Concept of Operations: Autonomous UAM Aircraft Operations and Vertiport Integration

April 2022

Executive Summary

This document is a comprehensive Concept of Operations (ConOps) for initial Autonomous Urban Air Mobility (UAM) operations that describes the journey of an autonomous[1] electric vertical takeoff and landing (eVTOL) aircraft and its relationship to UAM-specific, aircraft-agnostic aerodrome infrastructure (also referred to as a vertiport). The ConOps discusses the passenger journey on an autonomous eVTOL and the necessary systems and interactions between the aircraft, the aircraft's fleet operator, and the vertiport.

For the purposes of this ConOps, the vertiport in question will possess multiple touchdown and liftoff areas (TLOF) and electric aircraft parking and charging stands. At initial launch of autonomous UAM operations, the purpose-built vertiport may already be operational, hosting piloted eVTOL aircraft. However, the addition of autonomous eVTOL aircraft to existing infrastructure will require upgrades, retrofits, and procedure changes to accommodate safe operations.

[1]An autonomous system independently decides its own course of tasks to achieve its given objective without operator intervention. This document specifically refers to aircraft that autonomously aviate.

Table of Contents

Executive Summary 2
Table of Contents 3
Acronyms & Abbreviations 5
Common Terms 6
Introduction 7
Scope & Purpose 7
Day-One Autonomous Operational Environment 7
Operating and Design Assumptions 8
Infrastructure 8
Aircraft 8
Vertiport Automation & Data Systems 9
Vertiport Characteristics 9
Vertiport Resource Management & Scheduling System (RMSS) 10
Vertiport Reservations 11
Airside Vertiport Operations 11
Sensor Management 12
Situational Awareness Platform 12
Financial Operations 13
Equipment Monitoring 13
Passenger Management 14
Enrollment and Ticketing 14
Check-In 14
Passenger Communications 14
Physical & Cyber Security 15
Communications & Data Sharing 15
Personnel 16
Personnel 16
Maintenance & Charging Technician 16
Aircraft Handler 16
Passenger Operations Specialist 16
Vertiport Terminal Agent 17
FOC Staff 17
Pilot-In-Command (PIC) 17
Passenger Scheduling, Arrival, and Check-in 18
Flight Reservation 18
Arrival at Vertiport 19
Check-In 19

Stand – Departure....................20

Passenger Pre-Boarding....................20

Passenger Boarding....................20

Aircraft Pre-Flight Checks....................20

Aircraft Taxi-Route – Departure....................21

Tows/Tugs....................21

Departure from vertiport....................22

FATO – Departure....................22

Vertiport Operating Area (VOA) – Departure....................23

In Flight....................24

Vertiport Coordination....................24

Passenger Monitoring....................24

Aircraft Approach into Vertiport....................25

VOA – Approach....................25

Status Monitoring....................25

VOA Airspace Status Monitoring....................25

FATO Status Monitoring....................25

Weather and Environmental Status Monitoring....................25

Navigation....................26

Final Descent....................26

FATO – Arrival....................26

Aircraft Taxi-Route – Arrival....................27

Stand – Arrival....................28

Aircraft Turnaround....................28

Parking....................28

Charging....................28

Cabin Cleaning....................29

Maintenance....................29

Passenger Turnaround & Exit from Vertiport....................29

Off-Nominal or Emergency Procedures....................30

Contingency Landing Sites....................30

Abort....................30

Missed Approach....................31

Resumption of Flight....................31

Acronyms & Abbreviations

AAM	Advanced Air Mobility
ADA	American Disabilities Act
ANSP	Air Navigation Service Providers
API	Application Program Interface
ATC	Air Traffic Control
ATS Route	Air Traffic Service Route
BVLOS	Beyond Visual Line of Sight
C2	Command and Control
C2CSPs	C2 Communication Service Providers
ConOps	Concept of Operations
CSFL	Continued Safe Flight and Landing
DAA	Detect-and-Avoid
DAL	Design Assurance Level
DCB	Demand and Capacity Balancing
eVTOL	electric Vertical Take-Off and Landing
FATO	Final Approach and Take-Off Area
FinOps	Financial Operations
FLMS	Fleet Management System
FOC	Flight Operations Center
GPS	Global Positioning System
GSE	Ground Support Equipment
IFP	Instrument Flight Procedures
ILS	Instrument Landing System
LDP	Landing Decision Point
LHA	Landing Hazard Avoidance
NAS	National Airspace System
NASA	National Aeronautics and Space Administration
NOTAM	Notice to Air Missions
OFA	Object Free Area
PI	Personal Information
PIC	Pilot-in-Command
POTL	Pilot-over-the-Loop
PSU	Provider of Services for UAM
RMSS	Resource Management Scheduling System
RNAV	Helicopter Area Navigation Routes
RNP	Required Navigation Performance
SA	Situational Awareness
SDSP	Supplementary Data Service Provider
sUAS	Small Unmanned Aircraft System
TDP	Take-Off Decision Point
TFDM	Terminal Flight Data Management
TFMS	Traffic Flow Management System
TLOF	Touchdown and Liftoff Area
UAM	Urban Air Mobility
UML	UAM Maturity Level
UTM	Uncrewed Aircraft Traffic Management
VOA	Vertiport Operating Area
VPV	Vertiport Protection Volume

Common Terms

14 CFR PART 135: Provides the regulatory framework in the U.S. for commercial commuter and non-scheduled aircraft operations under an Air Carrier or Operating Certificate.

AERODROME: A location from which aircraft flight operations take place. This includes the ground take off and landing infrastructure as well as the airspace surrounding such infrastructure.

AUTONOMOUS OPERATIONS: An autonomous system independently decides its own course of tasks to achieve its given objective without operator intervention. This document specifically refers to aircraft that autonomously aviate, using human oversight for navigation and communication functions.

CONTINUED SAFE FLIGHT AND LANDING (CSFL): The capability of a eVTOL aircraft to maintain continued control and land at a compatible aerodrome, possibly using emergency procedures, without exceptional piloting skills or strength.

DAY-ONE AUTONOMOUS OPERATIONS: This operational environment will consist of traditional aviation users, an expansion of small unmanned aircraft system (sUAS) users, and multiple fleets of piloted eVTOL aircraft operating in select metropolitan markets from both traditional aerodromes and purpose-built vertiports. Autonomous eVTOL aircraft operations will leverage uncontrolled airspace as well as traditional air traffic control (ATC) mechanisms within controlled airspace to complete planned operations. Providers of Services for UAM (PSUs) may be operational, but will need to further advance their capabilities before they can manage all aspects of piloted and unpiloted eVTOL operations.

