, the fleet operator’s agents provide the passengers with a full boarding safety briefing prior to boarding their aircraft. Once boarded on the aircraft, a pre-flight safety briefing is provided either fully automated through a video or supported by the flight crew members, if onboard.

Steps 5 to 8 are identical to the Passenger Gate-to-Gate presented in Section 5.1.1.1.

5.1.3.2 Taxi for Takeoff

All steps are identical to the Passenger Gate-to-Gate presented in Section 5.1.1.2.

5.1.3.3 Climb and Cruise

All steps are identical to the Passenger Gate-to-Gate presented in Section 5.1.1.3.

5.1.3.4 Approach

All steps are identical to the Passenger Gate-to-Gate presented in Section 5.1.1.4.

5.1.3.5 Land, Taxi, and Deplane

Steps 1 and 2 (a-c(i)) are identical to the Passenger Gate-to-Gate presented in Section 5.1.1.5.

        ii) Any cargo onboard the aircraft is either carried by the passengers or offloaded by the ground crew at the gate. If the cargo requires offloading at the cargo terminal on the vertiport, the aircraft will be repositioned to the cargo ramp after passengers have deplaned and are safely located in the terminal.

    d) The aircraft and flight crew informs the arrival VAS that the aircraft is deplaned, and cargo is unloaded, and the arrival VAS coordinates the servicing of the aircraft by the ground crew through the MRO.

i) If the aircraft requires repositioning on the vertiport surface for any of these services, the arrival VAS will issue a surface trajectory to the aircraft for the repositioning.

ii) The aircraft, remote flight crew, or onboard flight crew then executes the vertiport surface trajectory and maintains V2V and V2I data exchange, as well as tactical deconfliction with other aircraft and obstacles encountered along the path.

3) The aircraft arrives at its desired location on the vertiport.

5.1.3.6 Variations of Nominal Mixed Passenger and Cargo Scenario

5.1.3.6.1 Maintenance Required on Arrival

If an arriving aircraft requires maintenance on arrival, in general the passengers would be deplaned at the arrival gate and brought into the terminal as normal. In some cases, the cargo may be offloaded by either the passengers or the ground crew. Thereafter, the following would occur:

1) Minor maintenance issues would be taken care of at the gate, and any enplaning passengers and cargo would be held in the terminal until the maintenance activities are completed. Subsequently, the passengers would board as normal, the cargo would be loaded by either the passengers or ground crew, and the flight would proceed to depart as described in the nominal scenario.

2) More substantial maintenance issues would require the aircraft to reposition to the maintenance hangar or facility on the vertiport (if available). The aircraft would be designated as out of service and would remain out of service until the required maintenance is performed and the aircraft is returned to service. The out-of-service time carries uncertainty of the maintenance requirements.

   a) If a substitute aircraft is available for the next flight leg of the arriving aircraft, the new aircraft would be located at a gate awaiting passenger boarding and cargo loading, and the flight would continue as scheduled.

   b) In the absence of a substitute aircraft, the subsequent flight operation is cancelled, and the passengers and cargo would be redirected to other flights or transportation modes.

3) If there is no maintenance facility available at the vertiport, the aircraft would be repositioned from the gate to a parking pad or ramp until on-call maintenance personnel arrive to perform the requisite maintenance. The aircraft would be designated out of service and would remain in that state until returned to service post-maintenance.

5.1.3.6.2 Aircraft Repositioning

As described in the case for aircraft maintenance, and as applicable for a variety of other events, the arriving aircraft or any aircraft located on the vertiport surface may require movement to another area of the vertiport. In this scenario, the steps for repositioning are those described for passenger aircraft in Section 5.1.1.6.2.

5.1.3.6.3 Long- or Short-Term Parking

If the arriving aircraft with passengers and cargo does not choose to arrive at a passenger or cargo gate but seeks long- or short-term parking at the vertiport, then:

1) The initial operating plan filed by the FOCC or aircraft operator would have indicated the request for long- or short-term parking, including estimated parking duration, and that request would have been considered by the VAS in approving the arrival reservation.
2) The trajectory provided by the VAS on arrival of the aircraft would indicate the designated long- or short-term parking pad as the vertiport destination for the aircraft, and the aircraft would follow that trajectory as described in the nominal scenario.

5.1.3.6.4 Refueling or Charging Request on Arrival

If an arriving aircraft requires refueling or charging, this service request would be present in the initial or amended flight plan filed for the arrival flight and approved and reserved by the vertiport, including the duration of the refueling or charging service. The vertiport may be configured in two ways, such that:

1) The fueling or recharging service can be performed at the gate or parking destination on the vertiport.
   a) In this case, the aircraft would not require repositioning, and the service would be performed in situ. The duration of the service would be accounted for in the reservation.
2) The aircraft must be repositioned to avail itself of the refueling or charging services.
   a) In this case, the aircraft would be repositioned as described above, and the duration of both the repositioning and fueling service would be considered in the aircraft's reservation at the vertiport.

5.2 Off-Nominal Scenarios

The off-nominal scenario vignettes that appear in this section are variations on the three nominal scenarios presented earlier. That is, the nominal scenario can be exercised as described, but the presence of an off-nominal condition can be injected in an appropriate segment of the nominal scenario. The off-nominal events would replace the events in the nominal scenario until a return to nominal operations.

Off-nominal vignettes described in Section 5.2.1 are:

1) Aircraft Arrival at Vertiport with Missed Approach in the Presence of Severe and Quickly Changing Vertiport Weather Conditions
2) Late or Early Arrival at Vertiport with Reservation Negotiation
3) Vertiport Infrastructure Failure
4) Communications Failure Between the Vertiport, PSUs, Fleet Operators, Aircraft and Flight Crew, or ATC
5) Physical or Cybersecurity Breach on the Vertiport
6) Vertiport Contingencies

7) Control by Exception
8) Aircraft Contingency or Aircraft Failure
9) Passenger in Distress
10) Non-Cooperative Aircraft
11) Loss of Navigation
12) Emergency Landing at Vertiport
13) Aircraft Crash on Arrival at Vertiport
14) Physical Infrastructure Emergency
15) All Aircraft Land
16) Pre-Approved Procedure

Section 5.2.2, Resource Constraints, describes several scenarios that are associated with or generate constraints on vertiport resources:

1) Aircraft Based at Vertiport
2) Mixed Equipage
3) Environmental Impact Mitigation
4) Vertiport Traffic Flow Changes Due to Traffic Flow at a Nearby Airport or Other Vertiport
5) ATC Airspace Flow Control and Restrictions

5.2.1 Off-Nominal Scenario Vignettes

5.2.1.1 Aircraft Arrival at Vertiport with Missed Approach in the Presence of Severe and Quickly Changing Vertiport Weather Conditions

As an aircraft approaches the arrival vertiport, the following events occur:

1) The arrival VAS monitors the aircraft flight status and determines when the aircraft is in range of the vertiport.

2) As the aircraft begins its approach to the arrival vertiport, the arrival VAS commences its monitoring, reconfirms that the vertiport is clear for aircraft landing, finalizes the allocation of the landing pad, and shares that information with the PSU, aircraft, fleet operator ground crew, and flight crew, as appropriate, using the Hazard Identification Service, Risk Assessment Service, and the VA_SDSP Interface for information transfer.

3) As the aircraft approaches the arrival vertiport, a weather event takes place on or near the vertiport. This event could be one of a large set of weather conditions that include: (1) a wind shift that causes significant orographic turbulence at the landing pad, (2) the presence of a microburst over the landing pad or vertiport, (3) sudden reduction in visibility to below minimums at the landing pad due to fog, or (4) other meteorological conditions that negate the possibility of a successful landing.

    a) If the weather event occurs suddenly and the aircraft is within the VPV of the arrival vertiport, the arrival VAS will directly notify the aircraft through the VA-SDSP Interface of the conditions detected by the Hazard Identification Service and Risk Assessment Service, and allow the aircraft and flight crew to determine the desired course of action. If the aircraft and flight crew decide to execute a missed approach, they will inform the PSU Network, who will inform VAS of the missed approach decision.

i) The arrival VAS will monitor the aircraft to assure that a missed approach is in progress and will confirm with the PSU that the aircraft is executing a missed approach.

b) If the aircraft approaching the vertiport is outside the VPV or not on its final approach to the landing pad, the arrival VAS can alert the aircraft of the detected weather phenomena through the PSU, since there is adequate time to implement missed approach instructions or whatever course of action is determined to be delivered to the aircraft by the PSU.

