VERTIPORT AUTOMATION
SOFTWARE ARCHITECTURE AND REQUIREMENTS

New York UAS Test Site (NYUASTS)
Northeast UAS Airspace Integration Research Alliance (NUAIR)
Created in support of National Aeronautics and Space Administration (NASA)
Aeronautics Research Mission Directorate (ARMD) Integrated Aviation Systems
Program (IASP) Advanced Air Mobility (AAM) Project Number 395872
Contract Number: NND15SA83B
July 26 2021

Contents

Tables

Figures

Acronyms

4D	Four-Dimensional
AAM	Advanced Air Mobility
AC	Advisory Circular
ACM	Aircraft Conformance Monitor
ADS	Arrival and Departure Scheduler
ANSP	Air Navigation Service Provider
ARMD	Aeronautics Research Mission Directorate
ASTM	American Society for Testing and Materials
ATC	Air Traffic Control
BDD	Behavior-Driven Development
CIWS	Corridor Integrated Weather System
CLIN	Contract Line Item Number
CNS	Communications, Navigation, and Surveillance
ConOps	Concept of Operations
CSS	Cybersecurity Service
DMS	Data Management System
DNS	Domain Name System
DOS	Denial of Service
DoDAF	Department of Defense Architectural Framework
ePIC	Electronic Pilot in Command
FAA	Federal Aviation Administration
FOCC	Fleet Operational Control Center
FOD	Foreign Object Debris
GUI	Graphical User Interface
HIS	Hazard Identification Service
HDV	High-Density Vertiplex
IASP	Integrated Aviation Systems Program
NASA	National Aeronautics and Space Administration
NC	National Campaign
NEXRAD	Next Generation Weather Radar
NIST	National Institute of Standards and Technology
NOTAM	Notice to Airmen
NUAIR	Northeast Unmanned Aircraft System Airspace Integration Research Alliance
PIC	Pilot in Command
PSU	Provider of Services to Urban Air Mobility
RAS	Risk Assessment Service
RESTful	Representational State Transfer
RM	Resource Manager
RMSS	Resource Management and Scheduling Service
RPIC	Remote Pilot in Command
SDR	System Design Review
SDSP	Supplemental Data Service Provider
SIC	Second in Command
SPD	System Performance Dashboard
SQL	Structured Query Language
STS	Surface Trajectory Service
SvcV-1	Service Viewpoint One
SvcV-4	Service Viewpoint Four
TAF	Terminal Aerodrome Forecast
TFR	Temporary Flight Restriction
TLOF	Touchdown and Liftoff
UOE	Urban Air Mobility Operations Environment
UAM	Urban Air Mobility
UML-4	Urban Air Mobility Maturity Level Four

UX	User Experience
VAS	Vertiport Automation System
VA-SDSP Interface	Vertiport Automation Supplemental Data Service Provider Interface
V-IDS	Vertiport Information Display System
VMD	Vertiport Manager Display
VOA	Vertiport Operations Area
VPV	Vertiport Volume
VTOL	Vertical Takeoff and Landing
WD	Weather Display
Wx	Weather

1 Introduction

In June 2020, the National Aeronautics and Space Administration (NASA) Aeronautics Research Mission Directorate (ARMD) Integrated Aviation Systems Program (IASP) Advanced Air Mobility (AAM) Project High-Density Vertiplex (HDV) Subproject issued a request for proposals to contribute to its research in autonomy associated with high-density vertiport operations. The objective of the HDV Subproject is to understand barriers to operationalization of vertiports, development of infrastructure requirements needed to increase the scale of operations at vertiports and maturing of automation technologies to support the growth of traffic throughput at vertiports. Artifacts developed by the HDV Subproject will be used as input into testing range requirements for the AAM National Campaign (NC) series highlighting high-density vertiport operations for passenger- and cargo-carrying vertical takeoff and landing (VTOL) aircraft operations.

The AAM Vertiport Automation Project consists of three major Contract Line Item Numbers (CLIN):

CLIN 1: Vertiport Automation Technology Trade Study (COMPLETED)

The purpose of CLIN 1 was to perform a trade study of the applicable vertiport technologies and capabilities required to enable automated high-density vertiport operations and document the results. The scope of the trade study includes:

- Identification and characterization of technologies needed for safety, security, efficiency, and resilience;
- Identification of functional allocations between vertiport infrastructure, aircraft, and airspace services; and
- Identification of current vertiport technology gaps.

CLIN 2: High-Density Automated Vertiport Concept of Operations (COMPLETED)

The purpose of CLIN 2 was the development of a Concept of Operations (ConOps) covering vertiports of varying sizes, configurations, service offerings, and locations. UAM aircraft include conventional rotorcraft, unmanned VTOL aircraft, and novel piloted VTOL aircraft. The 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). The purpose of the ConOps is to:

- Serve as a communications tool;
- Provide a consolidated view to guide future technology developers and innovators in creating solutions;
- Document a representation of community views of an automated vertiport system;
- Define the roles and responsibilities of vertiport users, vertiport operators, and connected stakeholders;
- Serve as a basis to develop vertiport automation prototype requirements, specifications, data interface requirements, and system performance criteria; and
- Identify technology, regulatory, and research needs for vertiport operations.

CLIN 3: Vertiport Automation Software Architecture and Functional Requirements (THIS DOCUMENT)

The purpose of CLIN 3 was to mature the VAS described in the High-Density Automated Vertiport ConOps[1], into a set of artifacts that enable the development of a VAS prototype. The scope of CLIN 3 was to develop:

- A VAS Software Architecture diagram that logically organizes VAS functionality into specific software components;
- A VAS Software Trade Study identifying existing commercial products and NASA research that can be used in part or with modifications to fulfill VAS functionality.
- A set of VAS Functional Requirements which decompose the VAS concept into software functionality, including any interfaces and data flows needed;
- A set of VAS Test Approaches describing a methodology for verification of the VAS Functional Requirements; and
- An application user experience (UX) design study describing the general features needed in a VAS user interface.

1.1 Purpose and Scope

The purpose of this Final Report is to provide context and background information to the artifacts developed during CLIN 3. Table 1 below contains a copy of all CLIN 3 artifacts.

Table 1. CLIN 3 Artifacts

CLIN 3 Artifact Title	CLIN 3 Artifact File
VAS Software Architecture	VAS SvcV-1 Architecture Diagrar; VAS SvcV-4 Architecture Diagrar
VAS Functional Requirements	VAS Functional Requirements - Fina
VAS Test Approaches	VAS Software Test Approaches - Final -
VAS Software Trade Study	VAS Software Trade Study - Final.docx
VAS UI Design Concepts & Examples	VAS UI Design Concepts and Examp

[1] "High-Density Automated Vertiport Concept of Operations," NUAIR, https://ntrs.nasa.gov/citations/20210016168

The VAS artifacts listed in Table 1 were developed using the High-Density Automated Vertiport ConOps as their primary input. In this context, the VAS is a Supplementary Data Service Provider (SDSP) as defined by the NASA UAM Vision ConOps UML-4[2]. As such, the VAS artifacts not only include details regarding internal VAS services and functions, but also details of interoperability and interfacing with external entities such as Providers of Services to UAM (PSU), fleet operators, and flight crew. The systems engineering team responsible for VAS Functional Requirements analysis and decomposition maintained a system-level focus favoring breadth over depth, decomposing functional requirements to a third tier. This approach provided a strong set of initial functional requirements for the full range of envisioned VAS services. Subsequent systems engineering, and software development efforts may then use these foundational artifacts as a starting point for detailed systems design and prototype development.

1.2 Assumptions

The systems engineering team applied the following assumptions during functional requirements analysis and decomposition:

- All the assumptions listed in the Northeast Unmanned Aircraft System Airspace Integration Research Alliance (NUAIR) High-Density Automated Vertiport ConOps are applicable to the VAS Software Architecture, VAS Functional Requirements, and VAS Test Approaches. Refer to the ConOps for traffic density, airspace design, regulatory (authority, rules, and procedures), stakeholder roles, and infrastructure assumptions.
- Concepts and assumptions of the following technical references broadly apply:
  - NASA UAM Vision ConOps UML-4 v1.0
  - Federal Aviation Administration (FAA) UAM ConOps v1.0[3]
- The VAS (both automated and manual functions), PSU, fleet operator, and flight crew roles and responsibilities are shown in Table 2 and Table 3 which depicts assumptions made for those stakeholders.

  The VAS services are connected through the Data Management System (DMS) (described in Section 2.3) which transmits and stores VAS service data and messages. The DMS is not included in the VAS Functional Requirements and VAS Test Approaches, however, note that the DMS plays a vital role in the storage and transmission of VAS service data.
- The VAS is responsible for management of the vertiport resources under its control.
  - This responsibility includes vehicles operating on the vertiport surface as defined by AC 150/5210-20A.
  - The VAS issues recommended surface trajectories to aircraft for navigating between touchdown and liftoff (TLOF) pads, parking pads, and other surface destinations.
- The PSU is responsible for authorizing aircraft for take off and landing, and airborne strategic separation. Prior to issuing a clearance, the PSU coordinates with the VAS to verify resource availability.

[2] "UAM Vision Concept of Operations (ConOps) UAM Maturity Level (UML) 4 Version 1.0," NASA, https://ntrs.nasa.gov/citations/20205011091
[3] "Urban Air Mobility (UAM) Concept of Operations (ConOps) Version 1.0," FAA, https://nari.arc.nasa.gov/sites/default/files/attachments/UAM_ConOps_v1.0.pdf

- The flight crew is responsible for tactical separation and collision avoidance of aircraft while airborne.
- The flight crew is responsible for executing the surface trajectory and maintaining safe separation between other aircraft and ground vehicles on vertiport movement areas.
  - This assumption is an evolution of the following statements taken from the NASA UAM Vision ConOps UML-4 v1.0, FAA UAM ConOps v1.0, and NUAIR High-Density Automated Vertiport ConOps:
    - NASA UAM Vision ConOps UML- 4 v1.0, Section – 4.2.4 Ground Operations and Maintenance: "Aircraft ground traffic control (i.e., navigation from the gate at which passengers board/disembark to the area where the aircraft lifts off and vice-versa) is managed by PSU-to-PSU connection."
    - FAA UAM ConOps v1.0, Section – 4.3.7 UAM Aerodrome: "The UAM aerodrome information is used by UAM operators and PSUs for UAM operation planning including strategic deconfliction and DCB; however, the UAM aerodromes do not provide strategic deconfliction or DCB services."
    - NUAIR High-Density Automated Vertiport ConOps, Section – 4.4.4 Surface Trajectory Service: "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."
- The VAS is NOT responsible for tactical separation or collision avoidance of aircraft airborne or on the vertiport surface.
- The VAS continuously shares its operational status and other relevant tactical data (e.g., TLOF pad closed for foreign object debris [FOD] or surface visibility) with UAM stakeholders (i.e., PSUs, fleet operators, and flight crew). These other stakeholders, and NOT the VAS, are responsible for determining whether extant conditions warrant avoiding or using the vertiport.
  - To illustrate, consider a scenario where an aircraft is en route to a vertiport but local weather conditions at the vertiport deteriorate to a level below the recommended tolerances of the approaching aircraft. The VAS shares this weather data with the PSU, fleet operator, and aircraft but cannot prevent the aircraft from landing at the vertiport. The approach and subsequent landing is performed "at-risk" by the other stakeholders.

1.3 Document Organization

The remainder of this document is organized into four sections: Vertiport Automation System, VAS Functional Requirement, VAS Test Approaches, and Follow-On Research Opportunities.

- **Vertiport Automation System Software Architecture:** This section introduces the VAS software architecture, depicts VAS services context descriptions and functionality, and describes core VAS components.

- **Vertiport Automation System Stakeholders:** This section provides an overview of the UAM stakeholders defined in the software architecture.
- **Vertiport Automation System Services Overview:** This section describes the VAS services functionality as derived from the High-Density Automated Vertiport Concept of Operation.
- **Vertiport Automation System Functional Requirements:** This section introduces the VAS Functional Requirements and describes the process used in their development.
- **Vertiport Automation System Test Approaches:** This section introduces the VAS Test Approaches and describes the process used in their development.
- **Follow-on Research Opportunities:** This section summarizes additional research needed for the development VAS to guide future research efforts relating to UAM and high-density automated vertiports.

2 Vertiport Automation System Software Architecture

2.1 Services Context Description

Figure 1 displays the VAS Service Viewpoint One (SvcV-1) architectural diagram. A SvcV-1 is type of architectural diagram as outlined in the Department of Defense's Architectural Framework (DoDAF):

"The SvcV-1 addresses the composition and interaction of [VAS] Services. The SvcV-1 links together the operational and services architecture models by depicting how resources are structured and interact to realize the logical architecture[4]."

The systems engineering team designed the VAS SvcV-1 following the precedent set by the UAM high-level architecture. The figure follows the same configuration, layout, and coloring as the UAM architecture and presents the VAS as an SDSP interfacing with the PSU, fleet operator, and UAM aircraft. The SvcV-1 also includes messages communicated between stakeholders to provide additional insight into the general types of data and information the VAS will manage. The NUAIR High-Density Automated Vertiport ConOps served as the primary reference for the development of the SvcV-1 and other systems engineering artifacts. From the ConOps, the systems engineering team distilled and identified discrete, logical software components to form the VAS Software Architecture.

Figure 1 shows the VAS encapsulated as a chief component of a vertiport, with vertiport infrastructure being a complementary component. Discussed in more detail below, the VAS itself includes four conceptual types of sub-components:

1. An interface for interoperability with external stakeholders (i.e., the Vertiport Automation – Supplemental Data Service Provider Interface [VA-SDSP Interface]);
2. A common software infrastructure for cybersecurity, system monitoring, and data management;
3. An interface for vertiport infrastructure and instrumentation (e.g., weather sensors); and
4. Internal software services (e.g., Risk Assessment Service [RAS]).

2.2 External Stakeholder Interfacing

The VA-SDSP Interface establishes a mechanism for communication with external entities and includes three types of interfaces: a representational state transfer (RESTful) interface, a direct communication link and an external connection client. These interfaces cover both ground-to-ground and ground-to-air communication. The RESTful interface provides external stakeholders a mechanism for interaction with the VAS to perform functions such as requesting a vertiport resources or subscribing to data published by the VAS. Aircraft operating on or near the vertiport communicate directly with the VA-SDSP using the direct communication link. Coordination with other vertiports controlled by different organizations is also accomplish via the VA-SDSP. Because the VAS not only produces data, but also consumes data from external sources, an external connection client is also needed.

The systems engineering team believes that standardization of the VA-SDSP Interface is paramount for the future success of UAM. This is to ensure that the diverse set of emergent UAM aircraft speak the same language when interoperating with vertiports regardless of ownership or geographical location. Section 4.1 provides more details about the VA-SDSP Interface.

2.3 Common Software Infrastructure

Several principal software design concepts span the entirety of the VAS earning a devoted category in the SvcV-1. These include cybersecurity, system monitoring, and data management. Cybersecurity involves the protection and safeguarding of the VAS and its operation by providing authentication, authorization,

[4] "DoDAF Viewpoints and Models," DoD, https://dodcio.defense.gov/Library/DoD-Architecture-Framework/dodaf20_services1/

and auditing of users. System monitoring is associated with cybersecurity but also provides for the continuous determination of system and subsystem status to ensure all components of the VAS and its infrastructure are operating properly and within design tolerances. Data management includes routing of data between VAS services, a centralized data repository, matching of data to individual flight, and data mediation functionality.

2.4 Vertiport Infrastructure Data Connectors

Vertiports will require an array of sensors and other instrumentation to detect and measure the surrounding operational environment. Such sensors and instrumentation include weather (Wx) sensors, FOD, and noise level meters. This VAS sub-component is simply an interface for the management, configuration, and data-receipt of the underlying vertiport infrastructure.

2.5 Internal Software Services

Six internal services are responsible for a significant amount of VAS functionality. These services, detailed in Section 4, include:

- Resource Management and Scheduling Service (RMSS);
- Surface Trajectory Service (STS);
- Aircraft Conformance Monitor (ACM);
- Hazard Identification Service (HIS);
- Risk Assessment Service; and
- Vertiport Manager Display (VMD).