VERTIPORT: An area of land, water, or a structure, purpose built to be used or intended to be used, for eVTOL landings and takeoffs, including associated buildings and facilities for vehicle turnaround and passenger or cargo egress.

LANDING DECISION POINTS (LDP): A point along the approach path which is defined as the last point from which a go-around can reasonably be performed by the eVTOL aircraft.

TAKEOFF DECISION POINTS (TDP): A point along the departure path which is defined as the last point at which a rejected takeoff can be performed by a eVTOL aircraft, safely returning it to the TLOF.

Introduction

SCOPE & PURPOSE

This ConOps document was produced through a partnership between Wisk Aero, a leading autonomous eVTOL aircraft manufacturer, and Skyports, a leading vertiport developer and operator. The document is published openly and envisioned to inform industry and regulators about some of the mechanisms needed to safely integrate autonomous eVTOL operations into a vertiport and the national airspace system (NAS).

This document focuses on the unique aspects of autonomous eVTOL aircraft operations, where pilot-over-the-loop (POTL) mechanisms are utilized to supervise the safe operation of aircraft from takeoff to landing and taxi to turnaround. The ConOps discusses areas where on-aircraft and on-infrastructure system and hardware redundancy may be needed to maintain the safety levels achieved by piloted aircraft.

While the introduction of commercial autonomous eVTOL aircraft may not be immediate, Wisk and Skyports are focused on developing and testing processes and solutions that will be critical to the advancement of urban air mobility (UAM). Considering autonomous eVTOL integration today will help future-proof the development of UAM aviation infrastructure and challenge the advancement of more sophisticated and safer solutions that could benefit piloted eVTOL aircraft and all advanced air mobility (AAM) operations. Finally, this ConOps serves as a basis for discussion as industry and regulators begin to consider the integration of autonomous eVTOL aircraft systems into the NAS.

Much of this document is applicable to the carriage of both cargo and passengers by autonomous eVTOL aircraft; however, this ConOps will focus on the safe transport of passengers.

DAY-ONE AUTONOMOUS OPERATIONAL ENVIRONMENT

This ConOps contemplates the introduction of autonomous eVTOL aircraft operations into an existing, but early-stage, UAM environment that supports the evolution of UAM from UAM maturity level (UML) 2 through UML-4, as defined by the U.S. National Aeronautics and Space Administration (NASA).[2] This day-one operational environment will consist of traditional aviation users, an expansion of Small Unmanned Aircraft System (sUAS) users, and multiple fleets of piloted eVTOL aircraft operating in select metropolitan markets from both traditional infrastructure and purpose-built vertiports. In this environment, autonomous eVTOL aircraft operations will leverage uncontrolled airspace, as well as traditional air traffic control (ATC) mechanisms within controlled airspace, to complete planned operations. Providers of Services for UAM (PSUs) may be operational for day-one autonomous operations, but their capabilities will need to further advance before they can manage all aspects of piloted and unpiloted eVTOL operations within the vertiport operating area (VOA).

[2] UAM Operational Concept - Passenger-Carrying Operations, NASA

OPERATING AND DESIGN ASSUMPTIONS

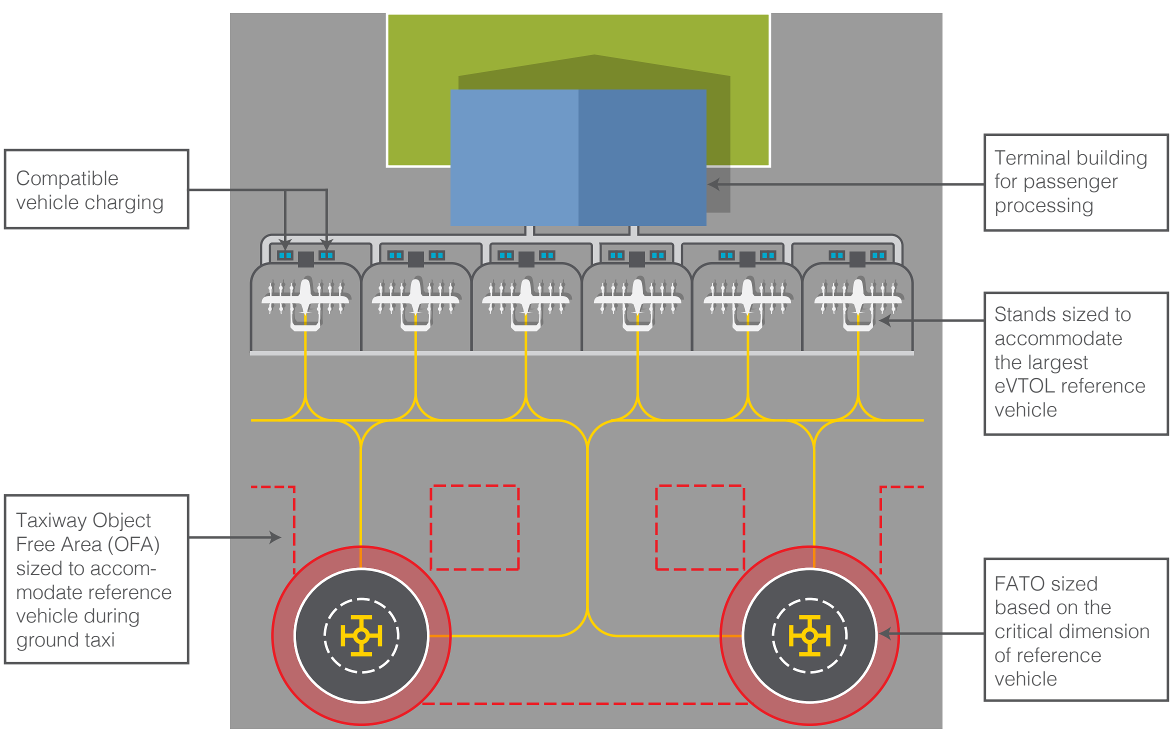
INFRASTRUCTURE

This ConOps assumes eVTOL aircraft services to and from a vertiport with six-gates, two takeoff and liftoff (TLOF) areas, and two final approach and takeoff (FATO) areas, where each TLOF is co-located with a FATO, and appropriately separated for simultaneous operations. While this layout allows for multiple operations, including ground movement, to occur simultaneously, the concepts discussed within the ConOps remain applicable to vertiports of any size. The figure below represents the layout of the vertiport used in the discussion and development of this ConOps.

AIRCRAFT

The commercial operation of autonomous eVTOL aircraft will generally be expected to occur under the relevant regulatory scheme for commuter and on demand operations such as 14 CFR Part 135 in the United States. Throughout this ConOps, it is assumed that an aircraft or fleet operator will be a relevant certificate holder with a type certificated autonomous eVTOL aircraft on their operating certificate.