4) The aircraft executes the published missed approach procedure.

5) The determination of follow-on activities after the missed approach involves collaboration between the fleet operator, flight crew, PSU, Weather SDSP, and, potentially, the arrival vertiport.

6) If the weather condition is brief and conditions are expected to improve rapidly, the aircraft may desire to attempt another approach in the near term.

a) The PSU can broker a new arrival time for the aircraft with the arrival VAS, and this option may offer alternatives for the flight operation that would adjust the prior arrival reservation in accordance with the current vertiport status.

i) If the arrival vertiport resources are fully booked and are therefore constrained, the PSU can broker negotiations between the fleet operator and the arrival VAS. In this case, the arrival vertiport may be able to accommodate the aircraft arrival through prioritization of its resources. In the negotiation process, the arrival vertiport may offer alternatives for the re-arrival of the aircraft.

b) The PSU, flight crew, and fleet operator can accept one of the alternatives offered, propose a new alternative, change the priority for this arrival vertiport, or choose to land at an alternate destination.

7) Subsequent to the negotiated re-arrival resolution, the flight plan will be amended in accordance with the resolution and the aircraft will follow its new flight plan and trajectory at the completion of the missed approach or as directed by the PSU and reflected in the flight plan and trajectory.

8) If the aircraft is returning to land at the original arrival vertiport, the PSU determines a new arrival sequence based on the current aircraft timing, updates the landing information, and communicates the updates to the arrival VAS, fleet operator, aircraft, and flight crew.

9) The aircraft resumes its approach as in the nominal case.

5.2.1.2 Late or Early Arrival at Vertiport with Reservation Negotiation

An aircraft departs one vertiport, travels en route to another vertiport, and lands at the arrival vertiport. With the projected traffic densities, the airspace and vertiport reservations are timed, and the accuracy of the windows in time will need to be precise. There may be some tolerance in timing; for example, if an arrival reservation is scheduled for 10:32 Zulu (Z), the window reserved may run from 10:31 Z to 10:33 Z. When the aircraft cannot meet the time window, there will be a need for renegotiation of the arrival reservation with the arrival vertiport. The number of alternatives and options for the renegotiation will depend on many considerations, and the further in advance that the aircraft, fleet operator, and PSU recognize the need to negotiate, the more options may be available for a solution.

In this scenario, the aircraft operation was approved prior to departure and the flight plan was filed. A 4D trajectory was created for the flight operation, and this trajectory was shared with the appropriate stakeholders, and the appropriate airspace and vertiport resources have all been reserved and committed by the appropriate stakeholders.

1) The flight has departed and is en route, managed by the PSU. As the flight progresses, the winds encountered differ from the winds used to develop the 4D trajectory. The trajectory deviation has been monitored by the PSU, aircraft and flight crew, and FOCC. In addition, progress along the trajectory has been monitored by the arrival vertiport through the PSU Network.
2) The stakeholders have now determined that the aircraft cannot meet the arrival reservation window, being either too early or too late. Changing the aircraft speed to compensate for the winds is not adequately effective, and the arrival reservation will need to be changed.
3) A negotiation is activated between the fleet operator and the arrival vertiport, using the PSU as the broker.
4) The goal of the fleet operator, in consultation with the aircraft and flight crew, is to negotiate an achievable revised reservation window.
5) The goal of the arrival vertiport is to accommodate the revised reservation window, but not to the extent of jeopardizing the current vertiport resource plan and allocation. The number of options may thus be limited, depending on the traffic density at the arrival vertiport.
6) The PSU, acting as broker, contacts the arrival vertiport VAS and initiates negotiations for a revised arrival reservation time. The initial offering from the fleet operator would be to request a revised arrival time based on projection of the current trajectory given the wind error corrections.
7) The PSU proposes the revised arrival and vertiport reservation times, the arrival vertiport checks the revised arrival and reservations times against its available resources and their scheduled use, and determines either:
    a) If the revised arrival time is compatible with the arrival vertiport resource schedule, the negotiations close and the trajectory and flight plan are revised from the original arrival reservation. The flight continues along the revised trajectory and arrives in the nominal manner.

b) If the revised arrival time is not compatible with the arrival vertiport resource schedule and the arrival vertiport cannot accommodate the revised trajectory; depending on the arrival vertiport resource load, several alternatives are available for the negotiations:
   i) The trajectory is altered to meet an available arrival reservation slot. This option might work for an early arrival, where the aircraft can slow its speed to lose time and meet the original trajectory. This solution might be more difficult if the aircraft is late, but it could work if there is a later arrival slot available.
   ii) The parameters of the trajectory alteration above exceed the available capabilities of the aircraft based on fuel, power, or battery reserve. In this case, the aircraft may be forced to choose an alternate arrival vertiport where an open reservation is available. The fleet operator would have planned for these contingencies during its flight planning activity, and the PSU would broker this negotiation based on the desires of the fleet operator. If a successful alternate is found, the flight plan is altered, and the aircraft flies the revised trajectory and arrives at the alternate vertiport in a nominal manner. The fleet operator would deal with relocating the passengers or cargo from the new arrival vertiport, as required.

c) If the original arrival vertiport is booked and cannot accommodate the revised trajectory, a form of prioritization may be possible whereby the arrival vertiport can adapt other booked reservations to accommodate the flight in question if the flight in question has a higher priority than the booked reservation that it bumps. Section 5.2.2 presents additional discussion of this option.

5.2.1.3 Vertiport Infrastructure Failure

Providing services that allow the safe, expeditious flow of traffic into, on, and from the vertiport requires many systems, sensors, and guidance devices. This scenario examines the effects of failures in weather sensors, surface navigation equipment, vertiport approach and departure surveillance and navigation equipment, vertiport signs, lights, RF tags, in-ground loops, and other sensors associated with the vertiport operations. Failure of any single sensor or equipment may result in the loss of use of a vertiport resource, such as a parking pad, a gate, or even an approach to a landing pad. The impact of such failures can be short lived or long lasting, depending on the time interval required to recognize the occurrence of a failure, determine the cause of the failure, and repair the failure. In some cases, there may be redundant equipment that switches into service immediately on failure of equipment. In other cases, such as sensors or loops buried under the concrete parking pads, repair time can be extensive.

Effectively, all such failures have the following potential outcomes:

1) The use of the resource is lost during the outage.
   a) The VAS must adjust its resource list to reflect that the resource is not available. Any reservations for that resource during the projected time of the outage must be cancelled. If there are aircraft in flight with reservations for the resource, then either spare resources must be assigned or negotiations for resource reservations must be conducted.
2) A significant reduction of vertiport services occurs:

a) For example, a large vertiport having arrival and departure pads on the east and west side of the vertiport, with numerous parking pads located in the middle, loses power to one side of the vertiport. All power is lost for the west side arrival and departure pads and half of the parking pads. Vertiport maintenance has been called and estimated repair time is two hours.
b) The VAS must reschedule the resources that are affected by the power outage over the next two hours.
c) For aircraft on final approach, the VAS may issue missed approach orders until the plan is revised.
d) Departing aircraft may need to hold at the gate or parking pad until the replan is completed.
e) The replan is negotiated with the holders of each affected flight reservation and may include prioritization or use of alternate vertiport assets.
f) The replan is executed.
g) Upon completion of the repairs, the vertiport resumes normal operations.

Communications between external nodes, including PSUs, fleet operators, aircraft and flight crew, and ATC (if the aircraft traverses ATC airspace), is critical, and the communications infrastructure must be designed for extremely high availability to prevent failure of the network. Nevertheless, certain rules are established to deal with such failures.