2.6 VAS Modularity

The systems engineering team designed the VAS with modularity as a driving design tenet. Though UML-4 was the target maturity level for the VAS design, the team deliberately followed a modular approach to accommodate lower UML levels. For example, a UML-1 vertiport will likely not need the full gamut of VAS services. Such a vertiport may only need a VMD and RMSS. Alternatively, a single VAS may be control multiple vertiports. A modular approach provides the flexibility to accommodate a range of UML levels and vertiport configurations.

2.7 Services Functionality Description

Figure 2 displays the VAS SvcV-4 architectural diagram. A SvcV-4 is type of architectural diagram as outlined in the DoDAF:

"The SvcV-4 DODAF-described Model addresses human and service functionality. The primary purpose of SvcV-4 is to:

- Develop a clear description of the necessary data flows that are input (consumed) by and output (produced) by each resource;
- Ensure that the service functional connectivity is complete (i.e., that a resource's required inputs are all satisfied); and
- Ensure that the functional decomposition reaches an appropriate level of detail[4]."

Figure 2, while similar, elaborates on Figure 1 and presents more details on the message exchange between internal and external VAS components. As revealed by the legend, color-coded lines, both solid and dashed, reveal the context of the message exchange, including details about the producer and consumer and whether the exchange features a direct communication link. The messages shown in Figure 2 are captured in the functional requirements by service and in the corresponding test approaches.

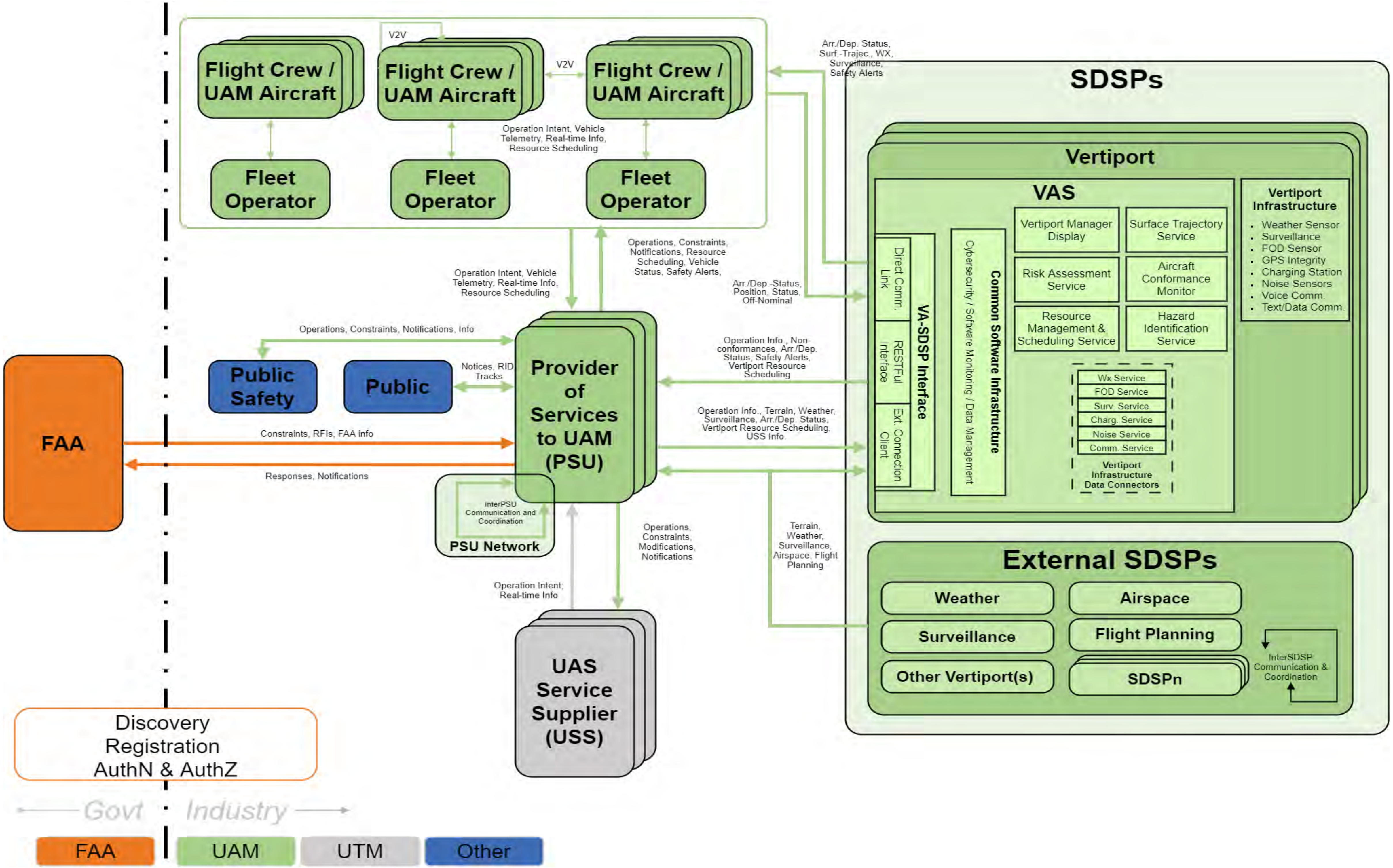


Figure 1. SvcV-1 Services Context Description

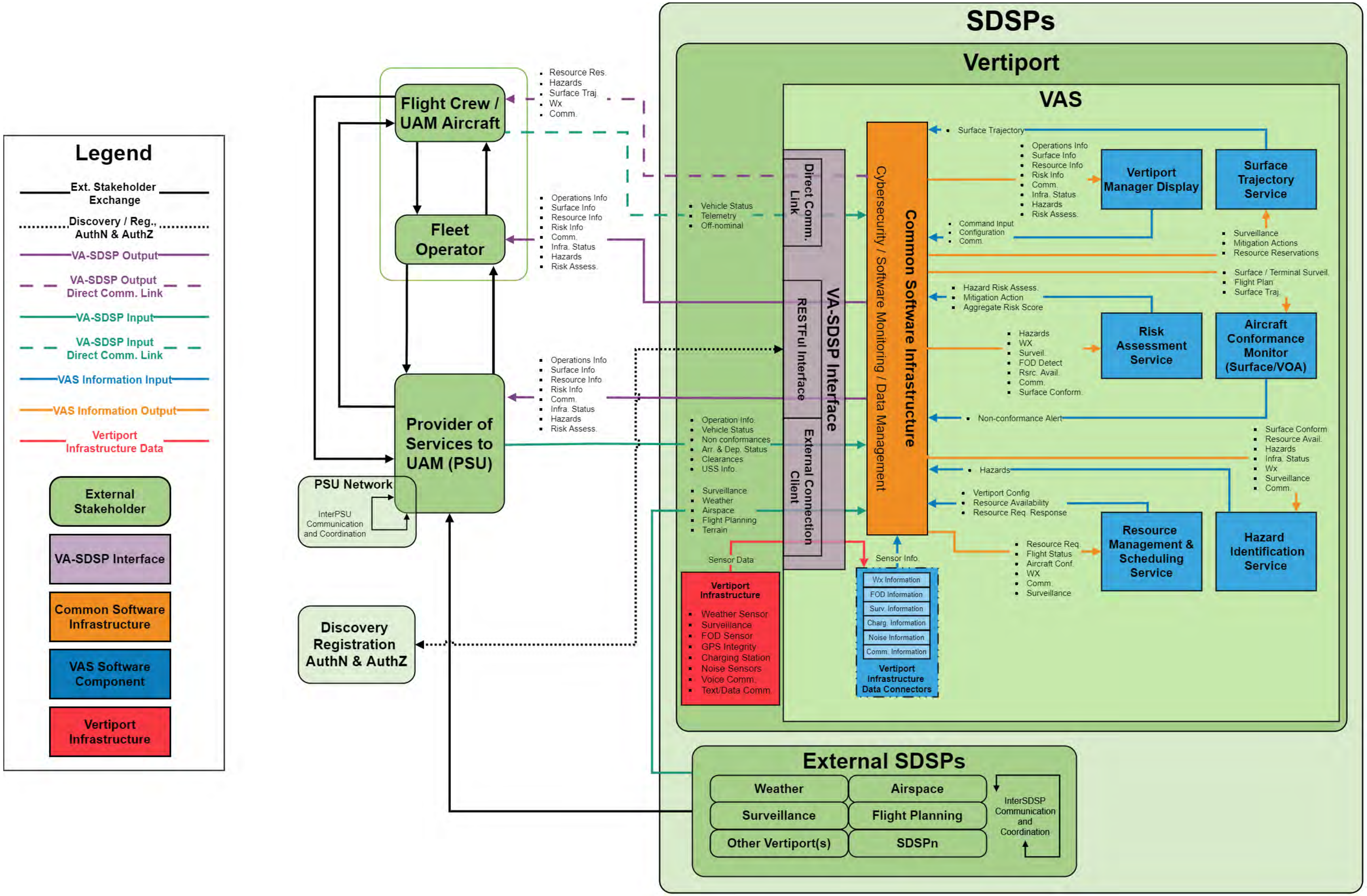


Figure 2. SvcV-4 Services Functionality Description

3 Vertiport Automation System Stakeholders

Brief descriptions of the vertiport stakeholders depicted in the VAS Software Architecture and referenced in the VAS Functional Requirements are provided below. While the stakeholders are decomposed to represent their specific functions, roles, and responsibilities, organizations may take on the role of a single stakeholder or many stakeholders. These descriptions are intended to provide context to the CLIN 3 artifacts.

3.1 Vertiport Automation System

The VAS is a SDSP designed to support UML-4 operations by automating the following functions:

- Scheduling the use of TLOF pads for aircraft arrival and departures;
- Efficiently routing aircraft on the vertiport surface;
- Enhancing safety through hazard identification and risk mitigation;
- Monitoring vertiport infrastructure and VAS software; and
- Detecting and responding to cybersecurity incidents.

The VAS is composed of nine services (further defined in Section 4) organized in a decentralized software architecture. Services share pertinent data with each other through digital messages. The VAS automation is controlled by the vertiport manager using a user interface to provide manual inputs or override VAS decision-making, when necessary. A core purpose of the VAS is the control of vertiport resource availability and coordination of the vertiport schedule. Resource availability is published to external stakeholders who submit requests for use of vertiport resources at a given time and date. Publishing the vertiport resource availibity provides the vertiport manager flexibility in generating prioritized resource availibity and reduces the negotiations with the vertiport for high-density scheduling. Resource availability is set by the vertiport manager and can be tailored to specific business rules. VAS can be configured to prioritize access to vertiport resources to specific fleet operators and PSUs depending on the business relationships. Once a resource request is approved, VAS assigns TLOF pads to aircraft.

During operations, Surface trajectories are generated for vertiports with surface taxi operations. The strategically deconflicted trajectories provide flight crews with a path connecting origin-to-destination on the vertiport surface, supporting efficient movement of aircraft and ground vehicles on the vertiport surface. The flight crew is responsible for executing the surface trajectory and maintaining safe separation between other aircraft and ground vehicles on vertiport movement areas. The progress of arriving and departing aircraft is continuously monitored and subsequent changes are made to reservations as arrival and departure times change. While operations are progressing, the VAS monitors and identifies hazards, alerting the vertiport manager of any extant risks and suggesting risk mitigation actions.

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. The vertiport manager manages the VAS via the VMD and supervises the operational status, VAS services, and connectivity to external stakeholders. At UML-4, the vertiport manager will serve as a supervisor for VAS services, using the VMD to monitor nominal vertiport metrics, potential hazards or anomalies, or providing input for risk mitigation. The vertiport manager also may need to manually communicate, when time is critical, with external stakeholders if equipment at the vertiport or on the aircraft has malfunctioned or has lost functionality to implement risk mitigation strategies. While many of the VAS services are highly automated for UML-4 operations, the vertiport manager provides necessary inputs to configure and define monitoring frequencies, decision criteria, and system conformance criteria.

3.3 Fleet Operator

The fleet operator is a Part 121 or Part 135 FAA-certified operator responsible for day-to-day fleet management, including maintaining airworthiness and scheduling fleet resources. The fleet operator combines both roles of Fleet Operational Control Center (FOCC) and Fleet Dispatcher. Fleet operators retrieve published vertiport resource availability and submit flight plans to a PSU to broker negotiations between the arrival and departure vertiports. The fleet operator must subscribe to a PSU and receive traffic management services prior to operating in the UAM Operations Environment (UOE), Vertiport Operations Area (VOA), or Vertiport Volume (VPV). Traffic management services can be provided by 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. 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.

3.4 Flight Crew

The flight crew may consist of the pilot in command (PIC), remote PIC (RPIC), second in command (SIC), and electronic pilot in command (ePIC)[5]. It is assumed there will be a mixed fleet comprising both manned (PIC) and unmanned (RPIC or ePIC) aircraft that arrive and depart from the vertiport. Therefore, flight crew broadly captures the decision-making agent, be it a pilot or autonomous aircraft system, in which the VAS communicates with. In either scenario, the flight crew manages the aircraft from gate-to-gate. The role of the flight crew 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.

3.5 Provider of Services to Urban Air Mobility

The PSU acts as broker between the fleet operator and vertiport manager, connecting vertiport resource supply with fleet operator demand. Aircraft operating in the UOE, including aircraft operating in the VOA or VPV, must be subscribed to a PSU. The PSU coordinated with vertiports to sequence arrival and departure traffic according to reservations made and authorizes arrivals and departures from vertiports. Additionally, PSUs provide strategic deconfliction services to UAM aircraft during operations. The PSU help the fleet operator achieve an acceptable trajectory and desired timing while ensuring that the flight plan meets the required performance standards of the UOE. Trajectories generated by PSUs are four-dimensional (4D) (longitude, latitude, altitude, and time) and are monitored for adherence during all phases of flight. PSUs adhere to standards on data exchange, data logging, and adjusting flight trajectories based on issued UOE airspace design changes. Multiple PSUs, qualified by the FAA, may serve a geographic region.

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. The PSU Network relies on a digital infrastructure that connects various PSUs to enable safe, efficient, and scalable airspace operations. Using this network, PSUs will share information amongst one another such as FAA-provided data such as changes to UOEs, Notices to Airmen (NOTAM), temporary flight restrictions (TFR), or other airspace-related publicly available information that can be accessed by stakeholders. The digital infrastructure connecting PSUs provides

[5] "Electronic Pilot in Command" describes the complex system, designated by the operator, that is ultimately responsible for the safe operation of the flight in the absence of a remote or onboard human pilot in command.

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.

3.7 Supplemental Data Service Provider

SDSPs provide supplemental data to support air and surface flight operations. Traditional functions served by the FAA and other government agencies, such as the broadcast of weather observations and forecasts, may be performed by third-party organizations providing data-as-a-service. FAA approval may be necessary for SDSPs that provide flight-critical information to FAA qualified stakeholders. SDSPs may also provide ancillary data services 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 services. SDSPs may be located at the vertiport, or adjacent to the vertiport, providing localized data pertinent to VOA, VPV, or surface conditions to enable VAS services. The VAS is classified as an SDSP because it provides vertiport data (e.g., resource availability, local conditions, surface trajectories) to the PSU and fleet operator to support flight planning and decision-making.

3.8 Federal Aviation Administration

The FAA establishes rules, regulations, and policies for the airspace and the stakeholders involved in public flight operations. Additionally, the FAA serves as both a civil aviation authority and an air navigation service provider (ANSP). FAA authority includes defining the areas of high-density UAM operations (e.g., high-density routes, UOEs) and establishing operational rules for flight in those environments. The FAA will qualify 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.

3.9 Stakeholder Decision Making Roles and Responsibilities for Vertiport Flight Operations

All vertiport stakeholders contribute to a highly interconnected process that supports gate-to-gate flight operations, from pre-flight procedures and coordination to post-flight wind down activities. The VAS Functional Requirements focus on the VAS (automated) and vertiport manager (manual), however, because of the close dependencies amongst VAS external and internal stakeholders, external and internal roles and responsibilities must be considered. Table 2 and Table 3 display the roles and responsibilities for vertiport stakeholders by phase of flight. The purpose is to highlight the systems engineering team's assumptions made when generating the functional requirements and highlight key decisions made across stakeholders (**in bold text**). Not every stakeholder is indicated in the table, such as the PSU Network and SDSPs. These stakeholders do not make final approval or rejection decisions, but rather support flight operations. The FAA is also excluded from the table because the FAA will not be providing air traffic separation services like what is done today with air traffic control (ATC); however, the FAA has final decision-making authority with respect to the airspace, operating procedures, and stakeholder qualification.