It is expected that service will be scheduled in advance. Eventually, as demand and density increase, robust capacity planning will enable on-demand flights to the general public.



*Internationally generic vertiport layout, not drawn to scale.

Depending on other factors, including airspace impacts, charging requirements, and local operating agreements, this vertiport could support day-one piloted and unpiloted operations in the neighborhood of 20-30 movements per hour.

Vertiport Automation & Data Systems

Central to the functioning of a vertiport, and especially the introduction of autonomous eVTOL, is a standardized data system that provides a complete picture of a VOA and terminal facility as well as the current and future vertiport status to all operators of aircraft and infrastructure in the region. The data system should also provide an interface for eVTOL aircraft operators and other vertiport partners (e.g., public agencies, transit operators, etc.) to exchange information including booking vertiport resources.

Initially, the Vertiport Automation System (VAS) will passively interface with the existing ATC traffic flow management system (TFMS) for awareness of flow management along air traffic service (ATS) routes and ATC controlled instrument flight procedures (IFPs). Active coordination will be facilitated by the FOC, which will serve as a conduit between ATC Systems and the VAS. The VAS will also interface with UTM provider systems for UAM-specific routes through both controlled and uncontrolled airspace. As the industry matures to UML-4, the VAS and FOC will interface with PSUs for handling all traffic along approved UAM corridors.

Expected benefits of VAS include minimizing the use of voice communications while simultaneously enabling flight and vertiport operational efficiency.

VERTIPORT CHARACTERISTICS

The aircraft's fleet operator will need to know which vertiports meet the specific requirements of their aircraft (including but not limited to size and strength of infrastructure, charging capacity and type, navigational aids, airspace restrictions or obstructions) when selecting a destination vertiport and designating any en-route alternative vertiports for Continued Safe Flight and Landing (CSFL).

The capabilities and capacities of vertiports within a network will be updated and provided by the vertiport operator via the VAS. The VAS will also provide near-real time information on the status of the vertiport resources to aid in schedule management. This concept of VAS is consistent with the framework found in NASA's High Density Vertiports ConOps.[3]

[3] High Density Automated Vertiport Concept of Operations, NASA

VERTIPORT RESOURCE MANAGEMENT & SCHEDULING SYSTEM (RMSS)

The vertiport operator will provide information interfaces that show all arrival and departure reservations at each vertiport in the network and allow fleet operators to reserve resources at their desired vertiport. Similar to a traditional airport's Conditions of Use document, this interface will be a digital image that provides all of the information about individual vertiports and the requirements to operate at each. This will include vertiport metadata, available features, types of Ground Support Equipment (GSE), availability and size of stands, staffing, etc.

The reservation system will account for FATO and aircraft stand usage, as well as reserve vertiport terminal space for passengers, charging infrastructure and energy capacity, GSE, and assign landside and airside vertiport crews. The RMSS will also confirm the intended VOA occupancy of the aircraft.

The vertiport RMSS will monitor all resources in real-time and adapt the scheduling as and when needed. In particular, the RMSS will dynamically allocate/un-allocate resources to mitigate any risks or delays arising due to an off-nominal situation detected via the VAS situational awareness (SA) system or reported by any aircraft operator, ATC, or vertiport operator in the region. Dynamic allocation changes may lead to schedule changes that will be disseminated across the vertiport network during the day of operation.

There may be an instance where the vertiport has available space but does not have the necessary resources immediately available to turn around an aircraft. This will need to be considered when designing any reservation system. The system will also need to consider the likelihood of off-nominal events, weather or airspace delays, and other impacts.

In general, RMSS communications will be designed to a lower design assurance level (DAL) and will not be used for safety-critical information transfer.

VERTIPORT RESERVATIONS

As soon as possible, the eVTOL aircraft fleet operator will make a reservation at the desired destination vertiport through the vertiport's RMSS. The vertiport operator will then confirm the reservation. Upon confirmation, the vertiport's RMSS will allocate the necessary resources to the specific eVTOL aircraft operation and the system will update the availability of resources.

The RMSS of the vertiport and the fleet operator will passively update reservations until the time of flight. The updates from the fleet operator will include a manifest of passenger information including identities, weight, anticipated luggage, and any special accommodations or mobility needs. This information will be used by the vertiport operator for security, aircraft loading purposes, and to determine other resource blocking (e.g., need for a wheelchair). On the day of operation, the vertiport RMSS will provide the operator with the real-time status of all reserved resources and passenger arrivals.

As part of the VAS, the vertiport RMSS of both the origin and destination vertiports will re-allocate airside resources based on updated availability. These resources will be continuously monitored for availability based on information including updated weather forecasts, real-time operational data, and systemic delays. This concept is consistent with section 5.1.1.1 of NASA's High Density Vertiports ConOps' for pre-flight procedures.[4]

AIRSIDE VERTIPORT OPERATIONS

The VAS will provide mobile and desktop-enabled systems to display, acknowledge, and action all airside turnaround tasks including but not limited to:

- turnaround task coordination and assignment to appropriate ground staff;
- tracking and updating task statuses; and,
- graphic visualization of aircraft statuses (e.g., landing, taxiing, turn around commenced, etc.).

The VAS will also communicate with the operator's Fleet Operations Center (FOC) through an application program interface (API) that displays aircraft status information such as:

- maintenance data (e.g., line maintenance tasks); and,
- the charging status of aircraft.

The VAS will provide administrators and airside operations super users the capability to define and monitor work schedule planning and forecasting along with service level monitoring and validation.

The roles and responsibilities for airside operations may be allocated to, or shared between, the staff of the vertiport operator and the eVTOL aircraft operator. Thus, the VAS system will integrate with the FOC to provide a single source of truth (consisting of task lists and their statuses). The system will provide the ability to assign, manage, and monitor these tasks remotely for a network of vertiports from a centralized operations center.

[4] High Density Automated Vertiport Concept of Operations, NASA

SENSOR MANAGEMENT

Vertiports will be equipped with a variety of sensors intended to ensure the vertiport and surrounding environment remain in a safe state for operations, to review operational efficiencies, and to measure and mitigate any impacts of the vertiport on the surrounding environment (e.g., noise, emissions, runoff, etc.). This information can be shared with eVTOL aircraft operators and vertiport partners through the VAS.

The vertiport will have localized weather data and will be able to produce weather visualization displays in a platform available to the FOC. The vertiport may also allow third parties to install weather sensors that could provide supplemental data directly to the FOC.