1) A communications failure between the aircraft and the PSU, VAS, or ATC would follow the same procedure as established for contemporary ATC.[78]
2) The aircraft would follow its last updated trajectory, and the PSU, VAS, and ATC would continue to monitor the aircraft for trajectory compliance until the flight operation is completed.
3) If the aircraft does not appear to be following its last updated trajectory, the PSU, VAS, and ATC will continue to track and monitor the aircraft movement, providing separation as possible between the aircraft and other traffic.
4) If the aircraft does not conform to its trajectory, it will be treated as a nonconforming aircraft and appropriate authorities will be alerted.
5) A communication failure between the PSU and the VAS, as well as loss of ATC communications, would be resolved as follows:
   a) Mandatory backup mechanisms for communication, such as fault tolerant links, rerouting communications pathways, and use of other communications capabilities, to reestablish communications with the aircraft.
   b) The development of a comprehensive contingency plan that would use other PSUs to back up failed PSUs, other ATC facilities to back up failed ATC facilities, and, potentially, light signals at vertiports to communicate with aircraft if flight crews are onboard the aircraft.

[78] CFR Title 14§91.185

c) The use of light signals from the vertiport to the aircraft is feasible only if there is a flight crew on board the aircraft. Remote pilots and autonomous aircraft would require the vertiport to use another communication path to establish communications with the remote pilot or the autonomy equipment.

5.2.1.4 Physical or Cybersecurity Breach on Vertiport

The normal operation of a vertiport requires both physical and cybersecurity. Physical security around the perimeter of the vertiport is critical to eliminating threats from nefarious acts and can be achieved by a physical barricade (a fence or a wall) and by electronic surveillance capable of detecting intruders. Within the confines of the vertiport, access will be limited and controlled by physical barriers and will depend on the security level of the person requiring access to the contained area of the vertiport complex.

Cybersecurity is a system-wide VAS issue and is increasingly critical due to growing reliance on automation. Moving the human element of the VAS from the center of the decision loop to supervision from the edge impairs the capability for humans to detect cyberattacks. Cyberattacks must be both prevented by the system design and detected and resolved by the VAS should the protective measures fail.

In the case of a vertiport physical intrusion scenario, a rogue agent (person or object) has penetrated the perimeter and is moving toward a restricted location. The detection of the intrusion and tracking of the intruder would be accomplished by the vertiport security SDSP. The VAS would be notified of the intrusion and, depending on the location of the intruder and the presumed intentions of the intruder, the VAS would react as follows:

1) If the intruder is within the non-movement area of the vertiport and is presumed to be focused on the non-movement area, the VAS would alert all aircraft and personnel located on or within the movement area. However, no action would be taken beyond the alert.
    a) The alert would notify the aircraft and personnel of a potential threat and instruct them on what actions they should begin in accordance with current aviation security policy and guidelines. The VAS would update the alert as the situation progresses.
2) If the intruder appears to have targeted a location on the movement area, the VAS alerts all aircraft and personnel on or within the movement area with an explicit warning of imminent danger. In this case, an aircraft might halt in its present position, ensure that entry into the aircraft is prevented, and take evasive action as required. Personnel on the movement area would take shelter as best they can until security forces neutralize the threat.
    a) Arriving aircraft are given missed approach orders and their arrival would be delayed or deferred as necessary to address the vertiport security situation. The expected time of arrival would be negotiated with the aircraft and fleet operator through the PSU.
    b) Departing aircraft are alerted and allowed to depart if possible, based on the nature and location of the threat.

c) Aircraft in taxi status are alerted and told either to stop or to continue along their original or a modified trajectory, depending on the location and nature of the threat on the vertiport movement area.

d) Parked aircraft at gates, parking pads, and ramp areas are alerted and informed by the VAS of the nature and location of the threat.

5.2.1.5 Vertiport Contingencies

Vertiport contingencies include vertiport closure, closure of one or more arrival and departure pads, and closure of a UOE by the FAA. Note that closure of a UOE in the vicinity of a vertiport effectively closes the vertiport unless the airspace closure is only partial, in which case the vertiport may have some remaining operational capability. Thus, this scenario results in one of the following situations:

1) The vertiport is completely closed.
   a) In this case, the VAS stops all departures for the duration of the closure. The affected departure flight plans are renegotiated with the affected FOCC through the PSU. Nominal departure operations restart at the end of the closure period and in accordance with the revised flight plans and trajectories.
   b) For arriving aircraft, the PSU, VAS, and ATC will negotiate the plan for active aircraft en route to the destination vertiport prior to the closure of the airspace, or the procedure for closure of the airspace will be established in a letter of agreement between these entities.
   c) For aircraft on approach to the vertiport, VAS will notify the PSU of the closure, and any arriving aircraft will be either rerouted by the PSU or ordered to execute a missed approach by the VAS, and then rerouted by the PSU. In either case, the aircraft flight plans will be renegotiated through the PSU with the closed vertiport or alternate vertiports.
   d) Aircraft in taxi mode will be given specific parking instructions by the VAS and, in the case of departures, their flight plans will be terminated and resubmitted for a new departure time as discussed in a) above. Arriving flights that are taxiing will be directed to the appropriate gate, as required.
2) The vertiport is partially closed.
   a) Depending on the vertiport resources affected, the VAS will close those resources in its resource database for the duration of the closure, so they will not be available for use.
   b) Closure of any resources that were scheduled for use will result in negotiations between the VAS and the fleet operator through the PSU Network for resolution.
   c) Aircraft that are active and have not arrived at the destination vertiport at time of closure will require negotiations among the PSU Network, ATC, and VAS with respect to the FAA airspace closure. Such aircraft may be allowed to continue for arrival or will be rerouted by the PSU as appropriate to the resulting agreement among the PSU, ATC, and VAS, or as dictated by the letter of agreement between the PSU, ATC, and VAS that covers this situation.

5.2.1.6 Control by Exception

Control by exception is a concept used in the context of a human overseeing automation. As UAM stakeholders, such as the aircraft, PSU, VAS, and other SDSPs become more automated and move toward autonomy, the human is pushed further out of the loop, and a state is reached wherein the system deals with the situation it is controlling until an exception is generated. An exception is a situation that the automation is not designed to process, or a condition where the automation is failing, or a condition that was designed into the system as designated for human intervention. On generation of the exception, the human is responsible for resolution of the exception.

The most significant issue in control by exception is how the human in an oversight role reverts to a role in the loop to solve the exception-level problem. Exceptions often represent critical problems that are likely complex in their nature, and the expectation is that the human goes from a high-level oversight task to involvement in system details to resolve a critical problem with little time to find a solution.

The operation of an aircraft int the vertiport environment where separation of the aircraft from structures, terrain, and other aircraft requires precise control of the aircraft affords small tolerance for error. This situation is amplified by increased traffic volumes, where aircraft operate in close proximity to meet the vertiport demand. In this case, the aircraft is charged with precisely navigating the approach path, detecting and avoiding other aircraft as well as static and dynamic obstacles, and configuring the aircraft for landing. The PSU is charged with monitoring the conformance of the aircraft, as well as all aircraft in its charge) as it traverses its trajectory. The VAS is charged with monitoring the aircraft as it lands and then providing a post-arrival trajectory for the aircraft to traverse to reach its destination on the vertiport surface. The VAS also monitors the aircraft as it moves across the vertiport surface.

In this UML-4 scenario, as the actions to achieve the desired outcomes become more autonomous, with humans overseeing the automation, an exception can occur anywhere in the chain of events associated with the aircraft's approach to the vertiport. If the aircraft strays off the trajectory as it approaches the landing pad at the vertiport, the system could automatically command the aircraft to return to its trajectory and the aircraft could comply, resulting in a normal landing. However, it the aircraft does not respond to the command and continues to exceed the error tolerance of the trajectory, the system would declare an exception and a human pilot would be called on to restore the aircraft to its trajectory or to resolve the issue by commanding the aircraft to execute a missed approach.

5.2.1.7 Aircraft Contingency or Aircraft Failure

An aircraft operating in the vicinity of or directly on a vertiport may experience a malfunction. This malfunction might be insignificant in terms of the aircraft's ability to complete its mission safely and successfully, and the monitoring PSU and VAS might not be aware that the malfunction is present. Conversely, in this scenario the malfunction may be cause for the aircraft to alter its trajectory, in either a precautionary or an emergency sense.