Table 2. Stakeholder Decision Making Roles and Responsibilities.

Stakeholder Decision Making Roles and Responsibilities for Vertiport Flight Operations		
Phase of Flight	**VAS (Automated)**	**VAS (Vertiport Manager)**
Pre-Flight	- Receives reservation request - Confirms resource availability - **Allocates resources for reservation request** - Identifies alternatives when resources are unavailable - Generates resource notification (to PSU and Fleet Operator)	- Configures vertiport resources (to VAS) - Configures business rules (to VAS) - **Allocates and assigns physical assets**
Taxi for Takeoff	- **Assigns departure pad (to Fleet Operator and Flight Crew)** - Generates surface trajectory (to Flight Crew) - Monitors surface trajectory conformance	- Configures separation buffer and restricted vertiport volumes (to VAS)
Takeoff	- Confirms takeoff and takeoff time - Monitors aircraft status	- No action
Climb and Cruise	- Monitors aircraft status - **Updates resource availability based on aircraft timing (to PSU)**	- Defines monitoring frequency
Approach	- **Freezes resource assignments (to Fleet Operator and Flight Crew)** - Monitors aircraft status (with higher frequency) - Confirms arrival pad free of obstructions (to Flight Crew)	- Defines monitoring frequencies (external and internal) - Defines freeze waypoints for resource assignments
Land	- Monitors aircraft status (with higher frequency) - Confirms aircraft landing - Confirms parking position is free of obstructions	- Defines monitoring frequencies (external and internal)
Taxi	- Generates surface trajectory (to Flight Crew) - Monitors surface trajectory conformance	- Configures separation buffer and restricted vertiport volumes (to VAS)
Post-Flight	- Monitors aircraft status	- **Allocates and assigns physical assets**
Emergency Operations	- Passes the appropriate information to the Vertiport Manager - Monitors emergency - Makes informed decisions to return to nominal operating conditions	- **Intervenes with focus targeted at specific issue at hand** - **Allows automated VAS functions to continue to run if non-affected** - **Executes emergency action plan if appropriate**
Anytime	- Monitors, protects, responds, and recovers from cybersecurity events - Maintains external stakeholder interface - Monitors internal system - Detects anomalies and identify hazards - Performs risk assessment - Maintains regulatory compliance	- Adjusts anomaly, hazard, and risk decision criteria - Investigates detected anomalies, identified hazards, and calculated risks - Implements risk mitigation - Analyzes existing operational outlook via dashboard

[6]

[6] Key decisions made across stakeholders are in **bold text.**

Table 3. Stakeholder Decision Making Roles and Responsibilities Continued

Stakeholder Decision Making Roles and Responsibilities for Vertiport Flight Operations			
Phase of Flight	**PSU**	**Fleet Operator** *Fleet OCC and Fleet Dispatcher*	**Flight Crew and Aircraft** *PIC, RPIC, SIC, or ePIC*
Pre-Flight	- Receives flight plan from fleet operator - Checks and validates flight plan & time slots - Forwards the reservation requests for resources to the departure and arrival VAS. - **Generates airborne trajectory (to Fleet Operator and Flight Crew)** - **Transmits Approved Flight Plan & flight release**	- Verifies aircraft airworthiness - Verifies flight crew readiness - Files Flight Plan (to PSU) - Conducts passenger security screening - Conducts passenger briefing - Boards passengers & load cargo	- Conducts aircraft pre-flight - Verifies Flight Plan - Conducts Weather Check - Confirms Passenger Briefings - **Verifies passenger and cargo security**
Taxi for Takeoff	- **Assigns takeoff time slot** - Coordinates with departure and arrival VAS	- **Executes flight release** - Performs dispatch duties - Verifies release time - Verifies weather along route	- Sequences into ground traffic - Taxis into position and hold for release - Performs pre-takeoff checks - **Activates flight plan**
Takeoff	- **Generates sequence of departure traffic (to Fleet Operator and Flight Crew)** - **Authorizes departure (to Flight Crew)** - Verifies takeoff time (to VAS)	- Initiates flight following - Validates flight tracking - Updates arrival time	- Conducts final takeoff checks - Liftoff to hover, performs hover check - **Initiates takeoff** - Transitions to climb out profile
Climb and Cruise	- Monitors for aircraft airborne non-conformance - Brokers Flight Plan changes - **Generates Sequence arrival traffic** - **Assigns landing time slot**	- **Updates Flight Plan (to PSU)** - Reports aircraft status - Conducts flight following	- Flies departure procedure - Levels off at assigned altitude - Conducts level off checks - Flies designated routes
Approach	- **Authorizes arrival to land (to flight crew)** - Monitors for aircraft airborne non-conformance - Adjusts for any non-conformance	- Reports aircraft status	- Conducts pre-landing checks - Flies approach procedures - Transitions from cruise to hover profile
Land	- Verifies Landing (to VAS)	- Reports aircraft status - **Terminates flight plan**	- **Terminates approach to FATO** - Performs after landing checks - Verifies parking position and taxi route
Taxi	- No action	- Performs dispatch duties - Verifies parking destination - Initiates ground crews	- Taxis to assigned parking - Executes aircraft parking - Maintains separation from other aircraft, vehicles, and objects
Post-Flight	- No action	- **Determines maintenance actions** - Disembarks passengers and cargo - Resupplies, Refuels and/or Recharges	- Conducts aircraft shutdown - Offloads passengers - De-energizes systems - Secures aircraft - Conducts post flight checks & inspection - Oversees resupply, refuel and/or recharge
Emergency Operations	- **Updates airborne trajectory and traffic sequencing as appropriate** - Brokers between Vertiport Manager and Fleet Operator to implement mitigation - Monitors emergency	- Verifies type of emergency - Updates Flight Plan for affected aircraft - Notifies Vertiport Manager - Notifies FAA - Supports flight crew - Activates emergency action plan	- **Responds in real-time to emergency conditions.** - **Executes emergency procedures.** - **Declares an emergency**
Anytime	- Maintains open data exchange with PSU Network - Provides aircraft strategic deconfliction while in flight	- Maintains airworthiness of fleet - Tracks aircraft flight hours and cycles - Tracks flight hours & duty time of crews - Coordinates maintenance needs - Uploads and downloads aircraft flight data	- Aviates, navigates, and communicates - Executes tactical deconfliction (surface and airborne)

[7]

[7] Key decisions made across stakeholders are in **bold text.**

4 Vertiport Automation System Services Overview

Brief descriptions of the VAS Services depicted in the VAS Software Architecture and referenced in the VAS Functional Requirements are provided below. These descriptions are intended to provide context to CLIN 3 artifacts.

4.1 Vertiport Automation – Supplemental Data Service Provider Interface

The Vertiport Automation – Supplemental Data Service Provider Interface (VA-SDSP Interface) provides a mechanism for the exchange of information between external stakeholders and internal VAS services. Stakeholders discover the interface via the PSU Network. As part of the discovery process, stakeholders are made aware of VAS services and functionality available at each vertiport. The VA-SDSP Interface defines the VAS functionality that is available to the external stakeholders, such as reserving a vertiport resource or receiving a surface trajectory. Users are authenticated before any information is exchanged. Once connected, stakeholders interact with the VAS services using the methods defined in the VA-SDSP Interface. Needed information is published to the relevant external stakeholders as needed, for example when a resource reservation is changed.

The message exchanges are divided between a ground-to-ground and air-to-ground data link. The ground-to-ground connection is used by the PSU, fleet operator, FAA, and SDSPs for all data exchanges. The air-to-ground connection is used to exchange information directly with aircraft operating within the vicinity of the vertiport. Time critical information, such as messages alerting the flight crew to the presence of FOD on TLOF pads or a change in TLOF pad assignment, are sent to the aircraft over this link. Data from sensors deployed at the vertiport, such as weather, surveillance, and FOD detection is ingested through the VA-SDSP Interface using clients known as Vertiport Infrastructure Data Connectors.

Standardization of both the VA-SDSP Interface and language used to encode the data will be necessary to support UML-4 operations. To ensure that UAM aircraft can operate at any vertiport regardless of which organization owns it, a common VA-SDSP Interface will be required to support interoperability. This will also benefit PSUs, fleet operators, original equipment manufacturers, and communications, navigation, and surveillance (CNS) suppliers by providing a design standard to develop their respective products against. While the VA-SDSP Interface will be of a common design, the internal VAS components can be implemented using different technology choices since they are segregated from the stakeholders by the interface. ASTM International Subcommittee F38.02 has started the initial steps in development of a VA-SDSP Interface Standard[8].

4.2 Resource Management and Scheduling Service

The Resource Management and Scheduling Service (RMSS) manages the use of vertiport resources such as TLOF pads, taxiways, gates, parking, charging infrastructure, and ramp areas. RMSS manages vertiport resources by first determining the vertiport configuration. Vertiport configuration is determined based on arrival and departure flow directions, vertiport resource availability, local weather conditions, demand forecasts, and environmental considerations.

RMSS generates vertiport resource availability which are communicated to fleet operators and PSUs for resource scheduling purposes. Resource availability is broadcast at the start of the day of operations and as the availability of resources change, which can occur when a resource is reserved, or the resource is declared unavailable for risk mitigation. The vertiport resources are allocated as fleet operators file flight plans with PSUs indicating the following with respect to designated vertiport resources for the departure vertiport and arrival vertiport:

---

[8] "New Specification for Vertiport Automation Supplemental Data Service Provider (SDSP)," ASTM International, https://www.astm.org/DATABASE.CART/WORKITEMS/WK75981.htm.

- Which vertiport resources they require;
- The initial time that the vertiport resource is required;
- The planned duration of the use of the resource; and
- Any specific characteristic requirements pertaining to the resource, such as gate size or charging capabilities.

RMSS receives the resource request, analyzes the request, and determines if it can be accommodated based upon the resource schedule. Given that the vertiport resource availability is published, fleet operators can form their flight plans around vertiport resource availability. If the requested resources are available, then RMSS places a reservation on those resources for the flight operation. If the resources are not available, then RMSS may respond with a rejection and offers alternative available resources.

After the PSU approves the flight plan and the aircraft initiates flight operations, RMSS monitors the flight through the ACM to determine the viability of the flight operation with respect to the vertiport resources that have been reserved. If it appears that the flight will not adhere to its reservations at the vertiport, then RMSS may either wait to determine if corrective actions for the flight have been instituted, or RMSS may cancel the reservations if a timeout occurs. The resources can then be reclaimed for use by other flights in the case where non-conformance with the reservation is highly probable.

RMSS exercises prioritization of the vertiport resources under a set of configurable rules. Prioritization takes effect when contention for any vertiport resources exists, and RMSS is required to decide which flight operation receives the contested resource. In all cases, emergency flight operations or other high priority flight operations (e.g., medical transport or law enforcement) are given priority over routine flight operations; however, RMSS prioritizes nominal flight operation as required.

RMSS manages the vertiport resources to achieve efficient vertiport surface operation in accordance with the configurable business rules and local, state, and federal rules and regulations. RMSS records metrics associated with resource reservations, which can be analyzed to determine the overall efficiency of vertiport operation, allowing the vertiport manager to adjust and tune configurable rules and parameters. The vertiport manager monitors the scheduling prioritization algorithm and business rules to improve automated resource allocations. The vertiport manager also configures resource availability priority to broadcast specific resource availability to fleet operators and PSUs. Private vertiport managers may provide favorable preference to certain partners based on established relationships. For example, as with gates at conventional airports, specific staging areas and charging stations may be owned, leased, or reserved for specific fleet operators to guarantee high operational tempo. Conversely, public vertiport managers will have equity built in to ensure equitable resource allocation without bias.

4.3 Surface Trajectory Service

The core functionality of the Surface Trajectory Service (STS) is to construct 4D (longitude, latitude, altitude, and time) surface trajectories to connect aircraft from origin-to-destination on the vertiport surface. STS strategically separates vertiport surface traffic between aircraft and ground vehicles using vertiport manager input of resource prioritization parameters and separation buffer requirements. The flight crew is responsible for executing the STS constructed 4D surface trajectory and maintaining safe separation between other aircraft and ground vehicles on vertiport movement areas. While not all vertiports will require the use of all dimensions (such as altitude), the capability is specified as a requirement to support hover taxi concepts. Given the assumptions that vertiports will often have a small physical footprint and certain aircraft will require tugging to and from TLOF pads, ground vehicles are included under the purview of STS 4D surface trajectories. The RMSS provides any landing or ready for taxi approvals, alleviating the responsibility from the STS.

STS also relies on the RMSS to provide vertiport configuration, resource reservations, and resource availability information to construct taxiways and 4D surface trajectories based on resource reservations.

When RMSS updates the vertiport configuration, STS also must update any existing reservations impacted and construct a set of newly available surface taxiways, depending on the vertiport configuration changes. STS regenerates the current movement area map using a 4D model as the basis for 4D surface trajectory generation. The STS 4D mapping capability is central for human-machine interactions given the vertiport manager will seek to understand active movement areas during nominal and off-nominal operations. The 4D map can also be shared with stakeholders, such as the flight crew and fleet operator, to aid in decision-making and tactical execution of the 4D surface trajectory.

ACM and RMSS update STS on resource reservations and aircraft conformance status (airborne and surface) to facilitate notional 4D surface trajectory construction. Information provided by PSUs from fleet operators or flight crews provide the STS near real-time status updates on aircraft progress against the flight plan and indicate the corresponding phase of flight. Therefore, when an aircraft is approaching to land or preparing to taxi to the departure TLOF pad, the STS receives the appropriate information to connect vertiport origin-to-destination. STS balances demand against capacity to strategically separate trajectories. Aircraft taxi performance capabilities and demand-capacity balances are used to determine time from vertiport origin-to-destination. Timing is broken up into discrete waypoints that allow for precise monitoring of the 4D surface trajectories.

Post-trajectory generation, STS awaits any instructions from other services to regenerate alternative 4D surface trajectories. Following the subsequently discussed ACM, VA-SMS, HIS, RAS, and VMD (Sections 4.4 to 4.8), STS issues an alternative trajectory. Anomalies or hazards impacting surface trajectories may include obstacles blocking a taxiway, FOD on TLOF pads, conformance hazards (airborne or surface), and external threats to vertiport operations. Risk assessment and mitigation strategies inform the STS if 4D surface trajectory regeneration is required.

STS transmits 4D surface trajectories to fleet operators, flight crews, and vertiport ground vehicles as these stakeholders primarily support vertiport surface operations. STS transmits 4D surface trajectories to other VAS internal services to serve as input for resource scheduling, conformance monitoring, and risk assessment.

4.4 Aircraft Conformance Monitor

The Aircraft Conformance Monitor (ACM) monitors airborne and surface trajectory conformance to detect anomalies that could disrupt nominal vertiport operations. Airborne traffic is monitored as part of ACM. Even though the VAS does not generate airborne trajectories, non-conformance issues at any phase during the flight could cause downstream schedule impacts (domino effect). For example, a non-conforming aircraft during cruise phase of flight could cause cascading effects for multiple aircraft to miss their vertiport resource reservation timing, requiring updates to multiple resource reservations. During most of the flight, conformance is monitored through flight crew self-reporting and PSU provided surveillance data. When the aircraft enters the VOA, the ACM actively leverages vertiport infrastructure (or appropriate surveillance SDSP) to collect high frequency surveillance data. ACM also monitors surface trajectory adherence for anomalies. Flight crews are responsible for the tactical execution of the surface trajectory, and the VAS does not assume positive control over the flight crew at any phase of flight, therefore the VAS cannot compel the flight crew to adhere to the 4D surface trajectory.

The vertiport manager defines the VOA airspace, VPV airspace, and vertiport surface conformance criteria as input for ACM anomaly detection. Established decision-making criteria are the basis for the ACM anomaly detection algorithm to flag issues that arise, either airborne or on the vertiport surface. The vertiport manager also defines the monitoring frequencies for external data subscription (flight crew self-reporting or PSU surveillance) and vertiport surveillance (vertiport infrastructure) based on the available data and update rates. ACM compares surveillance data against resource reservations, resource availability, 4D surface trajectories, and the vertiport configuration when determining conformance status. If ACM does determine an aircraft or ground vehicle is non-conforming, a conformance anomaly is sent to VAS services for further processing.