The vertiport will be equipped with a suite of hazard detection sensors capable of monitoring all airside areas of the vertiport and airspace within the VOA. These sensors will enable the VAS to automatically detect and notify the vertiport and eVTOL operators of hazards, like the presence of foreign object debris (FOD), icing, birds, other aircraft, ground movement, etc., within the VOA, FATO, taxi route, and stand.

The vertiport will also have landing navigation aids on the airside that will enable autonomous aircraft to locate, navigate to, and precisely land within the FATO. The aircraft will leverage these landing aids from when it enters the VOA through the remainder of its descent to the vertiport surface.

The vertiport will be equipped with instruments to measure and record noise profiles and other possible emittance from the vertiport. This will assist in mitigating and addressing adverse impacts on the surrounding community and environment.

SITUATIONAL AWARENESS PLATFORM

One of the main purposes of the VAS will be to consolidate (SA) information within the VOA and make it available to the FOC. The SA platform will aim to merge multiple local and 3rd party data feeds, including the vertiport's hazard detection sensors, into a single source to provide a real-time picture of the airspace and environment around the vertiport.

The airspace information displayed through the SA platform will be a data fusion of aircraft telemetry, airspace status (surface and airborne routing as well as aircraft and aircraft conformance monitoring) and weather information. Other information overlays for airspace visualization will involve enabling the viewing of active and reserved airspace as well as the ability to show future reserved blocks. The SA platform will build API integrations with air navigation service providers (ANSP) and uncrewed aircraft management (UTM) providers to establish two-way communications for flow of airspace information, volumes, notice to air missions (NOTAM), etc.

SA for the airside environment of the vertiport will include providing various airside camera feeds – feeds of the FATO, TLOF, taxi route, stand, etc. – and visualization tools for the status of vertiport and surrounding airspace, as well as sensors for detecting hazards and other non-cooperative or non-conspicuous air traffic.

The SA platform will have the ability to store input data and record all movements within a network of vertiports. This information can then be used for auditing, training purposes, and safety improvement purposes.

FINANCIAL OPERATIONS

The VAS will provide a financial operations (FinOps) module for invoicing, billing, and payment management.

As part of the resource reservation booking process, the vertiport operator will invoice the fleet operator for each reservation. The FinOps module will provide API interfaces to manage reservation booking payments and other associated payments, such as for eVTOL charging, parking, etc. The FinOps module will also provide operator or category specific account statements for reconciliation purposes.

Surface reservation and payment data will be fed into the central VAS for building data models to analyze peak reservation times and associated costs for a network of vertiports.

EQUIPMENT MONITORING

To ensure safe, efficient, and uninterrupted operations throughout a network of vertiports, it will be essential to quickly detect faults (in hardware, remote sensors, software, etc.) and provide mitigations such as backup systems, tools, and processes for continuity.

The VAS will monitor the health and integrity of automated systems by providing a health monitoring dashboard for an individual and network of vertiports. Any fault detection will be mitigated by a pre-defined contingency management plan along with a data feed to the RMSS to update resource availability accordingly. The RMSS will also send a push notification to the affected aircraft operator(s).

PASSENGER MANAGEMENT

The VAS will manage and monitor the passenger journey in coordination with the fleet operator's or any other third-party passenger management systems. Capabilities of the VAS's passenger management include:

ENROLLMENT AND TICKETING

Passengers will primarily book tickets through the fleet operator and/or a demand aggregator. This booking system will enable collection of critical passenger data that will be shared with the vertiport for passenger check-in. Such passenger data could include a valid passenger ID and biometric information such as weight, height, and a photograph of the passenger's face. Certain circumstances or fleet operators may require the collection of additional information.

The operator and/or data aggregator will share this information with the vertiport operator as part of the passenger manifest before the day of operation. The passenger manifest will contain the information to validate passenger identities during the vertiport check-in process and support weight-and-balance calculations.

CHECK-IN

The vertiport will utilize a non-intrusive and automated check-in process which can recognize and verify authorized persons and passengers before granting access to the vertiport terminal. This system will also confirm any pre-provided information about the traveler and their baggage and communicate that information to the flight operator.

Due to the size of vertiport facilities, it is expected that only staff and verified passengers will enter the vertiport.

PASSENGER COMMUNICATIONS

Communication with passengers before their arrival and at the vertiport regarding boarding, security, any changes to flights, etc., will primarily be done via mobile devices. This will require an API integration between the Vertiport Automation System (VAS) and the fleet operator's system to appropriately, accurately, and concisely communicate with passengers.

The vertiport facility will also include additional communication infrastructure like speakers and signage in the case of an emergency or other digital communication impediment.

The vertiport will have in place the back-up processes and procedures (e.g., manual passenger identity validation) needed to deal with system malfunctions. System malfunctions may include a lost link between the vertiport and the fleet operator software, the vertiport and the vertiport ops control center, or a digitally unresponsive passenger.

PHYSICAL & CYBER SECURITY

As per industry best practices, the VAS will comply with the ISO/IEC 27001 standard for information security and will be updated as security protocols advance.

The VAS itself will incorporate physical and cyber security capabilities including:

- development of a Vertiport Threat Model – this will lead to development of defensive measures and appropriate backup processes to manage an unexpected cyber threat to the vertiport;
- development of authorization and authentication processes – covering identity management and roles-based access;
- establishment of auditing processes; and,
- establishment of a disaster recovery process in the event of a physical / cyber security incident.

COMMUNICATIONS & DATA SHARING

The vertiport will maintain a direct communication link between the vertiport and the aircraft operator's FOC. Once PSUs are mainstream, there will also be direct communication links between: (1) the FOC and PSU, and (2) the vertiport and PSU. For initial operations, these vertiport communication channels are assumed to be non-qualified (per ATC standards) digital communications used for strategic planning.

Separate to the vertiport communications systems, there will be C2 radio coverage on the vertiport surface for the FOC to monitor and control the aircraft. The vertiport will not communicate directly with the aircraft and will instead provide status updates through the FOC.

Personnel

The advancement of vertiport infrastructure and autonomous eVTOL aircraft includes the introduction of more sophisticated systems and new technologies. While these innovations should increase efficiencies and streamline processes, human personnel will remain a critical component to the industry's success, safety of operations, security of premises, and overall passenger experience.

Vertiport and eVTOL aircraft operators will need to hire personnel with a wide variety of backgrounds and education to manage a successful network of operations. Personnel will need to specialize in everything from security and technology adoption to maintaining charging equipment and monitoring aircraft systems. Throughout the ConOps, several personnel functions are referenced which are specific to the aircraft and passenger journeys. In some instances, personnel may be responsible for multiple functions, or a single function may be shared by multiple people.