1) Precautionary

a) The aircraft and flight crew notifies the PSU that it requires a specific deviation from its trajectory due to a malfunction.
b) The PSU examines the request, checks for availability of the airspace requested, and then grants the aircraft permission to depart from its trajectory.
    i) The PSU amends the trajectory to reflect the excursion.
    ii) The PSU notifies the PSU Network and the arrival VAS of the trajectory deviation and its status.
c) The arrival VAS determines the effect of the aircraft trajectory excursion on its resource plan and specifically on the aircraft's resource reservations.
d) If the reservation tolerance window is exceeded by the excursion, then the reservation will be cancelled and renegotiated between the fleet operator and VAS through brokerage by the PSU.
e) If resources are available in the negotiations, the aircraft's reservations are confirmed in accordance with the modified trajectory.
f) If the vertiport resources are not negotiated, then the aircraft must seek alternative vertiport resources and its trajectory is modified accordingly.

2) Emergency
    a) The aircraft and flight crew notifies the PSU that it is declaring an emergency and requires a specific deviation from its trajectory due to a malfunction.
    b) The PSU examines the specific request and assures the availability of the airspace requested, allowing the aircraft to depart from its trajectory.
        i) The PSU amends the trajectory to reflect the excursion, the status of the aircraft is set to emergency, and the aircraft is given emergency priority.
        ii) The PSU notifies the PSU Network and the arrival VAS of the aircraft status and its trajectory deviation.
    c) The arrival VAS determines the effect of the aircraft trajectory excursion on its resource plan and specifically on the aircraft's resource reservations.
    d) Since the aircraft is in an emergency status, the VAS holds the scheduled reservation open for the aircraft's use should that now be required.
    e) If the emergency aircraft has determined that the arrival vertiport remains its destination, the VAS takes the following actions:
        i) Hold the prior reservation.
        ii) Allocate any other resources at its disposal to the arriving emergency aircraft.
        iii) Alert fire and rescue of the emergency arrival.
        iv) Assure that all other traffic and operations will yield to the emergency aircraft.
        v) Negotiate revised trajectories and resource reservations with all affected fleet operators through the PSU Network as required to accommodate the emergency.

5.2.1.8 Passenger in Distress

From an operational perspective, a passenger in distress is like an aircraft contingency. An aircraft operating in the vicinity of or directly on a vertiport has experienced a passenger in distress. This situation may be urgent in terms of the passenger's medical state, but not life-threatening. Conversely, the passenger's medical state may be life-threatening and cause for the aircraft to alter its trajectory in an emergency sense.

1) Urgent medical attention required:
    a) The aircraft and flight crew notifies the PSU that it requires a specific deviation from its trajectory due to an urgent passenger medical condition.
    b) The PSU examines the specific request, checks for the availability of the airspace requested, allowing the aircraft to depart from its trajectory.
        i) The PSU amends the trajectory to reflect the excursion.
        ii) The PSU notifies the PSU Network and the arrival VAS of the trajectory deviation and the aircraft's status.
    c) The arrival VAS determines the effect of the aircraft trajectory excursion on its resource plan and specifically the aircraft's resource reservations.
        i) VAS holds the reservation or changes the reservation to provide better access to the passenger on arrival.
        ii) VAS does not alert First Responders and the vertiport fleet operator personnel will assume responsibility for the disposition of the affected passenger.
2) Emergency medical attention required:
    a) The aircraft and flight crew notifies the PSU that it is declaring an emergency and requires a specific deviation from its trajectory due to a passenger medical emergency.
    b) The PSU examines the specific request and assures the availability of the airspace requested, allowing the aircraft to depart from its trajectory.
        (1) The PSU amends the trajectory to reflect the excursion and the status of the aircraft is set to emergency.
        (2) The PSU notifies the PSU Network and the arrival VAS of the aircraft status and its trajectory deviation.
    c) The arrival VAS determines the effect of the aircraft trajectory excursion on its resource plan and specifically on the aircraft's resource reservations.
        i) Since the aircraft is in an emergency status, the VAS holds the scheduled reservation open for the aircraft's use should that now be required.
    d) If the emergency aircraft has determined that the arrival vertiport remains its destination, then the VAS takes the following actions:
        i) Hold the prior reservation.
        ii) Allocate any other resources at its disposal to the arriving emergency aircraft.
        iii) Alert medical and rescue first responders of the emergency arrival.

iv) Assure that all other traffic and operations will yield to the emergency aircraft.
v) Negotiate revised trajectories and resource reservations with all affected fleet operators through the PSU Network as required to accommodate the emergency.

5.2.1.9 Non-Cooperative Aircraft

With respect to vertiport operations, a non-cooperative aircraft is an aircraft that has not identified itself to the PSU or PSU Network, the VAS, any other cooperating aircraft, or ATC. It is operating illegally in the airspace or on the vertiport and is subject to sanctions if apprehended.

The UOE will have no way to manage or control rogue or unresponsive aircraft, but they can be tracked and identified through surveillance in the airspace or on the vertiport. In this case, appropriate authorities would be notified, and they would take appropriate actions.

The management of a non-cooperative aircraft with respect to cooperating traffic would require that all cooperating aircraft avoid and remain separated from the rogue aircraft.

1) Through the SSP, the VAS will identify any rogue or non-cooperative aircraft within the vertiport airspace or on the vertiport surface.
2) The VAS will notify the PSU and PSU Network of the discovery of a non-cooperative aircraft.
3) The VAS will attempt to contact the designated aircraft and may request other cooperating aircraft within its administration to attempt communication V2V with the rogue aircraft.
4) If communications can be established, the VAS will communicate with the rogue aircraft and determine its identity and intentions.
5) The VAS will report the information to the PSU and PSU Network
6) If the rogue aircraft is located on the vertiport surface, the VAS will instruct it to park in an unobtrusive location on the vertiport, establish proper communications with the PSU or PSU Network, and provide its intentions to the PSU Network.
7) If communications cannot be established with the rogue aircraft, the VAS will notify vertiport security to intercept the aircraft on the vertiport surface and neutralize the situation or determine the intentions of the rogue aircraft.
8) The VAS will report the findings to the PSU Network.
9) If the rogue aircraft is in the VPV, the VAS will inform the PSU Network and all aircraft within the VPV to alert them and advise them to avoid the rogue aircraft.

5.2.1.10 Loss of Navigation

Loss of navigation capability at a vertiport would mean that navigation augmentation services at that vertiport would be lost for the duration of the vertiport navigation failure. The impact of the navigation loss on the vertiport operations would depend on the nature of the navigation loss. Specifically:

1) The loss of surface navigation capabilities such as signage, ground loops, RF tags, or other guidance mechanisms could have multiple effects.

2) All surface traffic movement could be halted if the aircraft are automated and depend on the vertiport equipment to enhance or provide navigation.
3) Aircraft with an onboard flight crew could potentially navigate visually on the vertiport surface, with progressive instructions provided by the VAS if required.
4) Remotely piloted aircraft could potentially navigate visually if the aircraft are equipped with a camera or set of cameras that would enable the remote flight crew to navigate visually, and the VAS could provide progressive taxi instructions as required.
5) Robotic aircraft tugs could be dispatched to tow the aircraft across the vertiport surface if the tugs are capable of navigation on the vertiport surface despite the equipment failures.
6) In all cases, the throughput capacity of the vertiport operations would be diminished.
7) Aircraft approaching or departing the vertiport would be restricted to visual approaches and departures to the extent that they can conduct visual flight in the absence of the vertiport augmented navigation equipment. Since each aircraft will have basic navigation capabilities, the aircraft should be able to navigate the approach, but the precision that they achieve might limit their ability to complete low-ceiling and low-visibility operations that normally required the augmented navigation equipment.

5.2.1.11 Emergency Landing at Vertiport

An aircraft operating in the vicinity of or directly on a vertiport can experience a condition that leads the flight crew or aircraft to declare an emergency. In general, the declaration of an emergency enables the flight crew and aircraft to take any action they deem necessary to safely control the emergency. Near a vertiport, the action would be to land the aircraft at the vertiport as soon as practical. In all cases, the aircraft notifies the managing PSU and the VAS if the aircraft is within range of the vertiport. In general, if the aircraft transmits an emergency signal it will be received by all facilities near the aircraft. The aircraft will be given priority over all normal operations being conducted by the PSU, the PSU Network, and the vertiport, as appropriate.