ACM also projects future conformance status (airborne or surface) to inform resource scheduling and hazard identification. Using historical data and the current-state conformance status, ACM predicts airborne or surface conformance status. If the predicted status is non-conforming, VAS internal services may begin to prepare to handle an off-nominal or emergency scenario with potential for cascading impacts on schedule.

ACM routinely transmits the current- and future-state airborne and surface trajectory conformance status. Transmission of the conformance status based on change frequency provides visibility across VAS services and assurance that operations are proceeding as expected. The information then can be logged with a time-stamp to serve as input for future conformance predictions.

4.5 System Monitoring Service (VA-SMS)

The System Monitoring Service (VA-SMS) assesses the operational health and status of vertiport infrastructure sensors, VAS services, and hardware that supports VAS services. VA-SMS aggregates the health reports and logs of each service, software, and hardware component to monitor for anomalies that will be further assessed for hazards and risks. The vertiport manager defines decision-making criteria as input to anomaly detection. Configurable criteria may include expected data quantities, generation rates, transmission frequency, and latency.

VA-SMS will maintain a list of vertiport infrastructure sensors, VAS services, and hardware to routinely monitor. The vertiport manager may alter which software and hardware should be monitored, and the frequency of monitoring, during periods of testing or scheduled maintenance. VA-SMS will also update and validate the software and hardware monitoring list based on current vertiport operations. For example, if a risk mitigation strategy makes certain vertiport resources unavailable, then VA-SMS will stop monitoring those components. The vertiport manager may configure the VA-SMS to always monitor each vertiport infrastructure sensors, VAS service, and hardware, regardless of their operational status. When VA-SMS detects anomalies, a message is generated and transmitted for further hazard analysis including information on the data containing the anomaly, the source and destination of the data, and a list of the components involved in generation and transmission of the data.

The vertiport manager will receive anomaly detection messages from VA-SMS which may be integrated into the UX design. A detected anomaly does not denote a hazard or risk exists, and identified hazards or risks are processed by other VAS services. VA-SMS will also take advantage of historical learning to tune anomaly detection criteria to reduce errors made in anomaly detection and improve the quality of detection. This is imperative in larger, high-density operations as false detections of an anomaly can result in emergency situations at the vertiport. Reducing false detections will improve hazard identification and risk assessment. Logging of anomaly detection and hazard identification data enables the backpropagation and tuning of anomaly detection criteria to refine VA-SMS anomaly detection capabilities and accuracy. The vertiport manager may choose to disable this capability and simply tune the anomaly detection criteria to their liking.

4.6 Hazard Identification Service

The Hazard Identification Service (HIS) is designed to enhance safety by providing automated hazard identification. In this context, “hazard” is defined as conditions or physical items which could cause harm, damage, or injury and have been determined to pose a threat to a specific object, such as an aircraft. HIS is designed to identify hazards through analysis of vertiport data, using detection logic configured by the vertiport manager. This is done in two steps. First, the specific condition or item is identified and labeled as an “anomaly” by anomaly detection services (ACM and VA-SMS). Second, the anomaly is assessed to determine if it has the potential to cause harm to any aircraft, vertiport infrastructure component, flight crew, passengers, and other individuals at the vertiport. If so, it is labeled as a “hazard”. Once identified, the hazards are communicated to VAS components and external stakeholders as needed for risk analysis and decision-making. The objective is to rapidly identify dangerous situations and notify the appropriate stakeholders who can resolve the situation or may be impacted by the situation.

Hazard identification is accomplished by analyzing data for conditions or items which could cause harm. This begins with the vertiport manager defining the criteria HIS uses to identify anomalies not detected by other VAS services. The criteria take form as one or more attributes-value pairs. The end result is a finite list of anomalies, each with a corresponding set of attribute-value pairs. A simple example of this would be a baggage cart moving on the vertiport surface. The HIS could be configured so that any baggage cart is identifiable by the vertiport surface surveillance sensors is considered an anomaly. Once identified as an anomaly, the HIS will analyze the baggage cart for the potential to cause harm, and thus becoming a hazard.

To determine if an anomaly has the potential to cause harm, the vertiport manager will configure a second set of criteria for each anomaly. As before, this is a series of attribute-value pairs that define when the anomaly has become dangerous. Continuing the example above, the location of the baggage cart on the vertiport surface could be used to determine if it is a hazard. This is because a baggage cart parked in a non-movement area is not dangerous, but if left on an active TLOF pad that has an aircraft on approach to land, it is dangerous. In this case, the criteria would be the existence of the baggage cart, its location on the vertiport, and the arriving aircraft.

Once a hazard has been identified, HIS transmits the hazard information for risk analysis and mitigation. Additionally, if an aircraft is involved, a notification is sent to the flight crew. As the system runs, historical databases of identified anomalies and the conditions that made them hazardous could be used to train machine learning models. One potential use of these models would be to improve the criteria that is used to identify hazards.

4.7 Risk Assessment Service

The Risk Assessment Service (RAS) receives the hazards that HIS identifies and assesses their risk level. In this context, risk is defined as the probability that the hazard will cause damage or harm combined with the severity of the resulting damage. If the risk of a hazard exceeds the designated acceptable level, the RAS will recommend a pre-defined mitigation strategy designed to reduce the risk to an acceptable. The mitigations can be automatically initiated or displayed on the VMD for approval by the vertiport manager. However, it is important to note that these mitigations are only for the use by the vertiport manager and VAS services and will not contain actions for the flight crew. While the HIS will warn flight crews to potential hazard, flight crews are responsible for deciding the appropriate response. Mitigations generated by RAS will only apply to VAS functionality.

In a similar process to HIS, RAS relies on criteria set by the vertiport manager to determine how risk (probability and severity) should be calculated for each hazard and what level of risk is acceptable. Additionally, the vertiport manager will define one or more mitigation strategies for each hazard. For example, if the HIS generates a hazard alert due to a baggage cart left in an active TLOF pad, the RAS would use the aircraft arrival time as the definition of probability. Severity is a value set by the vertiport manager, which in this example is “Critical”. As the aircraft gets closer to landing, the risk calculated by RAS will increase as the probability increases. One the risk exceeds the acceptable level the pre-defined mitigation strategy is activated. In this case, the arriving aircraft is rescheduled for a different TLOF pad and ground crews are dispatched to remove the baggage cart.

The RAS also calculates an aggregate risk score for the vertiport. This vertiport aggregate risk score is designed as a strategic input into routine vertiport operations. The formula used to calculate this score is defined by the vertiport manager and includes factors such as weather, visibility, planned capacity, projected demand, time of day, and more. The intended use of this aggregate risk score is to inform vertiport configuration decisions made by the vertiport manager. For example, when the weather forecast predicts low visibility and high winds during a period of time that has high demand, the aggregate risk score will be higher. The vertiport manager may decide to reduce demand or increase capacity as a mitigation.

4.8 Vertiport Manager Display

The Vertiport Manager Display (VMD) service equips the vertiport manager and other vertiport operations personnel with an enterprise software system for the operation and management of vertiports. A rich and intuitive graphical user interface (GUI) allows the vertiport manager to interact with and manage all major VAS services. VMD general features and capabilities include:

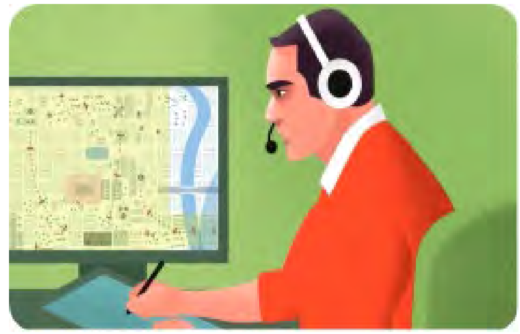


Figure 3. Vertiport Manager

- **Resource Management:** Management of all vertiport resources including TLOF pads, taxiways, gates, parking, charging infrastructure, and ramp areas.
- **Vertiport Operation Intent Management**: Management of vertiport arrivals, departures, and on-site service schedules.
- **Taxi Planning**: Management of the 4D surface trajectories aircraft may follow to navigate from origin-to-destination at the vertiport.
- **Surveillance Management**: Management of surveillance systems and situational awareness displays of surface and airborne traffic.
- **Weather System**: Current and forecast weather displays.
- **Conformance Monitoring**: Situational awareness of approach, departure, and surface trajectory compliance.
- **Risk Management**: Situational awareness of identified hazards and associated mitigation plans.
- **Health and Status**: Live system and subsystems status.
- **Communications:** Digital and analog communication systems including text, audio, and video.
- **VAS UI Design Concepts and Examples**: CLIN 3 Artifact located in Table 1 provides additional insight into the VMD UX. A multidisciplinary team of systems engineers, human factors engineers, and a retired FAA controller designed a conceptual VAS GUI.

Table 4. Proposed Four Core VMD Displays.

	Display Name	Sub-Components
1	**Resource Manager (RM)**	1. TLOF Pad Monitor 2. Arrival and Departure Displays 3. Surface Manager 4. Passenger and Cargo Gate Loading Zone Monitor 5. Charging and Refueling Station Monitor 6. Short-term Staging and Long-term Parking Monitor

		7. Deicing Manager
2	**Arrival and Departure Scheduler (ADS)**	1. Arrival Timeline 2. Departure Scheduler 3. Slot Reservation System 4. Trajectory Modeling and Conformance Monitor
3	**Weather Display (WD)**	1. Next Generation Weather Radar (NEXRAD) 2. Corridor Integrated Weather System (CIWS) 3. Terminal Aerodrome Forecast (TAF) 4. Vertiport Information Display System (V-IDS)
4	**System Performance Dashboard (SPD)**	1. System Operability 2. Connectivity 3. Cybersecurity 4. Risk Assessment and Safety Risk Management 5. Operational metrics

The VMD's functional requirements and corresponding test approaches (found in Section 5 and Section 6) primarily focus on the management of and interaction with internal VAS services and systems (e.g., the RAS and Infrastructure Data Connectors) and the chief external entities including PSUs, fleet operators, and aircraft (e.g., receiving flight plans and position data from PSUs via the VA-SDSP Interface). All other VAS services are covered within the VMD's functional requirements and test approaches, with functional requirements and tests that range from inter-service messages to service management and configuration. Knowing the value that both NASA and the FAA place on human factors engineering, the functional requirements include a section devoted to the field. These functional requirements have been intentionally written with the *should* rather than the *shall* qualifier to suggest to future systems engineers that they are not necessarily mandatory. The human factors engineers on the team, however, believe in the value of these functional requirements and hope that the requirements get serious consideration in subsequent research efforts.

4.9 Cybersecurity Service

Common cybersecurity threats today such as structured query language (SQL) injection, denials of service (DOS), domain name system (DNS) attacks, and unauthorized logins are so vicious that entire services can be completely disrupted causing severe financial loss and other disastrous consequences. The Cybersecurity Service (CSS) design is adapted from the National Institute of Standards and Technology (NIST) Cybersecurity Framework Version 1.1[9]. The NIST Cybersecurity Framework provides five functions of cybersecurity: Identify, Protect, Detect, Respond, and Recover. CSS leverages the framework as the core to the service functionality, integrating the five functions, in addition to inter-service messaging. The CSS features and capabilities include:

- **Identify**: Based on operational scenario, develop an organizational understanding to manage the current cybersecurity risk to systems, users, assets, data, and capabilities.

[9] "Cybersecurity Framework Version 1.1," NIST, https://www.nist.gov/cyberframework/framework

- **Protect**: Develop and implement appropriate safeguards to ensure delivery of critical services, including authentication, authorization, and auditing.
- **Detect**: Develop and implement appropriate activities to recognize the occurrence of a cybersecurity event.
- **Respond**: Develop and implement appropriate policies and activities to counter a detected cybersecurity incident.
- **Recover**: Develop and implement appropriate policies and activities to maintain resilience and restore any capabilities or services that were impaired due to a cybersecurity incident.

5 Vertiport Automation System Functional Requirements

The VAS Functional Requirements define the functionality required for safe and efficient vertiport operations at the volumes defined by UML-4. The High-Density Automated Vertiport ConOps provided the primary source of information from which the functional requirements were derived. The term "functional" is used deliberately to communicate that these functional requirements describe system behavior, as opposed to non-functional requirements such as operating cost or software reliability. The scope defined for the functional requirements is as follows:

- VAS must provide the following functionality:
- Scheduling the use of TLOF pads for aircraft arrival and departures;
- Efficiently routing aircraft on the vertiport surface;
- Enhancing safety through hazard identification and risk mitigation;
- Monitoring vertiport infrastructure and VAS software; and
- Detecting and responding to cybersecurity incidents.
- VAS must support communications with PSUs, fleet operators, flight crews, SDSPs, and the FAA.
- VAS must consider both nominal and off-nominal conditions.
- VAS must have a display for management by a vertiport manager.

The resulting functional requirements were captured in three tiers of complexity. Tier 1 functional requirements are the broadest and represent the most fundamental capabilities required. Tier 2 and Tier 3 refine Tier 1 functional requirements with increasingly specific system results, further fulfilling stakeholder needs. By design, lower tier functional requirements will always link back to at least one higher tier requirement. Requirements which are dependent on the functionality of another requirement are identified and the predecessor requirement identification number is included with successor requirement. A rationale statement describing why each requirement exists is also provided for each Tier 3 requirement. Finally, a matrix tracing the origin and destination of each message referenced in the requirement is provided.

5.1 Vertiport Automation System Functional Requirements Development Process

The development of the VAS Functional Requirements began with analysis of the High-Density Automated Vertiport ConOps. The ConOps scenarios were decomposed into the basic actions involved in each step. These basic actions were then presented to UAM industry partners as part of a System Design Review (SDR), during which the actions were discussed, and feedback was collected. The SDR feedback was incorporated and these actions were matured into an initial set of functional requirements, known as "Baseline 1". NASA leadership reviewed the Baseline 1 functional requirements and provided feedback. After the feedback was responded to, a review session was held to discuss the responses and reach consensus. The resulting set of functional requirements were captured as "Baseline 2" and served as the input for the test approaches for the nine VAS services described in Section 4. During the development of the test approaches described in Section 6, the inputs required, interim functions performed, and resulting output was documented for each requirement. While going through the actions required to write the test approaches, additional refinements were made to the requirements, resulting in the final set of VAS Functional Requirements which are accessible in Table 1.

6 Vertiport Automation System Test Approaches

The complement the functional requirements, the systems engineering team defined a corresponding set of VAS Software Test Approaches. The purpose behind the test approaches was to prepare future VAS software engineering teams with a preliminary construct of how certain VAS software behaviors could be tested in future development efforts. To author the test approaches, the team used the Gherkin syntax[10]. The Gherkin syntax is a test approach style guide of sorts, offered by a company called Cucumber[11] which specializes in behavior-driven development (BDD) engineering products. Section 6.1 provides and overview of the syntax and keywords used. A principal tenet of the BDD engineering approach is that software tests should be simple and intuitive to promote a common understanding between stakeholders of expected software behavior; Cucumber created Gherkin for this reason, to offer a method for writing executable specifications in plain and easily understood text. Each Tier 3 functional requirement was analyzed and described using the Gherkin syntax.

6.1 Gherkin Syntax Overview

The Gherkin syntax is a finite set of keywords which organize the requirements and describe the process for verifying their implementation. These keywords and their meaning are described in Table 5 below:

Table 5. Gherkin Syntax Keywords

Gherkin Syntax Keyword	Description
Feature	Broad description of a function
Scenario	Specific application of the function
Given	Pre-existing conditions which must exist for the functionality to occur
When	Action which initiates the function
Then	Expected result of the function used for verification of a requirement
And	Used when there are multiple Given, When, or Then statements
<#.#.#>	Contains requirement identification number of a dependency

Development of the VAS Test Approaches began with the mapping of the VAS Functional Requirements into the Gherkin Syntax. Since Features are designed group multiple Scenarios into logical grouping, Tier 2 requirements were converted into Features and Tier 3 requirements were converted into Scenarios. Each Scenario consists of three or more steps using the Given, When, and Then keywords in this order. If a Scenario contains multiple Given, When, or Then steps, the And keyword is used immediately after the keyword to denote each additional step. Any step which is dependent on functionality provided by another scenario is tagged using the <#.#.#>, in which the identification number of the dependency replaces the '#' symbols. The resulting documentation forms the VAS Test Approaches which are accessible in Table 1.