MAINTENANCE & CHARGING TECHNICIAN

An individual who is either employed by the vertiport, a specific OEM, or an eVTOL aircraft operator and responsible for light maintenance, physical aircraft inspection, and charging of eVTOL aircraft. This individual has completed aircraft-specific training programs and obtained any required certifications from the governing aviation authority.

AIRCRAFT HANDLER

An individual who is either employed by the vertiport or an eVTOL aircraft operator and responsible for the movement and placement of aircraft requiring GSE like tows or tugs. The Aircraft Handler will have completed aircraft-specific and GSE-specific training programs and have a strong understanding of airside operations.

PASSENGER OPERATIONS SPECIALIST

An individual employed by the vertiport or an aircraft operator and responsible for the final verification and movement of passengers from the terminal onto the airside of the vertiport, and loading of passengers and luggage onto an aircraft. This person has a strong knowledge of terminal operations, airside layout and operations, and aircraft scheduling. The Passenger Operation Specialist will be required to complete aircraft-specific training programs in order to safely execute enplanement and deplanement of the aircraft and provide any required briefing to passengers.

VERTIPORT TERMINAL AGENT

An individual employed by the vertiport and responsible for managing the operations of the passenger terminal. Vertiport Terminal Agents are the primary interaction point for passengers – arrival at the vertiport, passenger check-in, passenger security and screening, and providing passenger assistance.

FOC FLEET MANAGEMENT STAFF

An individual employed by an eVTOL aircraft operator who supports the management of an eVTOL aircraft fleet. The Fleet Manager will interact with the pilot-in-command (PIC) and communicate with vertiport staff to coordinate schedules, passenger hand-offs, and maintenance. This person is located at the FOC, which may or may not be co-located with a vertiport.

PILOT-IN-COMMAND (PIC)

An individual, employed by the eVTOL aircraft operator, who has responsibility and control over the aircraft's beyond visual line of sight (BVLOS) operations. The PIC assume responsibility and control from the time the aircraft doors close at the departure vertiport, through takeoff and landing, and until aircraft doors re-open at the destination vertiport. The PIC will have a POTL role whereby they monitor the aircraft and can step in to remotely pilot the aircraft if the need arises. This individual will directly communicate with the aircraft, vertiport staff, and ATC where applicable. This person is located at the FOC, which may or may not be co-located with a vertiport.

Passenger Scheduling, Arrival, and Check-in

UAM must solve for the inefficiencies of today's commercial air travel to be successful on a large scale. Consumers will judge UAM based on time savings, ease of use, integration into existing modes of transportation, impact to their communities, security of the system, intrusiveness of passenger processes, and the overall safety of the system. The passenger and eVTOL aircraft journeys described in this ConOps consider each of these themes.

The passenger journey consists of several stages from flight reservation through taking a flight, and eventually exiting a vertiport.

FLIGHT RESERVATION

Passengers will primarily book eVTOL flight reservations through an online app or computer-based system. This may be directly through the eVTOL aircraft fleet operator, through a third-party mobility platform or demand aggregator, or in conjunction with a larger travel itinerary (e.g., packaged with an airline ticket).

The reservation system will collect passenger information including weight, passenger preferences and accommodations, as well as basic personal information (PI) to ensure passenger identity. The passenger will also read and acknowledge disclosures covering prohibited items and materials, baggage size and weight, missed and delayed flight information, vertiport arrival guidance, and information regarding the use of biometrics and PI to shorten wait times and increase safety.

This system will also provide any additional information needed about each vertiport, including the level of American Disabilities Act (ADA) accommodations, types of passenger facilities (e.g., dining options, meeting room, etc.), and any relevant surface travel updates like restricted parking, limited curb space, and intermodal transit options.

ARRIVAL AT VERTIPORT

Travel to a vertiport can occur in many ways, but the vertiport should be situated such that intermodal transportation options are robust. There may be vertiport locations with limited or no excess parking. There may also be vertiports where curb access is limited.

Upon arrival at the vertiport, the facility will have any necessary arrangements in place (e.g., wheelchair or escort) to ensure, to the maximum extent possible, that every member of the public has full access to all vertiport facilities and eVTOL aircraft. In the case of vertiports that are elevated – located on the roof of a structure or built on a platform raised above grade – the facility will have access to an elevator or alternative means of access.

The vertiport operator will work with municipalities and other partners to ensure clear signage and markings are installed indicating the location of the vertiport entrance.

Passenger arrival at the vertiport is not expected to occur more than 15 minutes prior to their scheduled departure time.

CHECK-IN

Passenger check-in will be as contactless as possible, primarily using a digital boarding pass that will be presented to a kiosk. The kiosk will match their identity and information to their pre-registered information, remind the passenger of any prohibited items, provide any itinerary updates, and inform the passenger of their aircraft's gate. After passenger verification, passengers and luggage may go through a non-intrusive security scanner and weight check. Both of these activities will be overseen by a vertiport terminal agent who can perform in-person check-in and security actions as needed.

The passenger will then be ushered into the secure area of the vertiport and will move to either their assigned gate or terminal waiting area.

Stand-Departure

PASSENGER PRE-BOARDING

Many vertiports will consist of one terminal with a relatively small number of passenger gates. The facility will be compact with a seating area and amenities like restrooms, Wi-Fi, and electronic device charging ports.

Upon check-in, passengers will be provided a group boarding designation or a gate number, depending on the configuration of the vertiport. Passengers will wait within the vertiport passenger facility, as close to the loading gate as possible, until their aircraft begins boarding. Passengers will be notified on their personal mobile device as well as by vertiport notification systems that their boarding is commencing.

PASSENGER BOARDING

It is anticipated that most eVOTL aircraft will require ADA-compatible steps or ramps to access the aircraft cabin from the surface of the vertiport. Passenger operations specialists will place this boarding equipment in the appropriate position prior to initiating the passenger boarding process.

This staff member will also open the aircraft doors and luggage storage compartments to prepare for passenger boarding.

Once the aircraft is ready for boarding, a passenger operations specialist will greet the entire boarding group, verify their identities, and escort them out of the passenger facility onto the vertiport. Passengers will then be escorted to their eVTOL aircraft, maintaining a safe distance from all other eVTOL aircraft, ground crew, charging cables, and GSE. Walkways will be well lit and segregated to help maintain safedistances between the passengers and surface hazards.

It is anticipated that most eVTOL aircraft will be designed to accommodate the loading and unloading of passengers and cargo from both sides of the aircraft simultaneously to reduce boarding time; however boarding could occur from one side.