1) Emergency declaration from the aircraft:
    a) The aircraft and flight crew notifies the PSU and the VAS that it is declaring an emergency and requires a specific deviation from its trajectory to contend with the emergency. If possible, the flight crew or aircraft will inform the PSU and the VAS of their intentions.
    b) The PSU examines the request and ensures the availability of the airspace requested, allowing the aircraft to depart from its trajectory.
        i) The PSU amends the trajectory to reflect the excursion, the status of the aircraft is set to emergency, and the aircraft is given emergency priority.
        ii) The PSU notifies the PSU Network and the arrival VAS of the aircraft status and its trajectory deviation.
    c) The arrival VAS determines the effect of the aircraft trajectory excursion on its resource plan and specifically on the aircraft's resource reservations.

d) Since the aircraft is in an emergency status, VAS holds the scheduled reservation open for the aircraft's use should that now be required.
e) If the emergency aircraft has determined that the arrival vertiport remains its destination, the VAS takes the following actions:
   i) Hold the prior reservation.
   ii) Allocate any other resources at its disposal to the arriving emergency aircraft.
   iii) Alert fire and rescue of the emergency arrival.
   iv) Assure that all other traffic and operations will yield to the emergency aircraft.
   v) Negotiate revised trajectories and resource reservations with all affected fleet operators through the PSU Network as required to accommodate the emergency.
f) If the emergency aircraft has determined that it must land away from the vertiport, the flight crew would communicate their intentions to the PSU and would execute the landing as best as possible.
   i) The PSU would alert first responders and provide location information for the aircraft.

5.2.1.12 Aircraft Crash on Arrival at Vertiport

An aircraft approaching or departing a vertiport may experience a malfunction of the aircraft, human error, or environmental forces that cause the aircraft to become incapable of flight. As the PSU and VAS monitor the arrival or departing aircraft, they will observe the flight status of the aircraft and will be able to determine that the aircraft has ceased flight and returned to the ground. The actions taken by the VAS include:

1) Alert the appropriate first responders to the accident and provide location as accurately as possible.
2) Notify the PSU and PSU Network of the accident.
3) Divert arrival or departure traffic as appropriate.
4) Assist first responders as able.

5.2.1.13 Physical Infrastructure Emergency

An emergency condition, such as a fire, at or near a vertiport will cause disruption of services performed by the vertiport. If the condition exists on the vertiport property, the VAS will summon appropriate emergency crews to deal with the situation to the extent possible. If the condition is located on the vertiport property, the outcome will be that the vertiport is quickly shut down. If the emergency conditions exist around the vertiport, but not on the vertiport property, the vertiport may shut down or may be able to continue operations in a limited capacity. Thus, this scenario results in one of the following situations:

1) The vertiport is completely closed:
   a) In this case, the VAS stops all departures for the duration of the closure. The affected departure flight plans are renegotiated with the affected FOCC through the PSU. Nominal departure operations restart at the end of the closure period and in accordance with the revised flight plans and trajectories.

   b) For arriving aircraft, the PSU Network, VAS, and ATC will negotiate the fate of active aircraft en route to the destination vertiport prior to the closure of the airspace, or the closure of the airspace procedure will be detailed in a letter of agreement between the entities involved.
   c) For aircraft that are on approach to the vertiport, the VAS will notify the PSU of the closure, and any arriving aircraft will be either rerouted by the PSU or ordered by the VAS to execute a missed approach. In either case, the aircraft flight plans will be renegotiated through the PSU with the closed vertiport or alternate vertiports.
   d) Aircraft in taxi mode will be given specific parking instructions by the VAS and, for departures, their flight plans will be terminated and resubmitted for a new departure time, as discussed in a) above. Arriving flights that are taxiing will be directed to the appropriate gate as required.
2) The vertiport is partially closed:
   a) Depending on the vertiport resources affected, the VAS will close those resources in its resource database for the duration of the closure, so they will not be available for use.
   b) Any closed resources that were scheduled for use will result in negotiations between the VAS and the fleet operator through the PSU for resolution.
   c) Aircraft that are active and have not arrived at the destination vertiport at the time of closure will require negotiations between the PSU Network, ATC, and VAS with respect to the ATC airspace closure. Such aircraft may be allowed to continue for arrival or will be rerouted by the PSU as appropriate to the resulting agreement between the PSU, ATC, and VAS, or as dictated by the letter of agreement between the PSU, ATC, and VAS that covers this situation.

5.2.1.14 All Aircraft Land

In the event of a national emergency, such as that on September 11, 2001, an edict may be issued to clear the airspace and land all aircraft as soon as possible. The edict could cover the entire nation, as was the case in 2001, or it could cover a region or even a local area. With respect to the vertiport, the scenario would be the same in all cases.

1) The area of airspace to be cleared is identified and the PSU and PSU Network are notified by ATC.
2) The PSU and PSU Network notify all vertiports within their range that the edict has been issued.
3) Each vertiport stops departures and issues a return to gate or return to vertiport origin for taxiing aircraft.
4) Each PSU develops a revised trajectory for each aircraft it manages.
5) The PSU collaborates with all appropriate vertiports in the vicinity of the airborne traffic to determine a suitable termination point for the aircraft trajectory.
6) Aircraft approaching a vertiport at the time of the edict will continue their approach and will land at their arrival vertiport as planned and as reserved.
7) All other vertiport reservations are cleared, and the vertiport resources are negotiated with the PSUs for each of their flights that are designated to terminate at the vertiport.

8) The PSU coordinates with other PSUs on the PSU Network to assure all aircraft have revised trajectories that terminate at a vertiport and that reservations at the vertiport have been secured.
9) The PSU transmits the revised trajectory to the aircraft and flight crew, and the fleet operator is notified of the revised trajectory.
10) All aircraft follow their revised trajectories and land at their designated arrival vertiports in a normal manner.

5.2.1.15 Pre-Approved Procedure

Some off-nominal operations that are likely to occur frequently can be covered by predefined rules and procedures. These procedures can be adapted into the PSU, PSU Network, aircraft, and VAS, and they would be followed when the specified event occurs. For example, the loss of a PSU facility would be addressed by a preplanned contingency operation plan that would be executed when the PSU is incapable of providing service. This plan may transfer all PSU-managed aircraft to a predesignated backup PSU, and appropriate notifications of this change would be automatically distributed on the PSU Network and to all affected aircraft. The receiving PSU would be configured to accept the failed PSU's traffic, which would automatically be switched over to the recovery PSU.

5.2.2 Resource Constraints

5.2.2.1 Aircraft Based at Vertiport

UAM aircraft serving urban and suburban locations may need to be based at vertiports, although some could be based at airports. The location of the bases is of strategic importance in the following sense:

1) The home base vertiport should be accessible and offer all-weather operation so that aircraft can arrive and depart as needed to meet their schedule commitments.
2) The home base vertiport should be on or near the intended route that the aircraft is scheduled to fly.
3) There will need to be ample parking for aircraft to meet demand, especially for overnight parking when the aircraft are not operating or may be operating on limited schedules.
4) The home base vertiports should be selected to optimize the route schedule of each aircraft, considering its mission and capabilities for weather operations.
5) The home base vertiports should be capable of performing maintenance and charging on aircraft should that be required, preferably overnight for air-metro-like operations.

Urban center vertiports are not likely to have the capacity to serve as the base large numbers of aircraft, but they may have large demand for overnight parking if their fleets and schedule optimization demands it. In this case, the limited resources of urban vertiports will need to be prioritized.