[10] "Gherkin Syntax," Cucumber, https://cucumber.io/docs/gherkin/
[11] "Home," Cucumber, https://cucumber.io/

7 Follow-On Research Opportunities

Developing the VAS Software Architecture and VAS Functional Requirements forced the systems engineering team to think through details and considerations beyond the software. The following findings highlight emergent research topics identified by the systems engineering team.

1. The services provided by a PSU and an associated PSU Network are vital to the high-density automated vertiport concept, hence inclusion of the PSU concept in the overall UAM concept will require significant research and a robust ConOps for PSUs.
2. The roles of fleet operators, aircraft, PSUs, and SDSPs remain to be defined with greater clarity, including what information is shared and how the sharing will be accomplished.
3. Further research is required to define terminal airspace design, operating procedures, and requirements for the VOA and VPV described in the High-Density Automated Vertiport ConOps.
4. Traffic flow management on the vertiport surface, in terminal airspace, and in en route airspace is a key element of UAM operations. Research is required to develop appropriate procedures and methods for effective traffic metering and buffer management in conjunction with operation of high-density vertiports.
5. Simulation will play an essential role in developing a high-density vertiport automation system capable of supporting operations at 30-second intervals. The effects of perturbations to schedule timing must be carefully examined and simulated before proceeding to operational testing to verify and validate vertiport operational concepts. Simulation testing will also help to determine achievable operational tempos that can support the business case for investment in vertiport infrastructure.
6. Research involving stakeholders' roles, responsibilities, requirements, and contributions to concept development must actively engage and share information and assumptions with stakeholders to enable a cohesive approach.
7. High-density operations will require high quality digital information, particularly from the PSU, fleet operator, and aircraft. Research is required to enable effective information sharing with the required privacy, cybersecurity, latency, verifiability, and availability.
8. Industry buy-in to the NASA UAM Vision ConOps UML-4 is critical to incorporating high levels of automation. Collaboration and understanding among stakeholders across the UAM ecosystem will drive innovation, business models, and policies to support automated operations.
9. Understanding how to transition from the current state to future states will help to develop the pathway for industry.
10. The VA-SDSP Interface Standard being developed by ASTM will play an influential role in interaction and engagement to unite the UAM community behind a common vision for vertiports. It will be critical for key stakeholders to engage in developing this standard.
11. There is an opportunity to reduce uncertainty in the role of local and state government interfacing with the VAS and other UAM systems which will improve software architectures and requirements.

12. Further research is required to compose public-use and private-use vertiport prioritization rules and determine the entity(ies) that have authority to establish prioritization policies.
13. Refine requirements for Cybersecurity services to include items such as pushing out software updates and patches.

Flight Crew / UAM Aircraft
Flight Crew / UAM Aircraft
Flight Crew / UAM Aircraft
V2V
V2V
Fleet Operator
Fleet Operator
Fleet Operator
Operation Intent, Vehicle Telemetry, Real-time Info, Resource Scheduling
Arr./Dep. Status, Surf.-Trajec., WX, Surveillance, Safety Alerts
SDSPs
Vertiport
VAS
Vertiport Manager Display
Surface Trajectory Service
Risk Assessment Service
Aircraft Conformance Monitor
Resource Management & Scheduling Service
Hazard Identification Service
Vertiport Infrastructure
Weather Sensor
Surveillance
FOD Sensor
GPS Integrity
Charging Station
Noise Sensors
Voice Comm.
Text/Data Comm.
Direct Comm. Link
RESTFul Interface
Ext. Connection Client
VA-SDSP Interface
Cybersecurity / Software Monitoring / Data Management
Common Software Infrastructure
Wx Service
FOD Service
Surv. Service
Charg. Service
Noise Service
Comm. Service
Vertiport Infrastructure Data Connectors
Operations, Constraints, Notifications, Resource Scheduling, Vehicle Status, Safety Alerts,
Operation Intent, Vehicle Telemetry, Real-time Info, Resource Scheduling
Arr./Dep-Status, Position, Status, Off-Nominal
Operations, Constraints, Notifications, Info
Public Safety
Public
Notices, RID, Tracks
Provider of Services to UAM (PSU)
Operation Info., Non-conformances, Arr./Dep. Status, Safety Alerts, Vertiport Resource Scheduling
Operation Info., Terrain, Weather, Surveillance, Arr./Dep. Status, Vertiport Resource Scheduling, USS Info.
FAA
Constraints, RFIs, FAA info
Responses, Notifications
InterPSU Communication and Coordination
PSU Network
Operations, Constraints, Modifications, Notifications
Terrain, Weather, Surveillance, Airspace, Flight Planning
External SDSPs
Weather
Airspace
Surveillance
Flight Planning
Other Vertiport(s)
SDSPn
InterSDSP Communication & Coordination
Operation Intent; Real-time Info
UAS Service Supplier (USS)
Discovery
Registration
AuthN & AuthZ
Govt
Industry
FAA
UAM
UTM
Other

SDSPs
Vertiport
VAS
Legend
Ext. Stakeholder Exchange
Discovery / Reg., AuthN & AuthZ
VA-SDSP Output
VA-SDSP Output Direct Comm. Link
VA-SDSP Input
VA-SDSP Input Direct Comm. Link
VAS Information Input
VAS Information Output
Vertiport Infrastructure Data
External Stakeholder
VA-SDSP Interface
Common Software Infrastructure
VAS Software Component
Vertiport Infrastructure
Flight Crew / UAM Aircraft
Fleet Operator
Provider of Services to UAM (PSU)
PSU Network
InterPSU Communication and Coordination
Discovery Registration AuthN & AuthZ
Resource Res.
Hazards
Surface Traj.
Wx
Comm.
Operations Info
Surface Info
Resource Info
Risk Info
Comm.
Infra. Status
Hazards
Risk Assess.
Operations Info
Surface Info
Resource Info
Risk Info
Comm.
Infra. Status
Hazards
Risk Assess.
Vehicle Status
Telemetry
Off-nominal
Operation Info.
Vehicle Status
Non conformances
Arr. & Dep. Status
Clearances
USS Info.
Surveillance
Weather
Airspace
Flight Planning
Terrain
VA-SDSP Interface
Direct Comm. Link
RESTFul Interface
External Connection Client
Cybersecurity / Software Monitoring / Data Management
Common Software Infrastructure
Surface Trajectory
Operations Info
Surface Info
Resource Info
Risk Info
Comm.
Infra. Status
Hazards
Risk Assess.
Vertiport Manager Display
Surface Trajectory Service
Command Input
Configuration
Comm.
Surveillance
Mitigation Actions
Resource Reservations
Surface / Terminal Surveil.
Flight Plan
Surface Traj.
Hazard Risk Assess.
Mitigation Action
Aggregate Risk Score
Hazards
WX
Surveil.
FOD Detect
Rsrc. Avail.
Comm.
Surface Conform.
Risk Assessment Service
Aircraft Conformance Monitor (Surface/VOA)
Non-conformance Alert
Surface Conform.
Resource Avail.
Hazards
Infra. Status
Wx
Surveillance
Comm.
Hazards
Vertiport Config
Resource Availability
Resource Req. Response
Resource Req.
Flight Status
Aircraft Conf.
WX
Comm.
Surveillance
Resource Management & Scheduling Service
Hazard Identification Service
Sensor Data
Sensor Info.
Vertiport Infrastructure
Weather Sensor
Surveillance
FOD Sensor
GPS Integrity
Charging Station
Noise Sensors
Voice Comm.
Text/Data Comm.
Wx Information
FOD Information
Surv. Information
Charg. Information
Noise Information
Comm. Information
Vertiport Infrastructure Data Connectors
External SDSPs
Weather
Airspace
Surveillance
Flight Planning
Other Vertiport(s)
SDSPn
InterSDSP Communication and Coordination

2021

VERTIPORT AUTOMATION SYSTEM (VAS)

Functional Requirements

NUAIR®

MAKING FUTURE SKIES SAFER

Contents

Supplemental Data Service Provider Interface (VA-SDSP Interface)

ID #.#.#	Requirement	Dependencies	Rationale
VAS 1.0 Vertiport Automation VAS shall interface with external systems.			
1.1.0	VA-SDSP Interface shall provide a ground-to-ground interface for transmission of messages to external systems.		
1.1.1	VA-SDSP Interface shall transmit Resource Availability Schedule Messages to: - FAA - PSU - Fleet Operator - Flight Crew	2.6.2	External stakeholders need to know which resources are available for reservation and their configuration.
1.1.2	VA-SDSP Interface shall transmit Vertiport Resource Negotiation Response Messages to: - PSU - Fleet Operator	2.6.3	External stakeholders need to know if their reservation request has been confirmed or denied.
1.1.3	VA-SDSP Interface shall transmit Vertiport Configuration Messages to: - FAA - PSU - Fleet Operator	2.6.1	External stakeholders need to know the vertiport configuration.
1.1.4	VA-SDSP Interface shall transmit Vertiport Resource Reservation Summary Messages: - FAA - PSU - Fleet Operator	2.6.6	External stakeholders benefit from metrics regarding the number of resource request and the subsequent approval and denial metrics.
1.1.5	VA-SDSP Interface shall transmit Vertiport Resource Clear Messages to: - PSU - Fleet Operator	2.6.4	External stakeholders are notified that the landing pad is clear of obstacles just prior to the aircraft landing as an additional layer of safety.

1.1.6	VA-SDSP Interface shall transmit Risk Assessment Messages to: - PSU - Fleet Operator	7.6.1	External stakeholders are notified of relevant risk information for situational awareness.
1.1.7	VA-SDSP Interface shall transmit Aggregate Risk Score Messages to: - PSU - Fleet Operator	7.6.2	External stakeholders are notified of the overall risk level of the vertiport for situational awareness and planning.
1.1.8	VA-SDSP Interface shall transmit 4D Surface Trajectory Messages to the Fleet Operator.	3.3.1	External stakeholders are provided a copy of the surface trajectory assigned to a relevant aircraft.
1.1.9	VA-SDSP Interface shall transmit Hazard Messages to: - FAA - PSU - Fleet Operator	6.4.1	External stakeholders are notified of hazards with the potential to impact relevant flights.
1.2.0	VA-SDSP Interface shall provide a ground-to-ground interface for reception of messages from external systems.		
1.2.1	VA-SDSP Interface shall receive Resource Negotiation Messages from the PSU.		External stakeholders will need an interface for submitting resource requests.
1.2.2	VA-SDSP Interface shall receive Flight Plan Messages from PSU.		The VAS will need to be aware of incoming and outgoing aircraft flight plans, including the aircraft type.
1.2.3	VA-SDSP Interface shall receive Flight Status Messages from PSU.		The VAS will need regular updates on the aircraft's current status indicating its current state, estimated time of departure, estimated time of arrival, and other status information.
1.2.4	VA-SDSP Interface shall receive Flight Position Messages from the PSU.		The VAS will need to be aware of the current position, speed, and altitude of arriving and departing aircraft located outside of the VOA.
1.2.5	VA-SDSP Interface shall receive Airspace Configuration Messages from the PSU.		The VAS will need to be aware of the configuration of the airspace surrounding the vertiport and any impacting restrictions.
1.2.6	VA-SDSP Interface shall receive Vertiport Weather (Wx) Messages from the Vertiport Infrastructure Data Connectors.		The VAS will need weather information.
1.2.7	VA-SDSP Interface shall receive VOA Surveillance Messages from the Vertiport Infrastructure Data Connectors.		The VAS will need to be aware of the current position, speed, and altitude of arriving and departing airborne aircraft located inside the VOA.

1.2.8	VA-SDSP Interface shall receive the Vertiport Surface Surveillance Messages from the Vertiport Infrastructure Data Connectors.		The VAS will need to be aware of the current position, speed, and altitude of arriving and departing aircraft located vertiport surface.
1.2.9	VA-SDSP Interface shall receive the Vertiport FOD Detection Messages from the Vertiport Infrastructure Data Connectors.		The VAS will need to be aware of any FOD detected on the vertiport surface.
1.2.10	VA-SDSP Interface shall receive the Vertiport Charging Infrastructure Status Messages from the Vertiport Infrastructure Data Connectors.		The VAS will need to be aware of the status of the charging infrastructure at the vertiport.
1.2.11	VA-SDSP Interface shall receive the Vertiport Noise Monitoring Alert Messages from the Vertiport Infrastructure Data Connectors.		The VAS needs to be aware of the local noise levels associated with aircraft operations at the vertiport.
1.3.0	VA-SDSP Interface shall provide an air-ground interface for transmission of messages to Flight Crew.		
1.3.1	VA-SDSP Interface shall transmit Hazard Messages to the Flight Crew.	6.4.1	Aircraft control messages contain critical safety information and should be transmitted via the interface that provides the lowest transmission latency.
1.3.2	VA-SDSP Interface shall transmit Surface Trajectory Messages to the Flight Crew.	3.3.1	Aircraft on the VAS surface will be provide surface trajectories that route them from point A to point B on the vertiport surface.
1.3.3	VA-SDSP Interface shall transmit Vertiport Resource Clear Messages to the Flight Crew.	2.6.4	Aircraft will be sent a message indicating that the landing pad is clear of obstacles just prior to the aircraft landing.
1.3.4	VA-SDSP Interface shall transmit Resource Availability Schedule Messages to Flight Crew.	2.6.2	External stakeholders need to know which resources are available for reservation and their configuration.
1.4.0	VA-SDSP Interface shall provide an air-ground interface for reception of messages from Flight Crew.		
1.4.1	VA-SDSP Interface shall receive Flight Position Messages from Flight Crew.		The VAS will need to be aware of the current position, speed, and altitude of arriving and departing aircraft located inside the VOA.
1.5.0	VA-SDSP Interface shall be discoverable digitally by operational stakeholders.		
1.5.1	VA-SDSP Interface shall be discoverable by PSUs.		PSUs will need a mechanism to find the VA-SDSP Interface associated with the vertiport.
1.5.2	VA-SDSP Interface shall be discoverable by Fleet Operator.		Fleet Operators will need a mechanism to find the VA-SDSP Interface associated with the vertiport.

1.5.3	VA-SDSP Interface shall be discoverable by Flight Crew.		Aircraft will need a mechanism to find the VA-SDSP Interface associated with the vertiport.

Resource Management and Scheduling Service (RMSS)

ID #.#.#	Requirement	Dependencies	Rationale
VAS 2.0 - The VAS shall manage vertiport resources.			
2.1.0	RMSS shall receive messages.		
2.1.1	RMSS shall receive the following messages from the PSU: - Flight Plan - Flight Position - Flight Status - Resource Negotiation	1.2.2 / 1.2.4 / 1.2.3	VAS receives flight plans that contain reservation requests from Fleet Operators through the PSU. Flight position updates and flight status updates are also received from the PSU. Flight status messages are received from the Fleet Operator through the PSU or from the PIC/Aircraft in cases of urgency where there is little time for latency.
2.1.2	RMSS shall receive the VOA Surveillance Messages from the Vertiport Infrastructure Data Connector.	1.2.7	When a flight is located inside the VOA, the vertiport surveillance SDSP provides surveillance information to VAS. In addition, Flight Position and status information is also provided by the PSU inside the VOA, if available.
2.1.3	RMSS shall receive the following messages from the ACM: - Airborne Trajectory Conformance Status - Surface Trajectory Conformance Status - Projected Trajectory Conformance Status	4.5.1 / 4.5.2 / 4.5.3	Aircraft Conformance Monitoring (ACM) monitors the aircraft's conformance to its assigned trajectory in the VOA an on the vertiport surface. ACM provides conformance information to RMSS so that RMSS can maintain its resource schedule or renegotiate the resource reservations as required.
2.1.4	RMSS shall receive Risk Assessment Messages from the RAS.	7.6.1	RAS sends RMSS risk assessment and mitigation messages to RMSS, which are most likely associated with closing or reopening vertiport resources associated with a determined risk.
2.2.0	RMSS shall determine vertiport configuration.		