The passenger operations specialist will guide passengers to the pre-positioned boarding equipment and assist passengers into the aircraft cabin and to their designated seats (that maybe specifically assigned to maintain weight and balance and accommodate passenger needs). Staff will also load any luggage into the aircraft, considering weight and balance requirements.

Finally, staff will ensure passengers are seated and secured, their needs are met, and that they are ready for departure. At this time, they will verify that the passenger and cargo doors are secured and inform the vertiport operator who will relay to the FOC that the aircraft is ready for departure.

At some point during this process a safety briefing will be provided to the passengers.This will most likely occur after the cabin doors close using an automated recording.

AIRCRAFT PRE-FLIGHT CHECKS

Prior to beginning to taxi, and possibly through the taxi sequence, the aircraft and FOC will run system check sequences while a maintenance technician or aircraft handler completes required manual pre-flight checks at the stand. The results of the manual check will be reported to the vertiport and FOC.

Aircraft Taxi Route — Departure

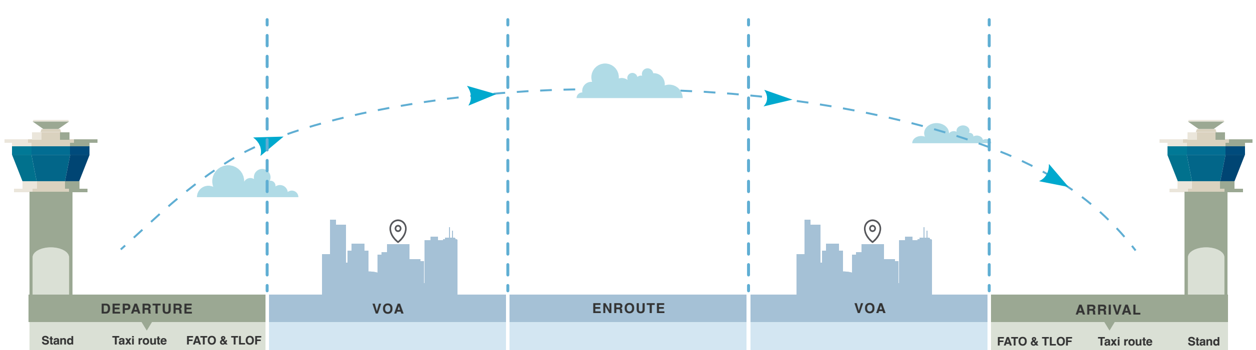
TOWS/TUGS

Regardless of vertiport location and present-day taxi procedures, this document assumes that, to minimize energy usage, all taxi movement will be conducted as ground movements, and in many instances, no hover taxi procedures in place. Eliminating hover taxi can reduce space requirements, increase the opportunity for simultaneous operations, and mitigate against the need for additional operational protocols and procedures to maintain a safe vertiport.

Therefore, autonomous eVTOL aircraft will most likely require a tow or tug solution that transports the aircraft on vertiport taxi routes.

It is expected that vertiports will have an aircraft-agnostic tow or tug solution for moving aircraft from the stand to the TLOF (and vice-versa) for day-one operations. In the case that an aircraft cannot use an aircraft-agnostic tow or tug, the vertiport will have either worked with the aircraft OEM or other providers to deploy a compatible tow or tug system. It is recognized that vertiports may have to offer multiple types of tows or tugs to accommodate different aircraft types. Based on landing gear type, there should be established standards for GSE that will inform the specific GSE mix required on each vertiport.

While day-one autonomous operations could require a human responsible for detaching the tug, it is anticipated that tugs will eventually autonomously attach and detach from aircraft.



*Generic vehicle journey

Departure from Vertiport

FATO — DEPARTURE

For the purposes of this ConOps, departing aircraft FATO operations will occur between the point at which the aircraft (and attached tug) receive go-ahead from the vertiport to enter the safety area, and the point at which the aircraft has reached its takeoff decision point (TDP) during flight.[5] Once the vertiport confirms the tug and aircraft are on the TLOF, the FOC will provide the all-clear to the vertiport and aircraft handler to approach the aircraft and detach the tug.

Once the tug and all personnel are off the FATO, the aircraft will finish all required system pre-flight checks (e.g., calibrating systems) that cannot be completed at the stand or during taxi. Upon successful completion of these checks, the aircraft will prepare for takeoff.

The aircraft, FATO, VOA, and weather statuses will be monitored redundantly in a combination of ways: for each system there must be a solution both on the vertiport and onboard the aircraft to ensure there is no lapse in SA. The aircraft, vertiport, and FOC will all be responsible for maintaining SA. If one of the three entities detects and reports an aircraft, airspace, ground, or weather status change that could impact the safety of the aircraft and passengers, that entity will be responsible for communicating the information to the other entities. The PIC and/or aircraft will then make the decision to abort the take off procedures. This is further discussed in the section titled Off-Nominal and Emergency Procedures.

[5] TDP is a legacy concept used for Category A helicopters and will be tailored for eVTOL operations.

VERTIPORT OPERATING AREA — DEPARTURE

Consistent with NASA's High-Density Automated Vertiport ConOps, the VOA is "the outermost volume surrounding an individual vertiport or several vertiports in which flight operations must be coordinated with [the vertiport and potentially ATC]. The [Vertiport Protective Volume (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."[6] The VOA is expected to have a defined radius of (eg. 6km); however, its shape and radius are dependent on vertiport location and surrounding environment.

It will be the vertiport's responsibility to monitor all traffic in the VOA, to maintain SA of all users in the surrounding airspace, to identify and track the presence of any obstacles, and to manage all traffic in the VPV. If there are multiple aircraft operators in the airspace surrounding a vertiport, any air traffic in the VOA destined for or originating from the vertiport will be managed by the vertiport. The vertiport will communicate the existence of any non-cooperative aircraft to the FOC of vertiport-managed aircraft. It is expected that some of this function will be managed by a PSU in later operations.

To the extent possible, the vertiport and cooperative operators will always maintain a clean VOA. Only aircraft with an assigned FATO for take-off and landing should occupy the VOA. All other aircraft will remain in a holding stack outside of the VOA. Flight within the VOA should be direct and minimal.

The vertiport will provide separation service to absorb uncertainties in the planning of flight operations in the VOA and for when there is an unscheduled or uncooperative aircraft in the VOA. The vertiport will communicate this information through the RMSS as a real-time data feed to the aircraft operator's FOC.

Once an aircraft leaves the VOA, it is no longer coordinated by the departure vertiport.

[6] High Density Automated Vertiport Concept of Operations, NASA

In Flight

The in-flight portion of this ConOps begins at the TDP and continues through flight until the landing decision point (LDP). Operations during the flight phase are completely determined by the operator and controlled by its FOC. Depending on the airspace, the FOC may coordinate with ATC.