5.2.2.2 Mixed Equipage

Vertiports in UML-4 will have to service aircraft fleets that have mixed levels and types of equipage and, therefore, mixed performance capabilities. Aircraft in that case may fall into the following categories:

1) Piloted with a pilot or supervisor on board, requiring voice communications backup equipment between the vertiport and aircraft. Such aircraft may also have limited performance capabilities due to having the pilot in the loop, as well as limited precision and capabilities to traverse severe IMC.
2) Remotely piloted aircraft may have restrictions similar to aircraft with pilots on board. There will be additional automation onboard the aircraft, but there will also be a control link between the aircraft and the remote pilots, which will be a critical capability. This link may limit the performance capabilities of the aircraft.
3) There may be aircraft that are piloted but incorporate semi-automated capabilities such as sophisticated autopilots, air-to-ground and air-to-air data link, and text message capabilities that enable some V2V communications and more precise pilotage, as well as operation with lower IFR minimums.
4) Aircraft that are highly automated with a supervisor on board will operate with the human acting more outside the loop. These aircraft will operate more in the control-by-exception paradigm, with VAS-to-aircraft-computer digital link, V2V and V2I communications to self-separate, automated navigation, and supervisor intervention when an exception occurs.
5) Autonomous aircraft that can conduct their mission without human intervention will have full automation and IP communications, with automated coordination and negotiations with UAM stakeholders. Such operations may involve remote management, whereby a crew oversees a fleet of aircraft and are called on to act when an exception occurs.

Operating a vertiport with a single class of aircraft, all exhibiting the same performance, enables a less complex operation than one with mixed capabilities. Operation with mixed capabilities imposes several requirements:

1) Multiple sets of equipment are needed serve aircraft with capabilities ranging from human pilots onboard to fully autonomous aircraft. This need includes vertiport surveillance, communications, and navigation equipment to serve all aircraft that require vertiport service.
2) The VAS and PSU will require additional automation capabilities to determine proper and efficient arrival, taxi, and departure aircraft sequencing to accommodate aircraft with differing performance capabilities. Slower aircraft in front of faster aircraft can restrict the performance of all aircraft in the approach sequence and may require aircraft to yield and pass in the arrival, taxi, or departure streams.

5.2.2.3 Environmental Impact Mitigation

The location of each vertiport will be a key determinant of the extent of environmental impact. Vertiport traffic will consist of VTOL aircraft, and to serve the demand projected for UML-4, vertiport arrivals and departures could number 120 per hour – two operations every minute. Some environmental impacts are expected in any case, since the aircraft will generate noise from the electric motors and fossil fuel generators onboard, as well as noise resulting from propeller or fan rotation. These impacts could act as a constraint on the vertiport and could restrict the capacity of the vertiport.

An approach or departure path to a vertiport may require aircraft to fly at low altitudes over noise-sensitive surroundings. Mitigation may require these operations to be limited to certain time periods or certain numbers of operations per hour, restricting the arrival and departure capacity of vertiport arrival and departure pathways. These restrictions could result in a need for additional approach and departure pathways to maintain the required service capacity at a vertiport, adding complexity to the vertiport infrastructure and operation.

5.2.2.4 Vertiport Traffic Flow Changes due to Traffic Flow at a Nearby Airport or Other Vertiport

To accommodate the traffic demand in an urban environment, many vertiports may be located within a region, and some may be in close proximity with each other. Additionally, vertiports may be located at or near airports that serve fixed wing transport aircraft. In light of the proximity and the expected demand, it is likely that traffic patterns for these airports will need to be separated from each other. This is the case in some urban areas today, such as the New York City, where airport traffic patterns at one airport can impact those at another airport. Vertiports are expected to be in even closer proximity in these areas.

The interference of traffic patterns translates into capacity constraints at the vertiports. One vertiport may be restricted from westbound departures because a proximate vertiport to the west is using eastbound departures, and the two departure streams would interfere. In this case the restriction could cause the eastern vertiport to reduce its arrival and departure capacity, since not all the arrival and departure pads would be usable.

Under nominal conditions, weather, traffic demand, and environmental mitigations may cause or result from off-nominal events. These effects will need to be considered in vertiport design and location, as well as in operation of the VAS to plan and schedule use of vertiport resources in the most efficient manner.

5.2.2.5 ATC Airspace Flow Control and Restrictions

UML-4 anticipates dedicated high-density routes for UAM traffic into and out of urban high-density vertiports. These routes are outside of the ATC airspace and are managed by PSUs and the PSU Network. Under some scenarios, UAM aircraft will traverse into ATC airspace in either IMC or VMC, potentially requiring a flight plan to enter controlled airspace.

1) This flight plan would be part of the flight plan filed with the PSU for departing the vertiport and initially traversing PSU-managed airspace. However, before crossing into ATC airspace the aircraft would require an ATC clearance into the airspace and the ability to adhere to the clearance and interact with ATC for the duration of its travels in controlled airspace.
2) When the flight plan is filed with ATC, it will be checked against ATC criteria, which include any flow restrictions in the area.
3) The presence of ATC flow restrictions for the controlled airspace must be considered by the PSU and the VAS in that the aircraft could be subject to a ground delay by ATC and will not be allowed to depart the vertiport due to a ground hold. This situation will affect the vertiport resources and will need to be considered in the VAS's utilization plan.

4) The inverse situation applies to vertiport arrival flights. A flight may receive a ground delay at its origin and hence will experience a delayed arrival. VAS must consider these arrival delays in the management of its resource plan and schedule.

5.3 Resource Allocation

In some situations in the UML-4 environment, operators may compete for the same volume of airspace and vertiport facilities. Unmanaged excess demand can degrade system efficiency and cause delays that ripple through the entire system. Rush hour at congested vertiports and hazardous weather events are examples of situations in which demand for a specific operating resource may exceed what is available.

Rules in effect in the NAS today, such as giving a lower-altitude flight the right of way over a higher-altitude flight when approaching for a landing at an uncontrolled airport,[79] are unlikely to be sufficient, and the UAM system architecture and traffic demands associated with UML-4 will likely preclude the use of such simple rules for allocating airspace and vertiport resources. The degree of automation expected in UAM systems will preclude manual intervention in cases of contention; requiring the use of automated algorithms to implement prioritization rules in case of resource contention. These algorithms embody community-based rules and regulations that are codified into the system to decide who should go first and who should have to wait, slow down, or take a different route.

Studies have examined the use of flight prioritization in NextGen,[80] but these rules may not apply precisely to a UOE. In NextGen the management of NAS resources is performed by an ANSP with the goal of granting equitable access to all operators within the NAS. The UAM concept, however, envisions that PSUs and vertiport management will operate as private businesses under FAA certification. The use of multiple PSUs to manage the same airspace and approach and departures from the same vertiport, as well as private vertiport ownership and management, complicates achieving the best use of contested resources.

5.3.1 Collaborative Decision Making

CDM, referred to in Section 2.1.5, is another approach that would exploit the capabilities of automation. CDM is an operating paradigm whereby decisions are based on a shared common view and an awareness of the consequences that the decisions may have on the system and its stakeholders. CDM for prioritizing use of contested UAM resources could consider each stakeholder's objective function – that is, the values assigned by each stakeholder to various possible outcomes – and render decisions that provide

[79] "14 CFR § 91.113", FAA, https://www.govinfo.gov/content/pkg/CFR-2012-title14-vol2/pdf/CFR-2012-title14-vol2-sec91-113.pdf
[80] "Flight Prioritization Deep Dive: Final Report", Joint Planning and Development Office, https://scholar.rhsmith.umd.edu/sites/default/files/mball/files/flight_prioritization_0.pdf?m=1467366850

the greatest overall value, in some sense, for the entire community of stakeholders. The decisions could thus consider the interests of outside stakeholders, such as the public.

With rapid automation, decisions could be reached by an iterative process, whereby stakeholders (or their computational proxies) are informed of the initial results and can modify their choices or objectives for successive rounds to converge on a “best” solution. For this approach to be accepted, the stakeholders must have trust in the impartiality and validity of the system and its results, and, as with auctions, the rules must prevent gaming and anti-competitive behavior.

With either approach, automation will play a key role in enhancing the use of UAM resources for best value to the stakeholders, and it represents a significant opportunity for research supporting UAM in UML-4.

5.3.2 Protocols for Collaboration and Prioritization

Contention for airspace and vertiport resources can occur in two regimes: strategic and tactical. The strategic regime generally involves a time frame of more than 10 minutes, while conflicts in the tactical regime occur in near-real time. In either case, the protocol for resolving conflicts involves the following three steps.