2.2.1	RMSS shall construct a 4D (longitude, latitude, altitude, and time) map of vertiport resources fused with vertiport resource performance and sizing information.		The RMSS includes the following information in the Vertiport Configuration: 1 - Arrival flow direction 2 - Arrival landing pad activation 3 - Departure flow direction 4 - Departure Pad selection 5 - availability of vertiport resources, and 6 - resource characteristics. In addition, vertiport resources are mapped as a function of time (resources may be time dependent) in the configuration.
2.2.2	RMSS shall designate restricted surface volumes on or above the surface of the vertiport from nominal aircraft operations.	2.2.1	There may be restricted areas of the vertiport that RMSS designates as unavailable for use.
2.2.3	RMSS shall update resource availability using arrival and departure traffic flow direction	2.2.2	RMSS needs to collaborate with the PSUs serving the vertiport to determine traffic flow into and out of the vertiport. RMSS also must account for local and government regulations in establishing ingress and egress at the vertiport. Consideration of weather and environmental conditions in the area of the vertiport also contribute to the flow direction decision.
2.2.4	RMSS shall generate Vertiport Configuration Messages.	2.2.3	RMSS creates messages related to the vertiport configuration.
2.3.0	RMSS shall determine vertiport resource availability, publish resource availability, and negotiate resource reservations.		
2.3.1	RMSS shall map resource prioritization to the vertiport configuration to configure a resource scheduling prioritization algorithm.	8.3.3	Various resources at the vertiport may be prioritized for certain classes of operators, and the configurable priority of these resources is associated with the resource information.
2.3.2	RMSS shall reserve a configurable number and type of vertiport resources to be utilized in an emergency or other high priority situation.	2.3.1	The vertiport must have some reserve of resources that can be utilized if an emergency or other high priority situation occurs.
2.3.3	RMSS shall generate Vertiport Resource Availability Schedule Messages at the start of the day of operations and as updates occur.	8.3.3	RMSS broadcasts the resource availability and schedule at the start of the day of operations and as the resource availability changes at the vertiport.
2.3.4	RMSS shall receive and validate resource reservation requests.	8.3.3	When resource reservations are requested, RMSS must check the availability of the resource per the reservation request. The resource requested needs to be able to accommodate the vehicle and its intended

			use. Vehicles could be too large to fit on all available parking pads. Intended use of vehicle may require specific resource, such as, passengers to a gate, cargo to a cargo loading area.
2.3.5	RMSS shall accept or reject resource reservation requests.	2.3.4	If the resource is not available (already booked) then the requestor must be notified that the resource is not available as requested. RMSS can determine alternatives to the unavailable resource and suggest those to the requestor for their acceptance or refusal.
2.3.6	RMSS shall generate Vertiport Resource Request Response Messages.	2.3.5	When a resource reservation is requested, RMSS responds to the requestor with: - resources requested are available - resource is not available at the requested time - alternatives to the resource reservation request
2.3.7	RMSS shall generate Vertiport Arrival Pad Clear Messages.	2.1.1	When an aircraft is about to arrive on the arrival pad, VAS issues a "*clear*" message to the PIC/Aircraft indicating that the arrival pad is clear and unoccupied.
2.3.8	RMSS shall generate Vertiport Departure Pad Clear Messages.	2.1.1	When an aircraft is ready to depart, VAS issues a "*clear*" message to the PIC/Aircraft indicating that the departure pad is clear and unoccupied.
2.4.0	RMSS shall respond to vertiport resource schedule disruptions.		
2.4.1	RMSS shall update vertiport resource reservations in response to resource negotiations.	2.1.1 / 2.1.3	When aircraft are unable to make their reservation time windows, then RMSS initiates a renegotiation of the affected reservations. If the aircraft is out of conformance, RMSS negotiates a new or modified reservation with the fleet operator using the PSU as a broker if the aircraft is in PSU airspace, and with the aircraft crew directly if the aircraft is on the vertiport surface.
2.4.2	RMSS shall update vertiport resource reservations in response to RAS and VMD risk mitigation strategies.	2.1.4 / 8.3.3	In the event that a risk is detected at the vertiport and RAS or VMS issue a mitigation strategy, RMSS updated the resource allocation should the mitigation affect a scheduled resource reservation.
2.4.3	RMSS shall update the vertiport configuration based on updated vertiport resource availability.	2.4.2	RMSS updates the vertiport configuration when resources are removed from operational status or returned to operational status.
2.5.0	RMSS shall calculate resource reservation metrics.		

2.5.1	RMSS shall calculate aggregate resource reservations, approvals, and rejections.		Resource metrics include total resource reservations and resource reservations approvals and rejections.
2.5.2	RMSS shall generate Vertiport Resource Reservation Summary Messages containing: -Aggregate totals of reservations requested -Reservations approved -Reservations disapproved (categorized by disapproval reason)	2.5.1	RMSS generates resource summary statistics in the form of messages for distribution.
2.5.3	RMSS shall calculate projected vertiport resource demand.		To avoid overbooking or gridlock of resources at the vertiport, RMSS must project resource demand against available capacity, and provide alerts to the vertiport operator and other stakeholders that within a configurable look-ahead window a configurable threshold of available capacity will be exceeded.
2.5.4	RMSS shall calculate vertiport resource demand-capacity balance.	2.5.3	To avoid overbooking or gridlock of resources at the vertiport, RMSS must project resource demand against available capacity, and provide alerts to the vertiport operator and other stakeholders that within a configurable look-ahead window a configurable threshold of available capacity will be exceeded.
2.5.5	RMSS shall generate Vertiport Demand-Capacity Imbalance Messages.	2.5.4	Messages are utilized to convey Demand-Capacity imbalance.
2.6.0	RMSS shall transmit the following messages.		
2.6.1	RMSS shall transmit Vertiport Configuration Message to the STS, ACM, RAS, and VMD.	2.2.4	Other VAS services need to be informed of the vertiport configuration. These configurations may dictate which resources are available for reservation during the time the configuration is enabled.
2.6.2	RMSS shall transmit Vertiport Resource Availability Schedule Message to the STS, ACM, HIS, RAS, and VMD.	2.3.3	Other VAS services need to be informed of the availability of resources so they understand the priority rules for each resource.
2.6.3	RMSS shall transmit Vertiport Resource Negotiation Response Message.	2.3.6	External stakeholders who have requested a vertiport resource must informed that their request has been approved or denied.
2.6.4	RMSS shall transmit Vertiport Resource Clear Message to the ACM.	2.3.7 / 2.3.8	The ACM uses the Resource Clear Message as an input into determining if an aircraft is out of conformance.
2.6.5	RMSS shall transmit Vertiport Demand-Capacity Imbalance Message to the HIS and VMD.	2.5.5	Other VAS services need to be informed when the demand for vertiport resources exceed its capacity.
2.6.6	RMSS shall transmit Vertiport Resource Reservation Summary Message to the STS, ACM, HIS, RAS, and VMD.	2.5.2	Other VAS services need to be aware of the current and future resource reservations that have been made at the vertiport.

Surface Trajectory Service (STS)

ID #.#.#	Requirement	Dependencies	Rationale
VAS 3.0 - The VAS shall manage surface trajectories.			
3.1.0	STS shall receive messages.		
3.1.1	STS shall receive the following messages from the PSU: - Flight Plan - Flight Position - Flight Status		The Flight Plan will contain aircraft information used to generate surface trajectories and the flight position and status information will be used to trigger generation and transmission of surface trajectories based on phase of flight.
3.1.2	STS shall receive the following messages from the RMSS: - Vertiport Configuration - Vertiport Resource Availability Schedule - Vertiport Resource Reservation Summary	2.6.1 / 2.6.2 / 2.6.6	Vertiport configurations, availability of vertiport resources, and resource reservations will influence the generation of surface trajectories.
3.1.3	STS shall receive Risk Assessment Messages from the RAS.	7.6.1	Risk Assessment Messages will include mitigation actions which involve updates to surface trajectories.
3.2.0	STS shall construct 4D surface trajectories for aircraft and ground vehicles.		
3.2.1	STS shall construct a 3D map containing: - Vertiport resource configuration - Vertiport resource availability - Taxi pathways	3.1.2	STS must build a 3D map to serve as the foundation for which 4D trajectories will be built.

3.2.2	STS shall construct the 3D (longitude, latitude, altitude) surface trajectory connecting origin to destination.	3.1.1	The surface trajectory generation process is incremental and first must build on the 3D map to generate a point-to-point trajectory.
3.2.3	STS shall calculate the origin to destination expected timing for the 3D surface trajectory to construct a 4D (time) surface trajectory.	3.2.2	STS must calculate estimated timing to strategically deconflict trajectories and provide other services with surface transit timing to influence resource availability, resource reservations, and potentially risk mitigations.
3.2.4	STS shall provide strategic deconfliction of surface trajectories to balance demand against surface capacity.	3.2.3	STS strategically deconflicts trajectories to balance aircraft and ground vehicle demand against vertiport surface resource capacity.
3.2.5	STS shall generate 4D Surface Trajectory Messages.	3.2.4	STS must package the surface trajectory in a format that can be transmitted, stored, and received.
3.2.6	STS shall regenerate 4D surface trajectories in response to RAS mitigations.	3.1.3	STS must be adaptable to changing surface trajectories impacted by risk mitigation strategy implementations.
3.3.0	STS shall transmit messages.		
3.3.1	STS shall transmit 4D Surface Trajectory Messages to the RMSS, ACM, HIS, RAS, and VMD.	3.2.5	STS provides the relevant stakeholders with surface trajectories.

Aircraft Conformance Monitor (ACM)

ID #.#.#	Requirement	Dependencies	Rationale
VAS 4.0 - The VAS shall monitor aircraft and ground vehicle conformance to trajectories.			
4.1.0	ACM shall receive messages.		
4.1.1	ACM shall receive the following messages from the PSU: - Flight Plan - Flight Position - Flight Status - Airspace Configuration		ACM needs to monitor the aircraft during all phases of flight, therefore the data collected by the PSU can provide the necessary situational awareness during takeoff, climb, cruise, and approach. The airspace configuration is used to determine the boundaries of airborne conformance outside of the VOA.
4.1.2	ACM shall receive the following messages from the Vertiport Infrastructure Data Connectors: - VOA Surveillance - Vertiport Surface Surveillance		ACM needs higher frequency and accuracy surveillance data when aircraft are in the VOA, VPV or on the vertiport surface.
4.1.3	ACM shall receive the following messages from the RMSS: - Vertiport Configuration - Vertiport Resource Availability Schedule - Vertiport Resource Clear - Vertiport Resource Reservation Summary	2.6.1 / 2.6.2 / 2.6.4 / 2.6.6	ACM needs resource management and scheduling information to define the boundaries of surface conformance and determine airborne and ground conformance.
4.1.4	ACM shall receive 4D Surface Trajectory Messages from the STS.	3.3.1	ACM will monitor for surface trajectory conformance for aircraft and ground vehicles.
4.2.0	ACM shall identify non-conforming airborne aircraft.		
4.2.1	ACM shall continuously predict aircraft arrival times.	4.1.1	ACM needs to provide accurate predictions to other VAS services on conformance to airborne trajectories and arrival pad timing for strategic resource allocation.
4.2.2	ACM shall identify airborne aircraft in non-conformance with landing pad reservation window.	4.2.1	ACM will use predicted aircraft arrival times to identify non-conformance for resource scheduling.
4.2.3	ACM shall monitor aircraft location in relation to VOA and VPV airspace boundaries.	4.1.2	ACM needs to understand aircraft airborne position to determine conformance status.

4.2.4	ACM shall identify airborne aircraft in non-conformance with VOA and VPV airspace boundaries.	4.2.3	ACM will use airspace configuration and surveillance data to determine when an aircraft is non-conforming near the vertiport for time critical situations.
4.2.5	ACM shall generate Airborne Trajectory Conformance Status Messages.	4.2.2	ACM must package the airborne trajectory conformance status in a format that can be transmitted, stored, and received.
4.3.0	ACM shall identify non-conforming surface aircraft or ground vehicles.		
4.3.1	ACM shall monitor surface aircraft or ground vehicle location in relation to surface trajectories issued by STS.	4.1.2	ACM needs to understand aircraft or ground vehicle surface position to determine conformance status.
4.3.2	ACM shall identify if surface aircraft or ground vehicles in non-conformance with surface trajectory issued by the STS.	4.3.1	ACM needs to identify surface trajectory conformance to determine potential hazards or risks.
4.3.3	ACM shall monitor surface aircraft or ground vehicle location in relation to other surface aircraft or ground vehicles.	4.1.2	ACM needs to understand if vehicle-to-vehicle separation is maintained on the vertiport surface.
4.3.4	ACM shall identify if aircraft or ground vehicles are in non-conformance with vehicle-to-vehicle separation.		ACM needs to identify vehicle-to-vehicle to determine potential hazards or risks.
4.3.5	ACM shall continuously predict aircraft departure times.	4.1.1	ACM needs to provide accurate predictions to other VAS services on conformance to surface trajectories and departure pad timing for strategic resource allocation.
4.3.6	ACM shall identify surface aircraft in non-conformance with departure pad reservation window.	4.3.5	ACM will use predicted aircraft departure times to identify non-conformance for resource scheduling.
4.3.7	ACM shall generate Surface Trajectory Conformance Status Messages.	4.3.1 / 4.3.2 / 4.3.3	ACM must package the surface trajectory conformance status in a format that can be transmitted, stored, and received.
4.4.0	ACM shall predict aircraft 4D trajectory non-conformance.		
4.4.1	ACM shall identify aircraft future non-conformance.		ACM needs to understand the predicted aircraft trajectories to monitor for future airborne hazards and risks.
4.4.2	ACM shall improve aircraft future non-conformance prediction through experience and use of historical data.	4.4.1	ACM will improve the accuracy of future aircraft trajectory predictions using historical data collected on predicted aircraft trajectory compared to actual trajectory.
4.4.3	ACM shall calculate projected aircraft 4D airborne and surface trajectory conformance probabilities.	4.4.1	ACM will use aircraft future non-conformance to generate predicted trajectories (airborne and surface) in addition to the probability of the generated trajectories.

4.4.4	ACM shall generate Projected Trajectory Conformance Status Messages.	4.4.3	ACM must package the projected trajectory conformance status in a format that can be transmitted, stored, and received.
4.5.0	ACM shall transmit messages.		
4.5.1	ACM shall transmit Airborne Trajectory Conformance Status Messages to the RMSS, HIS, and VMD.	4.2.3	ACM will provide the relevant stakeholders with airborne trajectory conformance status.
4.5.2	ACM shall transmit Surface Trajectory Conformance Status Messages to the RMSS, HIS, and VMD.	4.3.4	ACM will provide the relevant stakeholders with surface trajectory conformance status.
4.5.3	ACM shall transmit Projected Trajectory Conformance Status Messages to the RMSS, HIS, and VMD.	4.4.4	ACM will provide the relevant stakeholders with projected trajectory conformance status.

System Monitoring Service (SMS)

ID #.#.#	Requirement	Dependencies	Rationale
VAS 5.0 - The VAS shall monitor vertiport infrastructure and software.			
5.1.0	SMS shall monitor VAS services.		
5.1.1	SMS shall detect VAS service exceptions and faults.		SMS must monitor VAS services for any exceptions or faults so that any issues can be identified and resolved.
5.1.2	SMS shall monitor VAS service logs and detect errors.		SMS must monitor VAS service logs for errors so that any issues can be identified and resolved.
5.1.3	SMS shall generate a System Monitoring Alert Message.	5.1.1 / 5.1.2	SMS must gather the relevant information for any issues it has identified in a VAS service so that it can be communicated to the relevant system or stakeholder.
5.2.0	SMS shall monitor VAS Infrastructure.		
5.2.1	SMS shall monitor VAS digital storage and detect when the usage exceeds a configurable threshold.		SMS must monitor digital storage usage as it is critical to VAS operations. The configurable threshold is set at a level which allows an issue to be identified prior to the system failing.
5.2.2	SMS shall monitor VAS digital memory and detect when usage exceeds a configurable threshold.		SMS must monitor digital memory usage as it is critical to VAS operations. The configurable threshold is set at a level which allows an issue to be identified prior to the system failing.
5.2.3	SMS shall monitor VAS processing usage and detect when load exceeds a configurable threshold.		SMS must monitor processing usage as it is critical to VAS operations. The configurable threshold is set at a level which allows an issue to be identified prior to the system failing.
5.2.4	The SMS shall monitor VAS radio communication infrastructure and detect when interference exceeds the configurable threshold.		SMS must monitor radio communication infrastructure as it is critical to VAS operations. The configurable threshold is set at a level which allows an issue to be identified prior to the system failing.