VERTIPORT COORDINATION

While the aircraft is enroute to the destination vertiport, FOC will coordinate with the destination vertiport's RMSS to ensure that there will be a clear FATO and available resources for landing and turnaround operations. At this time, the aircraft operator may request additional resources or accommodations that were not originally reserved.

If the availability of destination vertiport resources affects the ongoing flight plan, the FOC and vertiport will communicate such changes to the PIC. Fleet management and/or the PIC will maintain SA of the aircraft throughout the journey and may make changes to the current flight plan or future scheduled operations. Deviation from the original flight plan is discussed in the section titled Off-Nominal and Emergency Procedures.

PASSENGER MONITORING

The FOC will maintain open communication channels with the aircraft's passengers and monitor passenger well-being and activities throughout the flight.

Aircraft Approach into Vertiport

VOA — APPROACH

The vertiport will be responsible for providing surface assurance authorization to land. Where there are no conflicting airspace regulations, the vertiport will be responsible for providing aircraft clearance into the VOA. Once landing authorization is communicated from the vertiport to the FOC, the aircraft will proceed to its LDP and communicate commencement of landing procedures to the vertiport.

Approach paths will be pre-defined and approved by the local aviation authority. Their design will be based on obstacle avoidance, wind patterns, and minimizing community impacts surrounding the destination vertiport. Approach paths will be defined on a strategic timeline and are changeable based on operational and environmental situations. The LOP could be at any point between the perimeters of the VOA and the aircraft's transition to vertical flight.[7]

STATUS MONITORING

VOA AIRSPACE STATUS MONITORING

VOA airspace status will be monitored redundantly in a combination of ways. The vertiport will provide close-range airspace monitoring and reporting. Autonomous eVTOL aircraft will also be equipped with an on-board detect-and-avoid (DAA) system that will enable the aircraft to alter its flight path to avoid unexpected obstacles. The aircraft will transmit the presence of unfriendly traffic and any flight path changes to the air carrier's FOC which will disseminate the information to vertiport operators and ATC.

Within controlled airspace, there will be active coordination between the vertiport, all aircraft, and ATC.

FATO STATUS MONITORING

Primarily, the vertiport will monitor and record FATO status both visually and with surface-mounted instruments. Furthermore, the vertiport will provide a video feed of the FATO and TLOF to the FOC which will be monitored by the PIC. Finally, there will be an aircraft-based landing hazard avoidance (LHA) system that monitors the status of the FATO and can detect any unexpected encumbrances. This information is sent in real-time from the aircraft to the aircraft operator's FOC. These three feeds will inform the landing decision-making of the aircraft.

Additionally, the operator and vertiport will develop visual, audible, and / or digital vertiport-initiated abort signals for both the FOC (ultimately relayed to the aircraft) and the aircraft. This redundancy will increase the operational safety of the vertiport and aircraft and offers a low-latency, vertiport to aircraft information flow to ensure landing incidents are mitigated.

WEATHER AND ENVIRONMENTAL STATUS MONITORING

To ensure the vertiport and aircraft have access to real-time weather and environmental information, the vertiport will supply or ensure the availability of real-time weather and turbulence information from local area sensors. The vertiport and FOC will also both ingest supplemental data service provider (SDSP) weather monitoring data. Finally, there will be on-board aircraft systems that monitor real-time conditions.

[7] LDP is a legacy concept used for Category A helicopters and will be tailored for eVTOL operations.

NAVIGATION

The aircraft navigation solution will be multi-source, including simple GPS in addition to other navigation solutions. It is assumed and will be necessary that instrument landing system (ILS) category 3 or an equivalent solution will be approved for use at a vertiport by day-one operations, enabling RNP to xLS precision performance procedures for full autoland capabilities.

FINAL DESCENT

After receiving direction from the FOC that the local aviation authority and vertiport have reported 'all-clears' for the airspace and ground space respectively, and a final confirmation of the FATO reservation, the aircraft will begin its final transition and descent to the TLOF. At this point, the aircraft, vertiport, and FOC assume the aircraft will approach the TLOF and land in a predefined manner unless one of the three entities detects and reports an aircraft, passenger, airspace, ground, or environmental status changes that could impact the safety of the aircraft or passengers.

FATO — ARRIVAL

For the purposes of this ConOps, arriving aircraft FATO operations will occur from the point that the aircraft has reached its LDP, through its transition into vertical flight, through touch down the TLOF, and until the point at which the aircraft (and attached tug) transitions out of the TLOF and safety area.

After landing, the aircraft will perform any safety checks critical for ground movement and will turn off its rotors. The aircraft handler will confirm to the vertiport that landing has occurred, rotors are off, and there are no abnormalities. Additional non-critical system checks can occur during taxi or at the vertiport stand to minimize the time spent occupying the FATO. Following the aircraft's ground movement critical checks, the aircraft operator will provide the all-clear to the vertiport and aircraft handler to approach the aircraft and attach any ground movement equipment. The vertiport will then confirm taxi-routing and indicate to the aircraft handler when they can begin taxi-movement past the hold line. The aircraft handlers will be assisted by various systems such as a taxi assist system.

Aircraft Taxi Route — Arrival

For the purposes of this report, the ground taxi route will occur from the point of transition from the FATO, until the aircraft comes to a final, parked position at the eVTOL aircraft stand or alternative destination, such as a maintenance or storage hanger. All taxi movement will be conducted as ground movements and there will be no hover taxi mandates or procedures in place.

Upon internal vertiport confirmation that the assigned eVTOL aircraft stand and taxi route are clear, the vertiport will communicate to the aircraft handler and the FOC that taxi movement can begin. If an assigned stand or taxi route becomes unavailable, the vertiport will instruct the aircraft handler to hold or use an alternative route or stand and inform the FOC of any changes. Once the aircraft is connected to the tug, taxiing off of the FATO will commence.

During taxi, the aircraft will connect to the flight operator's wireless network and the FOC will begin diagnostics checks on all aircraft flight systems. This will be supported by wireless infrastructure installed at the vertiport or through a wireless network.

During taxi, the FOC will also provide the vertiport with necessary aircraft and system health information related to battery charge and desired charge levels, aircraft cleaning, light maintenance or heavy maintenance needs, and anything else that may impact aircraft turnaround time, vertiport resource allocation, or vertiport scheduling.

From the point of eVTOL touchdown, through the aircraft turnaround process, and the aircraft's next departure from the TLOF, the vertiport will provide surface movement awareness to the FOC. This will be in addition to general camera feeds provided by the vertiport to validate aircraft, equipment, passenger, and staff assignments and clearances.