5.3.2.1 Detection

1) In the strategic regime, each flight plan contains a proposed 4D-trajectory that is evaluated by the host PSU for contention of airspace and vertiport resources, and contention for resources would be detected when flight plans are filed by the operators.
2) In the tactical regime, contention for resources could arise from changes in conditions (such as weather), requests for changes in flight plans or new flight plans, off-nominal conditions, or other unplanned events. Contention for resources would be detected when the host PSU examines the planned trajectories in its domain to determine the impact of the change.

5.3.2.2 Evaluation

1) The initial evaluation will determine the existence and source of any resource contention, indicating that a resolution is required.
2) The host PSU will determine the parameters for acceptable solutions, identify feasible solutions, evaluate the impacts of those solutions, and select the best solutions or a choice of solutions for further evaluation.
3) In addition, the host PSU will collaborate with other PSUs managing the same airspace, as well as arrival and destination vertiports.
4) This process will be highly automated for cases in the tactical regime.

5.3.2.3 Implementation

1) The host PSU will inform the affected stakeholders of the impacts on their trajectories and resources and confirm the solution with the stakeholders.

2) Once the solution is confirmed the PSU will update the trajectories and plans for affected resources and affected stakeholders will update their plans and take the necessary actions.
3) The PSU will monitor operations for conformance with the plan and unexpected impacts of the resolution.

6 Summary of Impacts

This Concept of Operations (ConOps) describes a high-density Vertiport Automation System (VAS) capable of supporting high-throughput operations projected in NASA's vision for Urban Air Mobility Maturity Level Four (UML-4). This ConOps envisions high-density UAM operations between vertiports connected by high-density airspace routes. Providers of Service for UAM (PSUs) manage traffic from departure spot to arrival spot in coordination with VAS operators, who manage surface operations within the vertiports. The capabilities of UML-4 collaborative and responsible automated systems enable high-density and complex operations under this concept. Operations described in this ConOps contrast with current operations, which rely largely on procedures for helicopter operations under rules and regulations developed for fixed wing aircraft. This ConOps focuses on aircraft operations within the Vertiport Operations Area (VOA), a designated area surrounding the vertiport. The Vertiport Volume (VPV) is a smaller space within the VOA reserved for traffic arriving or departing at the vertiport.

6.1 Operational Impacts

Top-level operational impacts can be summarized according to five major domains, as follows.

6.1.1 Communications

Data are diverse in size and content, with real-time updates. Data communications methods and standards enable cooperation among the vertiport, PSUs, fleet operators, and pilots-in-command and aircraft systems. A common geospatial framework for updates on aircraft condition and for communication of intent enables detect and avoid (DAA) capabilities.

6.1.2 Navigation

Precise airspace and surface navigation capabilities within obstructions in urban landscapes, provided by systems such as dual-frequency Global Positioning System (GPS), Ground Based Augmentation System (GBAS), or instrument landing system (ILS) enable sequencing, precise scheduling, and operational safety.

6.1.3 Surveillance

Sensing capabilities monitor the available resources of the vertiport and the surrounding aircraft within its operations area to determine current and projected operating conditions at the vertiport.

6.1.4 Information

Increasing levels of automation using machine learning (ML) algorithms and artificial intelligence (AI) capabilities enable safety assurance and management of high-density, closely spaced, complex operations at and near the vertiport.

6.1.5 Integration

High-density routes, designated airspace, and coordination with ATC minimize the adverse impact of high-density UAM operations on other users of the airspace. Standards, modular vertiport subsystems (including electrical charging infrastructure), and vertiport design facilitate integration with the surrounding AAM ecosystem.

6.2 Organizational Impacts

Compared to the current system, this ConOps introduces two new entities with new responsibilities: the manager of the VAS and the Provider of Services to Urban Air Mobility (PSU) described in the NASA UAM Vision ConOps UML-4.

6.2.1 Vertiport Automation System Manager

Responsibilities of the VAS manager include the following:

1) Manage the resources of the vertiport, including landing and departure pads, taxiways, long- and short-term parking pads, hangars, ramps; cargo or passenger processing, loading, and unloading facilities and equipment; refueling, recharging, and aircraft servicing; as well as provisions for physical and cybersecurity.
2) Develop a utilization plan for these resources and manage the plan in real time as conditions and demand change.
3) Provide four-dimensional surface trajectories (latitude, longitude, height above the surface, and time) for surface operations and manage and coordinate surface movements.
4) Maintain required communications with the aircraft, including direct communication with the aircraft in critical situations or on the vertiport surface and routine communications through the PSU or PSU network.
5) Disseminate vertiport resource information and status to PSUs and operators in real-time.
6) Confirm (or deny) land or no-land and takeoff or no-takeoff decisions within the VPV based on maintaining system safety on the surface of the vertiport.

6.2.2 Provider of Services to Urban Air Mobility

Responsibilities of the PSU include the following:

1) Assume management of aircraft from takeoff to landing, including scheduling of the route.
2) Provide automated tactical deconfliction and other airspace services.
3) Coordinate management of airspace with air traffic control (ATC), including provisions for aircraft entry to and exit from designated airspace.

6.2.3 Other Entities

FAA organizations will acquire new responsibilities to create and administer new rules and regulations, maintain oversight of VAS operators and PSUs, and coordinate ATC operations.

Aircraft fleet operators will acquire new responsibilities related to operations within PSU-managed airspace and on the surface of the vertiport, as well as planning and coordination for use of vertiport facilities.

6.3 Impacts During Development

Major impacts of the transition to this ConOps include the effects of the following changes:

1) Development and implementation of UML-4 technologies, including advanced automation.
2) Development of new vertiport infrastructure, including energy requirements, communications, and coordination with surface transportation for passengers and cargo, as well as coordination with local authorities and public organizations.
3) Development of new standards, rules, and regulations, including provisions for physical security and cybersecurity.
4) Impact of PSU-managed airspace on operations in the National Airspace System (NAS).

7 Analysis of the Proposed System

The proposed VAS concept is a key element toward realization of the UML-4 vision.

7.1 Summary of Improvements

Automation, UML-4 capabilities, efficient use of airspace, and efficient use of high-value urban land area enable major improvements in VTOL aircraft operations in or near urban areas, including:

1) An order of magnitude increase in the tempo of operations into and out of a vertiport, enabling as many as hundreds of simultaneous operations within a metropolitan region.
2) Minimal aircraft turnaround times and optimal use of vertiport surface area and other resources.
3) Safe high-density weather-tolerant operations in metropolitan areas, including proximity to urban structures, urban canyons, and micro-weather.
4) Flexibility to accommodate airspace operations with a wide breadth of business cases and aircraft capabilities in changing conditions of demand, weather, and operational constraints.
5) Integration of UAM operations with minimal adverse impact on other operations in the NAS.

7.2 Disadvantages and Limitations

The VAS concept will require technological and societal developments and costs, including the following:

1) Investments and efforts to achieve, implement, and certify advanced automation and other technologies.
2) Investment and operation costs of incorporating the required software and hardware capabilities.
3) The impact of setting aside designated UAM-managed airspace on capacity for other traffic in the NAS.
4) Use of urban real estate for vertiports.
5) Environmental impacts, including local air quality, climate change, and noise.
6) Acceptance by the public and local governments.
7) Establishment and administration of new laws, regulations, and standards.

7.3 Alternatives and Tradeoffs Considered

The proposed system includes significant tradeoffs in assignment of responsibilities for air traffic management (ATM) and control within the area surrounding vertiports.

7.3.1 Implementation of Provider of Services to Urban Air Mobility

The use of high-density routes in the airspace between vertiports and the designation of VOAs and VPVs relies on creation of PSUs to augment current ATC responsibilities and procedures. The tradeoffs leading to establishment of PSUs as a new entity, consistent with concepts for Unmanned Aircraft System Traffic

Management (UTM), enable high-density operations to meet projected volumes of demand for UAM while minimizing the adverse impact on other traffic in the NAS.

7.3.2 Management of Surface Movements

Management of operations within the vertiport surface involves a tradeoff of responsibilities between the PSU and the VAS manager. This ConOps assigns to the PSU the responsibility for managing flights from the point of departure on the vertiport surface to the point of landing, while the VAS manager monitors all surface movements. This arrangement establishes a clear point in the flight for the transfer of responsibilities and enables the most efficient use of vertiport surface area and other resources.