5.2.5	SMS shall monitor the VAS networking infrastructure and detect any faults or failures.		SMS must monitor networking infrastructure as it is critical to VAS operations. The configurable threshold is set at a level which allows an issue to be identified prior to the system failing.
5.2.6	SMS shall monitor VAS sensors and detect any faults are failures.		SMS must monitor all sensors as they are critical to VAS operations. The configurable threshold is set at a level which allows an issue to be identified prior to the system failing.
5.2.7	SMS shall monitor networking infrastructure used to provide connectivity to external stakeholders and detect faults or failures.		SMS must monitor networking infrastructure used for external connectivity as it is critical to VAS operations. The configurable threshold is set at a level which allows an issue to be identified prior to the system failing.
5.2.8	SMS shall generate System Monitoring Alert Messages.	5.2.5 / 5.2.6 / 5.2.7	When SMS identifies an issue with the VAS Infrastructure, a message containing the relevant details is required so the systems and personnel capable of responding can be notified.
5.3.0	SMS shall transmit messages.		
5.3.1	SMS shall transmit System Monitoring Alert Message to the HIS, VMD, and CSS.	5.2.8	Since the HIS, VMD, and CSS are the three systems capable of responding to issues identified by SMS, they receive the System Monitoring Alert Messages.

Hazard Identification Service (HIS)

ID #.#.#	Requirement	Dependencies	Rationale
	VAS 6.0 - The VAS shall identify hazards.		
6.1.0	HIS shall receive messages.		
6.1.1	HIS shall receive the following messages from the PSU: - Flight Plan - Flight Position - Flight Status		HIS uses the flight plan, current and planned aircraft position, and planned arrival and departure times to identify impacting hazards.
6.1.2	HIS shall receive Flight Position Messages from the Flight Crew.		HIS uses the current position of the aircraft identify impacting hazards.
6.1.3	HIS shall receive the following messages from the Vertiport Infrastructure Data Connectors: - Vertiport Weather (Wx) - VOA Surveillance - Vertiport Surface Surveillance - Vertiport FOD Detection - Vertiport Charging Infrastructure Status - Vertiport Noise Monitoring Alert		Information from the Vertiport Infrastructure Data Connectors provides HIS with situational awareness of the vertiport environment and is used to identify hazards.
6.1.4	HIS shall receive the following messages from the RMSS: - Vertiport Resource Availability Schedule - Vertiport Demand-Capacity Imbalance - Vertiport Resource Reservation Summary	2.6.2 / 2.6.5 / 2.6.6	HIS receives the information needed to determine vertiport demand and capacity, which is a potential source of hazards.
6.1.5	HIS shall receive 4D Surface Trajectory Messages from the STS.	3.3.1	HIS uses the planned aircraft position to identify impacting hazards.
6.1.6	HIS shall receive the following messages from the ACM: - Airborne Trajectory Conformance Status - Surface Trajectory Conformance Status - Projected Trajectory Conformance Status	4.5.1 / 4.5.2 / 4.5.3	Non-conforming aircraft are considered anomalies and are sent to HIS after detection by ACM for hazard determination.
6.1.7	HIS shall receive System Monitoring Alert Message from the SMS.	5.3.1	VAS hardware and software issues are considered anomalies and are sent to HIS after detection by SMS for hazard determination.

6.1.8	HIS shall receive the following messages from the CSS: - Cybersecurity Advisory - System Wide Cybersecurity Status	9.7.1 / 9.7.2	Cybersecurity issues are considered anomalies and are sent to HIS after detection by CSS for hazard determination.
6.2.0	HIS shall detect anomalies.		
6.2.1	HIS shall detect vertiport infrastructure sensor data anomalies.	6.1.3	Other Services, such as the System Monitoring Service, purely look at the health status of the hardware and data flow from the Infrastructure Data Connectors. This fills the gap of analyzing the data from the sensors to capture anomalies and hazards.
6.2.2	HIS shall detect external data source anomalies that could impact vertiport operations.		The focus being on the local region around the vertiport - external factors may impact those operations at the vertiport, so any anomalies from the nominal need to be addressed as potentially hazardous precursors.
6.2.3	HIS shall determine the location of the anomaly.	6.2.1 / 6.2.2	The location of anomalies needed to identify which aircraft could be impacted by the anomaly.
6.2.4	HIS shall determine if the anomaly is moving and in which direction and speed.	6.2.1 / 6.2.2	If the anomaly is an object which moves (e.g., FOD), then the direction and speed in which it moves is needed to determine which aircraft could be impacted by the anomaly.
6.2.5	HIS shall identify any aircraft which could be affected by identified anomalies.	6.2.4	A comparison of the current and future position of the anomaly and the current and future position of aircraft arriving and departing from the vertiport is needed to determine if and when an aircraft(s) will be affected by the anomaly.
6.3.0	HIS shall identify hazards.		
6.3.1	HIS shall analyze each anomaly to determine if it is a hazard.	6.2.1 / 6.2.2 / 8.7.3	Anomalies are potential hazards. The HIS must determine if an anomaly has the potential to cause harm, and therefore is a hazard, or if the anomaly poses no danger at all and does not need to be escalated.
6.3.2	HIS shall improve hazard identification through experience and use of historical data.	6.3.1	Learning from the past decision-making and understanding the impact of the inputs and outputs to this service will help to generate more meaningful hazard identification capabilities.
6.3.3	HIS shall generate Hazard Messages.	6.3.1	Upon identification of a hazard, HIS gathers the relevant information that will be used to notify the systems capable of mitigation.
6.4.0	HIS shall transmit messages.		
6.4.1	HIS shall transmit Hazard Messages to the RAS, VMD, and CSS.	6.3.3	RAS, VMD, and CSS are dependent on HIS to identified hazards for further assessment and mitigation.

Risk Assessment Service (RAS)

ID #.#.#	Requirement	Dependencies	Rationale
VAS 7.0 - The VAS shall assess operational risk.			
7.1.0	RAS shall receive messages.		
7.1.1	RAS shall receive the following messages from the PSU: - Flight Plan - Flight Position - Flight Status		RAS uses the flight plan, current and planned aircraft position, and planned arrival and departure times as an input into risk calculation.
7.1.2	RAS shall receive Flight Position Messages from the Flight Crew.		RAS uses current aircraft position as an input into risk calculation.
7.1.3	RAS shall receive the following messages from the Vertiport Infrastructure Data Connectors: - Vertiport Weather (Wx) - VOA Surveillance - Vertiport Surface Surveillance - Vertiport FOD Detection - Vertiport Charging Infrastructure Status - Vertiport Noise Monitoring Alert		Information from the Vertiport Infrastructure Data Connectors provides RAS with situational awareness of the vertiport environment and is used as input into risk calculation.
7.1.4	RAS shall receive the following messages from the RMSS: - Vertiport Configuration - Vertiport Resource Availability Schedule - Vertiport Resource Reservation Summary	2.6.1 / 2.6.2 / 2.6.6	RAS receives the information describing vertiport demand and capacity, which is used as an input into risk calculation.
7.1.5	RAS shall receive 4D Surface Trajectory Messages from the STS.	3.3.1	RAS uses the planned aircraft position as an input into risk calculation.
7.1.6	RAS shall receive Hazard Messages from the HIS.	6.4.1	RAS performs risk assessments on hazards identified by HIS and the risk assessment process is trigged by the reception of the Hazard Message.
7.2.0	RAS shall determine the probability of a hazard causing material loss or harm.		

7.2.1	RAS shall receive the necessary data to determine the probability of a hazards occurring.	7.1.6	Determination of a hazards probability requires evaluation of the factors that affect the probability. The vertiport manager will need to define what data RAS uses to make a determination.
7.2.2	RAS shall calculate the probability of a hazard occurrence as a series of values.	7.2.1	Risk is defined as the combination of the probability of a hazard occurring combined with the severity if a hazard were to occur. Determining the probability of a hazard fulfills half of this definition.
7.2.3	RAS shall improve probability calculation through experience and use of historical data.	7.2.2	Machine learning is well suited to determine future outcomes based on similar situation in the past and increases the accuracy of the probability prediction.
7.2.4	RAS shall recalculate the probability of a hazard occurrence after the implementation of a mitigation strategy.	8.8.4	Mitigation strategies are supposed to reduce risk, of which probability is 1/2. To determine how effective risk mitigation strategies are, a comparison is needed after the implementation of said risk mitigation strategy.
7.3.0	RAS shall determine the potential severity of loss or harm caused by a hazard occurring.		
7.3.1	RAS shall receive the necessary data to determine the severity of a hazards occurring.	7.1.6	Determination of a hazards probability will require evaluation of the factors that affect the probability. The vertiport manager will need to define what data RAS uses to make a determination.
7.3.2	RAS shall calculate the severity of a hazard occurrence as a series of categories defined by the VMD.	7.2.1	Risk is defined as the combination of the probability of a hazard occurring combined with the severity if a hazard were to occur. Determining the severity of a hazard fulfills half of this definition.
7.3.3	RAS shall improve severity calculation through experience and use of historical data.	7.3.2	Machine learning is well suited to determine future outcomes based on similar situation in the past and increases the accuracy of the severity prediction.
7.3.4	RAS shall recalculate the severity of a hazard occurrence after the implementation of a mitigation strategy.	8.8.4	Mitigation strategies are supposed to reduce risk, of which severity is 1/2. To determine how effective risk mitigation strategies are, a comparison is needed after the implementation of said risk mitigation strategy.
7.4.0	RAS shall determine mitigation strategy and calculate the effectiveness of recommended risk mitigation strategies.		
7.4.1	RAS shall match the appropriate mitigation strategies to a specific hazard.	7.1.6	RAS automates the risk assessment and mitigation process but cannot identify the appropriate mitigation without any guidance as this is a subjective decision. User input is needed to define the possible mitigation strategies and which hazards they should be applied to.
7.4.2	RAS shall generate Risk Assessment Messages.	7.2.2 / 7.3.2 / 7.4.1	Once a risk has been assessed and the appropriate mitigation identified, the information needs to be communicated to the services capable of acting on the mitigation.

7.4.3	RAS shall calculate the reduction in probability and severity of a hazard after the application of a mitigation strategy, known as effectiveness.	7.2.4 / 7.3.4	A key feature of risk assessment programs as defined by the Safety Management Systems concepts, is to determine how effective the mitigation was in reducing risk.
7.4.4	RAS shall track and calculate average effectiveness of risk mitigation strategies.	7.4.3	To determine the long-term effectiveness of a specific type of mitigation, a comparison must be performed of RAS's effectiveness against similar hazards.
7.5.0	RAS shall determine an aggregate risk score for the vertiport.		
7.5.1	RAS shall estimate the aggregate risk score for the vertiport.		The vertiport manager needs to understand the current overall risk associated with the vertiport at any given time.
7.5.2	RAS shall generate Aggregate Risk Score Messages.	7.5.1	Once a risk score has been generated based on current conditions, the information will be communicated to stakeholders.
7.6.0	RAS shall transmit messages.		
7.6.1	RAS shall transmit Risk Assessment Messages to the RMSS, STS, VMD, and CSS.	7.4.2	The RMSS, STS, and CSS are all services which are capable of responding to mitigations communicated by RAS and therefore receive Risk Assessment Messages. The VMD display risk information to the vertiport manager who in turn manages the RAS functionality.
7.6.2	RAS shall transmit Aggregate Risk Score Messages to the VMD.	7.5.2	The vertiport operator needs to understand the current overall risk associated with the vertiport at any given time.

Vertiport Manager Display (VMD)

ID #.#.#	Requirement	Dependencies	Rationale
VAS 8.0 - The VAS shall provide a physical user interface.			
8.1.0	VMD shall receive messages.		
8.1.1	VMD shall receive the following messages from PSU: - Flight Plan - Flight Position - Flight Status - Airspace Configuration		VMD uses this information for situational awareness displays.
8.1.2	VMD shall receive the following messages from Vertiport Infrastructure Data Connectors: - Vertiport Weather (Wx) - VOA Surveillance - Vertiport Surface Surveillance - Vertiport FOD Detection - Vertiport Charging Infrastructure Status - Vertiport Noise Monitoring Alert		VMD uses this information for situational awareness displays.
8.1.3	VMD shall receive the following messages from RMSS: - Vertiport Configuration - Vertiport Resource Availability Schedule - Vertiport Demand-Capacity Imbalance - Vertiport Resource Reservation Summary	2.6.1 / 2.6.2 / 2.6.5 / 2.6.6	VMD uses this information for RMSS displays.
8.1.4	VMD shall receive 4D Surface Trajectory Messages from STS.	3.3.1	VMD uses this information for STS displays.
8.1.5	VMD shall receive the following messages from the ACM: - Airborne Trajectory Conformance Status - Surface Trajectory Conformance Status - Projected Trajectory Conformance Status	4.5.1 / 4.5.2 / 4.5.3	VMD uses this information for ACM displays.
8.1.6	VMD shall receive System Monitoring Alert Messages from SMS.	5.3.1	VMD uses this information for SMS displays.

8.1.7	VMD shall receive Hazard Messages from HIS.	6.4.1	VMD uses this information for HIS displays.
8.1.8	VMD shall receive the following messages from the RAS: - Risk Assessment - Aggregate Risk Score	7.6.1 / 7.6.2	VMD uses this information for RAS displays.
8.1.9	VMD shall receive the following messages from the CSS:	9.7.1 / 9.7.2	VMD uses this information for CSS displays.
8.2.0	VMD shall provide a VA-SDSP Interface user interface.		
8.2.1	VMD shall display performance data and metrics from VA-SDSP Interface.		Network analysis is the process of inspecting and displaying network traffic to get information about network performance (data packages, senders, receivers, size, throughput etc.). It allows system administrators to identify and mitigate network issues.
8.2.2	VMD shall provide VA-SDSP Interface management capabilities.		Users should be able to configure, troubleshoot, reset, and check and inspect the VA-SDSP.
8.3.0	VMD shall provide a RMSS Vertiport Manager Interface.		
8.3.1	VMD shall display configuration, availability, capacity, demand, and reservation status information received from RMSS for all vertiport resources, including: - TLOF pads - Passenger gates - Cargo gates - Short term parking - Long-term parking - Charging stations - Vertiport ramp areas	8.1.2	Users need a dashboard/visualization of the resource schedule for situational awareness. This is essentially a timetable of current and expected vertiport events (e.g., when aircraft are expected to arrive, takeoff, etc.). It would include current and future capacity/demand data and information.
8.3.2	VMD shall provide vertiport resource configuration management capability.		Users need access to resource management functions (e.g., scheduling when vertiport resources are available, changing the status of a vertiport resource, etc.)
8.3.3	VMD shall provide vertiport resources reservation management capability.		Users should be able to create, edit, and activate different resource reservation business rules (e.g., prioritization of Company X over Company Y for reservation requests).
8.3.4	VMD shall provide a resource reservation metrics management capability.	8.3.1	Users should be able to add, remove, and update the types of metrics that are displayed for the RMSS.