Stand — Arrival

For the purposes of this report, the eVTOL stand will be the area designated for enplanement and deplanement of passengers. This is also where light aircraft maintenance activities will take place, where aircraft charging will occur, and where aircraft may be stored.

It is anticipated that, to the extent possible, maintenance and charging activities will occur physically distant from any passenger movements. These activities should be positioned on the same side or end of the aircraft to the extent possible, providing separation between the general public and any GSE.

AIRCRAFT TURNAROUND

PARKING

Upon the aircraft coming to a complete stop in the assigned position at the stand, the aircraft handler will notify the vertiport that the aircraft is parked, who will in turn notify the FOC. The aircraft will have an external indicator that will signal that it is safe for the vertiport personnel to approach. Additionally, the FOC will notify the vertiport when it is safe to approach the aircraft to perform aircraft turnaround tasks and deplane the aircraft. The aircraft handler will tie down the aircraft if necessary.

CHARGING

Simultaneously, the vertiport will send properly trained maintenance and charging technicians to attach aircraft-compatible charging GSE and inform the FOC that charging has begun. The health of charging infrastructure, the rate of charge, the accessibility of power into the vertiport, and the health and level of the aircraft's battery system will be continuously monitored passively and independently by the aircraft, FOC, vertiport systems, and vertiport staff. All four aforementioned entities have the ability to trigger a charging cut-off in the case of an emergency. Once charging is complete, the maintenance and charging technician will remove the GSE from the aircraft and ensure the GSE is clear of the stand and taxi route object free area (OFA).

Before day-one operations commence, the vertiport will work with piloted eVTOL operators and autonomous operators to encourage the adoption of interchangeable, multi-aircraft charging GSE.

CABIN CLEANING

The aircraft's cabin will be cleaned by an aircraft handler or passenger operations specialist using aircraft-friendly cleaning solutions and tools. This process is not expected to take more than 5 minutes after passengers have disembarked the aircraft.

MAINTENANCE

While at the stand, trained maintenance and charging technicians will coordinate directly with the FOC and perform any necessary checks and light maintenance on the aircraft.

If an aircraft requires heavier maintenance, it will be taken out of service and swapped out for another aircraft. If the vertiport possesses the necessary facilities, equipment, and personnel to perform heavy maintenance, the aircraft will either remain at its stand or, most likely, will be taken to an alternative aircraft stand or hanger dedicated to aircraft maintenance. This type of space and specialty work will not exist at most vertiports, but there should be at least one nearby location where such facilities and maintenance individuals are accessible by the out-of-service aircraft.

If an aircraft needs to be moved from a vertiport, ferrying and repositioning flights will most likely be the preferred method when feasible; however, eVTOL operators will work with vertiport operators to establish at least one alternative method of aircraft repositioning at each vertiport location.

PASSENGER TURNAROUND & EXIT FROM VERTIPORT

After any required system checks occur at the stand and the aircraft is safely in a parked position, a passenger operations specialist will approach the aircraft to deplane passengers. The vertiport staff will set up the GSE used for boarding (steps, ramps, or lifts) next to the aircraft doors, open the doors, and assist in deplaning passengers.

The staff will then unload any passenger luggage and escort the passengers onto designated walkways and to the vertiport exit, which may or may not be through the passenger facility, before beginning the boarding process for the next set of passengers.

Off-Nominal or Emergency Procedures

Off-nominal and emergency procedures will occur when either the aircraft, aircraft operator, or vertiport requests a change to the confirmed flight plan after departure has commenced. This could be due to a change in status of the aircraft, airspace traffic, surrounding environment, or availability of vertiport resources. Off-nominal and emergency procedures will be designed to safely land an aircraft as close to the original destination or take-off point as possible.

These procedures could occur at any point during flight: initial departure from FATO, at or before TDP, after transitioning to forward flight, enroute, or through the phases of arrival until touchdown on the TLOF. These procedures may involve returning to the departure FATO, utilizing an alternative FATO on the arrival or departure vertiport, performing a go-around within the VOA, exiting the VOA and returning to a holding stack, or proceeding to an alternative vertiport or landing site altogether.

CONTINGENCY LANDING SITES

For each scheduled flight, the eVTOL fleet operator will identify en route contingency landing sites – vertiports, heliports, airports, and other prepared landing sites. These locations can be used for emergency diversions, delay mitigation-prompted diversions, or aborted landings to ensure continued safe flight and landing (CSFL).

The fleet operator will inform all identified infrastructure operators of the aircraft operator's intent to designate them as an route alternate landing site. This information will either be route-based (and static) or mission-based and included with the aircraft's submitted mission intent. This allows the identified landing site to consider the possibility of needing to accommodate a diverted aircraft within its existing operations.

In the event of an aircraft-triggered diversion, the aircraft and FOC will communicate the route change and selected alternate vertiport to both the original destination vertiport and the new destination vertiport.

ABORT

In the instance of an abort, while the aircraft is within a VOA, the aircraft will take a predefined route and execute a missed approach and go-around in the VOA until there has been coordination between the vertiport, the FOC, and any additional traffic scheduled to enter the VOA. Then the vertiport will provide further direction to the aircraft regarding the use of the same FATO, an alternative FATO, or an alternative landing site. This should happen rapidly, possibly using highly-autonomized scheduling systems and active communication with vertiport personnel, FOC personnel, and all potentially affected operations scheduled to enter the VOA.

MISSED APPROACH

The vertiport, aircraft, and FOC are all responsible for communicating a missed approach. When a missed approach occurs, the vertiport will hold the FATO for the aircraft in question and direct any other aircraft scheduled to enter the VOA to fly an alternate approach or enter a holding stack.

Once the aircraft in question has landed, the vertiport will confirm the landing schedule, estimated timing, and place within the holding stack for other scheduled operations.

All missed approach procedures will be created with the applicable governing aviation authority and are subject to their approval.

RESUMPTION OF FLIGHT

After an emergency action is taken and the aircraft has safely landed, the FOC and vertiport will address any known issues. The vertiport, aircraft, and FOC must properly address all aircraft and infrastructure concerns and review the operation and environment to understand the impact of the emergency event and possible additional emergency procedures that need to be initiated.

There will be coordination between the vertiport, the FOC, and any additional traffic within the VOA, to determine whether the aircraft is able to recommence takeoff or if it must return to a stand (and which stand). This rapid coordination will leverage highly-autonomized scheduling systems and active communication with all affected parties. Once an updated flight plan has been filed with all parties involved, the aircraft can resume operations.

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