7.3.3 Establishment of Vertiport Volume

This ConOps establishes the VPV as a conceptual cylinder in the airspace restricted to operations to or from the vertiport. An alternative solution could employ designated approach and departure paths rather than the VPV, but the VPV concept enables simultaneous operation of multiple approach and departure paths, as well as flexible and rapid reconfiguration of these paths to meet changing conditions.

7.4 Path Forward

This document is based largely on UAM operations in UML-4 described in NASA UAM Vision ConOps UML-4. We expect that this ConOps will evolve as the relevant NASA and FAA ConOps documents are refined to reflect the community's thinking relative to AAM.

Glossary

This glossary defines terms introduced in this ConOps. Other terms taken from the NASA UAM Vision ConOps UML-4 are also included and identified as such.

Advanced Air Mobility (AAM): Safe, sustainable, affordable, and accessible aviation for transformational local and intraregional missions. AAM includes UAM as well as many other missions, including different forms of passenger transport, cargo transport, and aerial work missions. These missions may be performed with many types of aircraft (e.g., manned or unmanned; conventional takeoff and landing (CTOL), short takeoff and landing (STOL), or VTOL), over/between many different locations (e.g., urban, rural, suburban), and to/from far more locations than typical commercial aviation (e.g., novel UAM aerodromes, existing underutilized small/regional airports). Local and intraregional missions are likely less than approximately 75 nautical miles and 300 nautical miles, respectively, though these ranges are not strict upper limits. (NASA UAM Vision ConOps UML-4)

Barrier: Challenge(s) across the entire UAM ecosystem that must be addressed to enable the UAM vision. Barriers include, but are not limited to, challenges that have no currently known solution pathway. (NASA UAM Vision ConOps UML-4).

Detect and Avoid (DAA): Systems that provide situational awareness to an aircraft that enable the identification of other air traffic or hazards and the ability to take appropriate action to mitigate collision risk. DAA systems are typically categorized as onboard or ground-based depending on where the hardware of the system is located. (NASA UAM Vision ConOps UML-4)

Fleet Operator: The fleet operator of the aircraft who hires the aircraft crew (if the aircraft fleet operator is not also the aircraft crew) and in some instances performs dispatch duties. A fleet may consist of one aircraft. (NASA UAM Vision ConOps UML-4)

Flight Crew: A human or humans partially responsible for the safe flight of the aircraft who share this responsibility with some automated system(s). A flight crew member is not a traditional pilot, but rather performs the role of aircraft operator, multi-aircraft operator, or aircraft steward. An aircraft operator may be either onboard or off-board, a multi-aircraft operator is located off the aircraft, and an aircraft steward is located onboard. One flight crew member is designated the Pilot in Command (PIC) or Remote PIC (RPIC) at a time, though the PIC or RPIC may change during flight. Typically, the flight crew work on behalf of the fleet operator to support UAM operations. A fleet operator can utilize a traditional pilot, a single aircraft crew member, or a combination of flight crew members as required for safety in light of their particular business model. For example, the use of an onboard flight crew may bolster public acceptance by providing human interaction throughout the UAM experience. (NASA UAM Vision ConOps UML-4)

Four-dimensional (4D) Surface Trajectory: The trajectory of a vehicle operating on an aerodrome surface, expressed in terms of latitude, longitude, height above vertiport surface, and time. The trajectory includes height to enable hover taxi by VTOL aircraft.

High-Density Routes: Routes for high-density UAM/AAM operations connecting high-density vertiports and other routinely accessed landing and departure assets. Due to the operating proximity and speed of the vehicles, operating along these routes requires advanced equipage enabling close separation by assisting the human's capabilities. In some contexts, these routes may also be referred to as corridors.

Pad: An area on the surface of a vertiport designated for landings and takeoffs of VTOL aircraft. A pad must meet FAA-specified standards for dimensions, markings, lighting, and other requirements.

Performance Authorization: An FAA regulatory approval for fleet operators to perform a specific UAM operation. A performance authorization substantiates the fleet operator's ability to meet performance capabilities in their intended area of operation. The FAA grants a performance authorization when a fleet operator's proposed assets (including potentially both ground and air assets) are sufficient to meet an established level of performance in the airspace in which they intend to operate. Performance authorization requests must be submitted by the fleet operator, not a PSU or other entity, regardless of whether the PSU or SDSP will provide services or capability/technology packages to support the fleet operator's ability to meet the performance requirements. (NASA UAM Vision ConOps UML-4)

Pilot in Command (PIC): An individual, human person who has final authority and responsibility for the operation and safety of flight, has been designated as PIC by the fleet operator, and holds the appropriate licenses and qualifications to conduct the flight. A PIC may be on or off-board the aircraft. (NASA UAM Vision ConOps UML-4)

Provider of Services to Urban Air Mobility (PSU): Public or private (e.g., third-party) entities that provide ATC and flight safety services under rules and regulations established by the FAA. Services provided by PSUs include routing, traffic deconfliction, operational constraints, modifications, notifications, and information. A PSU is analogous to a USS in the UTM paradigm and is contracted by the fleet operator (i.e., airspace user). (NASA UAM Vision ConOps UML-4)

PSU Network: The amalgamation of PSUs connected to each other and exchanging information. Each PSU is required to share certain information with the other PSUs to provide a complete operating picture and situational awareness. (NASA UAM Vision ConOps UML-4)

Supplemental Data Service Provider (SDSP): Data sources external to the PSUs that supplement the decision making and information-sharing of the PSU and fleet operator. These can include weather sources and ground risk assessments, among others. PSUs can access SDSPs via the PSU Network for essential or enhanced services (e.g., terrain and obstacle data, specialized weather data, surveillance, constraint information). SDSPs may also provide information directly to PSUs or fleet operators through non-PSU Network sources (e.g., public or private internet sites). (NASA UAM Vision ConOps UML-4)

Tactical Deconfliction: Second-level conflict management to deconflict UAM operations during flight to maintain separation and avoid collisions. Whereas strategic deconfliction occurs prior to departure, tactical deconfliction occurs during flight. (NASA UAM Vision ConOps UML-4)

Terminal Area: The immediate vicinity around a UAM aerodrome or airport where departures and landings occur. (NASA UAM Vision ConOps UML-4)

Urban Air Mobility Operations Environment (UOE): For the purposes of this ConOps, a UOE is a flexible airspace volume encompassing areas of high UAM flight activity. UOEs may take the shape of a corridor, on/off area feeding a Vertiport or a wider section of airspace. UOE is not a separate airspace class.

Urban Air Mobility Maturity Level (UML): A NASA-developed framework categorizing anticipated evolutionary stages of a UAM transportation system from the beginning state to a highly developed state where UAM is a ubiquitous capability, similar to automobiles today. This framework includes six maturity levels, withUML-1 representing the earliest maturity level and UML-6 representing full ubiquity. The ConOps focuses on UML-4, an intermediate state, where hundreds of operations could be occurring at any given time within a single metropolitan area. (NASA UAM Vision ConOps UML-4)

Urban Air Mobility (UAM): The vision of UAM a safe, efficient, convenient, affordable, and accessible air transportation system for passengers and cargo that revolutionizes mobility around metropolitan areas. This vision includes everything from small package delivery drones to passenger-carrying air taxis that operate above populated areas. (NASA UAM Vision ConOps UML-4). UAM is a subset of the broader vision for Advanced Air Mobility (AAM).

Vertiport: An identifiable ground or elevated area, including any buildings or facilities thereon, used for the takeoff and landing of VTOL aircraft and rotorcraft.

Vertiport Automation System (VAS): A vertiport operations system capable of supporting high-throughput operations under conditions defined as NASA's Urban Air Mobility (UAM) Maturity Level Four (UML-4).

Vertiport Operations Area (VOA): A volume of airspace in which sufficient assurance of communications, navigation, and surveillance must be established through proper aircraft equipage as designated by the PSU Network and ground-based infrastructure.

Vertiport Volume (VPV): A volume of airspace relevant to the PSU Network through which air traffic cannot flow unless coordinating with that vertiport.

Vertistop: A vertiport intended solely for takeoff and landing of VTOL aircraft and rotorcraft to drop off or pick up passengers or cargo.