8.3.5	VMD shall provide RMSS performance analytics.	8.3.1	Users should be able to review resource and schedule performance metrics such as: Pad A utility rate, Parking Spot vacancy rate, On Time Arrival rates, On Time Departure rates, etc.
8.4.0	VMD shall display an STS user interface.		
8.4.1	VMD shall display surface 3D map, aircraft surface trajectory, and ground vehicle surface trajectory information received from STS.	8.1.2	Users should be able to review active and historic surface trajectories. This would include data such as the 4DT, the assigned aircraft, and conformance information
8.5.0	VMD shall provide an ACM user interface.		
8.5.1	VMD shall display the current and predicted non-conformance information for airborne aircraft, surface aircraft, and ground vehicles received from ACM.	8.1.5	Users should be able to review the conformance status for all aircraft, surface and airborne, under its purview.
8.5.2	VMD shall provide a conformance tolerance management capability.	8.5.1	User should be able to add, removed, and update the tolerance parameters used by ACM to determine if an aircraft is in or out of conformance.
8.5.3	VMD shall provide aircraft conformance performance analytics.	8.5.1	Users should be able to review the past performance of aircraft conformance, surface and airborne. The purpose here is to track key vertiport performance metrics which can help streamline and refine Operation Intent and vertiport scheduling and sequencing efforts. This data may also need to be publicly shared at some point in the future as a way of providing transparency about a facility's performance.
8.6.0	VMD shall provide a SMS user interface.		
8.6.1	VMD shall display system monitoring alert information received from SMS.	8.1.6	Users should be alerted to issues with the VAS software or hardware. This includes reading log files which may capture improperly formed data models, software exceptions, etc.
8.6.2	VMD shall provide a VAS service monitoring management capability.	8.6.1	Users should be able to configure, troubleshoot, reset, check, and inspect the monitoring of VAS services by SMS.
8.6.3	VMD shall provide a VAS infrastructure monitoring management capability.	8.6.1	Users should be able to configure, troubleshoot, reset, check, and inspect the monitoring of VAS infrastructure by SMS.
8.6.4	VMD shall display system monitoring data and metrics.	8.6.1	User should be able to view current and historical performance of SMS, including metrics describing the number and trends of issues identified.

8.7.0	VMD shall provide a HIS user interface.		
8.7.1	VMD shall display hazard information received from HIS.	8.1.7	For each hazard sent to the VMD, users should be able to review the identifying source, the type, the time it was discovered, its current status, etc.
8.7.2	VMD shall provide an anomaly detection management interface.	8.7.1	Users should be able to review and edit vertiport anomalies (e.g., a user may want to add, delete, and revise anomalies for example when the user knows something the automation does not).
8.7.3	VMD shall provide a hazard detection management interface.	8.7.1	Users should be able to define a custom list of hazards (i.e., a predefined hazards) and their associated features. Users should be able to configure decision-matrices and categorization levels.
8.7.4	VMD shall display active and historic hazards.	8.7.1	Users should be able to review current vertiport hazards and ones previously identified (historic). Information that the user should be able to review for a hazard includes likelihood, severity, timestamp, validity period, impacted stakeholders.
8.7.5	VMD shall provide hazard data and trend analytics.	8.7.1	Users should be able to review analytics regarding vertiport hazards. This includes details and trends about the number and type of hazards over the last day, week, month, etc.
8.8.0	VMD shall provide a RAS user interface.		
8.8.1	VMD shall display risk assessment and aggregate risk scores received from RAS.	8.1.8	Users should be able to review all aspects regarding the vertiport's risks, past, present, and future.
8.8.2	VMD shall provide a hazard probability management interface.	8.8.1	Users should be able to define the specific data elements used to determine the probability of a risk occurring.
8.8.3	VMD shall provide a hazard severity management interface.	8.8.1	Users should be able to define the specific data elements used to determine the severity of a risk, if it were to occur.
8.8.4	VMD shall provide a risk mitigation management interface.	8.8.1	Users should be able to define a custom list of mitigation strategies for handling risks.
8.8.5	VMD shall provide an aggregate risk score management interface.	8.8.1	Users should be able to review and edit active vertiport risks (e.g., a user may want to cancel or adjust a risk, revise active mitigation strategies, etc.)
8.8.6	VMD shall display active and historic risks.	8.8.1	Users should be able to review current vertiport risks (i.e., a dashboard or visualizer) and ones previously identified (historic). Information that the user should be able to review for a risk includes likelihood, severity,

			timestamp, validity period, impacted stakeholders, mitigation strategies, all recipients of risk messages. The user should also be able to review the underlying data (i.e., the hazards) used in the calculation of the risk. The user should be able to review current and historic aggregate risk scores, as well as future aggregate risk scores.
8.8.7	VMD shall provide risk mitigation performance analytics.	8.8.1	Users should be able to review the past performance of mitigation strategy efficacy (e.g., mitigation strategy a is historically x% effective against hazard b)
8.9.0	VMD shall provide a CSS user interface.		
8.9.1	VMD shall display cybersecurity advisories and system wide cybersecurity status received from CSS.	8.1.9	Cybersecurity systems allow system administrators to review historic and active cybersecurity risks as well as suggested mitigation strategies.
8.9.2	VMD shall provide a cybersecurity protection management interface.	8.9.1	Users should be able to configure, upgrade, troubleshoot, reset, and check and inspect the Cybersecurity service.
8.9.3	VMD shall provide a cybersecurity incident detection management interface.	8.9.1	Users should be able to configure the signals that CSS will use to identify each possible cybersecurity incident.
8.9.4	VMD shall provide a cybersecurity incident response management interface.	8.9.1	Users should be able to configure the response actions CSS will apply to each possible cybersecurity incident.
8.9.5	VMD shall provide a cybersecurity incident recovery management interface.	8.9.1	Users should be able to configure the recovery actions CSS will apply to each possible cybersecurity incident.
8.9.6	VMD shall display cybersecurity risks and mitigation strategies.	8.9.1	Cybersecurity systems allow system administrators to review historic and active cybersecurity risks as well as suggested mitigation strategies.
8.9.7	VMD shall provide cybersecurity data analytics.	8.9.1	Users should be able to review analytics regarding vertiport cybersecurity risks. This includes details and trends about the number and type of cybersecurity risks over the last day, week, month, etc.
8.10.0	8.10.0 Feature: VMD shall comply with the FAA Human Factors Design Standard, HF-STD-001 [Ahlstrom, V., & Longo, K. (2003). Human Factors Design Standard (HF-STD-001). Atlantic City International Airport, NJ: Federal Aviation Administration William J. Hughes Technical Center]		
8.10.1	The system shall comply with general requirements of the FAA Human Factors Design Standard, HF-STD-001, to consider: - Basic Design Elements		A suggested requirement for general HFE design standards, categorized into eight sections. Future efforts should decide which sections and requirements of those sections apply to the VAS. The following VAS

	- Simplicity - Consistency - Standardization - Safety - Vertiport Manager-centered Perspective - Support - Maintenance		requirement, 7.10.2, provides a specific example of the HFE "4.5 Safety" section.
8.10.2	Provide a fail-safe design. A fail-safe design shall be provided for systems in which failure could cause catastrophic damage, injury to personnel, or inadvertent operation of equipment. [Source: HF-STD-001 Safety 4.5.2]		One example of potentially hundreds of general HFE requirements. Future efforts should carefully review the FAA's standard to determine which apply to the VAS.
8.10.3	The system should comply with specific requirements of the FAA Human Factors Design Standard, HF-STD-001, to consider: - Automation - Design for Maintenance - Displays and Printers - Controls and Visual Indicators - Alarms, Audio, and Voice Communications - Computer-Human Interface - Keyboards and Input Devices - Workstation and Workplace Design - System Security - Personnel Safety - Environment - Anthropometry and Biomechanics - Vertiport Manager Documentation		A suggested requirement for specific HFE design standards, categorized into thirteen sections. Future efforts should decide which sections and requirements of those sections apply to the VAS. The following VAS requirement, 7.10.4, provides a specific example of the HFE "5.1 Automation" section.
8.10.4	An automated system should: - Provide sufficient information to keep the Vertiport Manager informed of its operating mode, intent, function, and output; - Inform the Vertiport Manager of automation failure or degradation; - Inform the Vertiport Manager if potentially unsafe modes are manually selected; - Not interfere with manual task performance; and - Allow for manual override. [Source: HF-STD-001 5.1.1.1 Minimum automation human factors requirements]		One example of potentially hundreds of specific HFE requirements. Automation requirements, in particular for the VAS, should be given focused consideration in future efforts, as the VAS will require high-levels of automation.

8.11.0	VMD shall provide an aircraft surveillance interface.		
8.11.1	VMD shall display past, current, and planned aircraft surveillance data received from PSU, and Vertiport Infrastructure Data Connectors.	8.1.1 / 8.1.2	Users should be able to monitor all pertinent airborne and surface traffic.
8.11.2	VMD shall display current position of surface aircraft.	8.11.1	Users should be able to see the current reported position of surface aircraft.
8.11.3	VMD shall display historic path of surface aircraft.	8.11.1	Users should be able to review the historic paths of surface aircraft.
8.11.4	VMD shall display planned path of surface aircraft.	8.11.1	Users should be able to review the planned path of surface aircraft.
8.11.5	VMD shall display current position of airborne aircraft within x nmi from the vertiport.	8.11.1	Users should be able to see the current reported position of AAM and ATM aircraft pertinent to the vertiport
8.11.6	VMD shall display historic path (i.e., the trail) of active airborne aircraft within x nm from the vertiport.	8.11.1	Users should be able to see the historic path (i.e., trail) for all active AAM and ATM aircraft pertinent to the vertiport
8.11.7	VMD shall display the planned path of active airborne aircraft within x nmi from the vertiport.	8.11.1	Users should be able to see the planned path (i.e., the trajectory) for all active AAM and ATM aircraft pertinent to the vertiport
8.11.8	VMD shall display current status of all pertinent aircraft.	8.11.1	Users should be able to quickly ascertain whether the aircraft is active, nonconforming, contingent.
8.12.0	VMD shall provide a weather interface.		
8.12.1	VMD shall display weather data received from PSU, VOA Surveillance, and Surface Surveillance.	8.1.2	Users should be able to review historic, current, and forecast weather as it relates to the operation of the vertiport.

Cybersecurity Service (CSS)

ID #.#.#	Requirement	Dependencies	Rationale
VAS 9.0 - VAS shall deter and mitigate hostile digital acts.			
9.1.0	CSS shall receive messages.		CSS needs to have information and data about the VAS operations through other coordinated services to perform Cybersecurity requirements.
9.1.1	CSS shall receive System Monitoring Alert Messages from the SMS.	5.3.1	To perform cybersecurity requirement in real-time, CSS depends on monitoring information provided by SMS defined by various stakeholders according to their business and operation needs.
9.1.2	CSS shall receive Hazard Messages from the HIS.	6.4.1	CSS depends on the identified hazards by HIS to assess the nature of the potential threat to the system, and update the security policy templates for improved handling in the future.
9.1.3	CSS shall receive Risk Assessment Messages from the RAS.	7.6.1	CSS depends on the RAS assessment for maintaining most current cybersecurity status for reporting, for updating security policy templates, and for improving future handling.
9.2.0	CSS shall identify the systems, users, assets, data, and capabilities that support critical functions for the purpose of cybersecurity protection.		Identifying resources and the associated cybersecurity risks enables the effective application of INST Cybersecurity Framework Version 1.1. The identification dynamically focuses on the current scope of operations under monitoring. Examples of outcome include: Asset Management; Business Environment; Governance; Risk Assessment; and Risk Management Strategy.
9.2.1	CSS shall identify the systems that support critical functions for purpose of cybersecurity protection.	8.9.2	Identify the systems, interfaces, components, and the associated cybersecurity risks to define and design a modern zero-trust architecture for cybersecurity
9.2.2	CSS shall identify the users that support critical functions in operating scenarios for purpose of cybersecurity protection.	8.9.2	Identify people interacting with VAS, and the associated system operation and access leads to the requirement in governance and access control.
9.2.3	CSS shall identify the assets that support critical functions in operating scenarios for purpose of cybersecurity protection.	8.9.2	Identify assets needed for critical functions, and the associated system operation and access to define requirement in governance and access control.
9.2.4	CSS shall identify the data that support critical functions in operating scenarios for purpose of cybersecurity protection.	8.9.2	Identify data that VAS collects, stores, and delivers, and the associated risks enables to define protection strategy and policy for data at rest and in transit.

9.2.5	CSS shall identify the capabilities that support critical functions in operating scenarios for purpose of cybersecurity protection.	8.9.2	Identify the mission critical technical capabilities and the associated risk to define the recovery strategy and contingency plan in the events of system failure or attack.
9.3.0	CSS shall protect VAS systems, data, assets, and capabilities from digital attacks to ensure delivery of the required critical services.		The Protect Function supports the ability to limit or contain the impact of a potential cybersecurity event. Examples include: Identity Management and Access Control; Awareness and Training; Data Security; Information Protection Processes and Procedures; Maintenance; and Protective Technology.
9.3.1	CSS shall implement authentication and authorization for identity management and access control.		Assets and associated facilities are limited to authorized users, processes, and devices, and is managed consistent with the assessed risk of unauthorized access to authorized activities and transactions.
9.3.2	CSS shall implement data at-rest protection.		Protect data that is stored / archived in digital media such as hard disks, flash memory, or long-term storage.
9.3.3	CSS shall implement data in-transit protection.		Protect data that is in motion traveling in the system and network between system components.
9.3.4	CSS shall protect against data leaks and unauthorized access.		Protect data IP and user privacy against unintended / unauthorized purpose.
9.3.5	CSS shall monitor system redundancy for critical systems, components, and services.	9.1.1 / 9.1.2 / 9.1.3	There shall be no single point of failure in any critical service or critical component that will jeopardize overall integrity of mission.
9.3.6	CSS shall implement system integrity checking mechanisms for self-correctness and self-consistency verification.		Self-consistency and self-correctness refer to a system that all components or services see the same single-source-of-truth information so that the additional information they derive or conclude with will be well coordinated and do not conflict.
9.4.0	CSS shall detect the occurrence of a cybersecurity incident with the traceability required to respond and mitigate.		The Detect Function includes appropriate activities to identify the occurrence of a cybersecurity event, and enable timely discovery of cybersecurity events.
9.4.1	CSS shall establish and manage a baseline of operations and expected outcome and data.		Baseline operations and data flows define the expected VAS behavior and enables the detection of anomalies.
9.4.2	CSS shall monitor VAS for anomalies against the baseline behaviors.		The VAS needs to be constantly and continuously under monitoring to ensure the operation integrity without disruption.
9.4.3	CSS shall detect anomalies compared against the baseline operation and outcome.	9.4.1	Compare the behavior against the most updated baseline to identify the potential anomaly for further analysis and mitigation.

9.4.4	CSS shall generate Cybersecurity Advisory Messages for each incident that requires IT security handling with specific handling instructions.	9.4.3	Cybersecurity incidents can be highly specialized as digital threat schemes never stop being improved. CSS is responsible for providing updated mitigation strategy and instructions.
9.4.5	CSS shall improve detection mechanism and policies through experience and use of historical data.	9.4.4	Detection system shall be continuously updated according to latest cyberspace activities.
9.5.0	CSS shall respond to detected cybersecurity incidents with a defined set of actions according to security and privacy policies and procedures.		The Respond Function takes action on a detected cybersecurity incident to contain the impact of a potential cybersecurity incident.
9.5.1	CSS shall execute a response plan upon a cybersecurity incident.	9.4.4	Cybersecurity requires a precise and timely response upon any incident.
9.5.2	CSS shall define stakeholder roles and actions during a cybersecurity incident.	9.4.4	The stakeholders' decision roles and users' operational roles shall be defined precisely for a timely response in the event of an actual incident.
9.5.3	CSS shall contain and mitigate a cybersecurity incident.	9.4.4	A cybersecurity incident needs to be handled promptly and appropriately to maintain the mission and service integrity.
9.5.4	CSS shall generate System Wide Cybersecurity Status Messages for each incident containing the following information: - Nature of the incident - Severity of the incident - Response status	9.5.3	When an incident occurs, stakeholders need cybersecurity status including the nature, severity, and the updated status of response execution.
9.5.5	CSS shall improve its cybersecurity response plan through experience and use of historical data.	9.5.3	The attackers are always devising new scheme of attacks. Lessons learned enable VAS to understand unknown and future threats to the system.
9.6.0	CSS shall recover from a cybersecurity incident to maintain critical services.		The Recover Function enables resilience and restore any capabilities or services that were impaired due to a cybersecurity incident. The Recover Function supports timely recovery to normal operations to reduce the impact from a cybersecurity incident.
9.6.1	CSS shall execute a pre-defined cybersecurity recovery plan during and after a cybersecurity incident to maintain critical services.	9.5.3	Recovery processes and procedures are executed and coordinated according to pre-defined and agreed recovery plan upon cyber attacks.
9.6.2	CSS shall improve its cybersecurity recovery plan through experience and use of historical data.	9.6.1	Lessons learned from execution of recovery plan serves the purpose of future improvement and repair of public relation trust.
9.7.0	CSS shall transmit messages.		
9.7.1	CSS shall transmit Cybersecurity Advisory Messages to the HIS, RAS, and VMD.	9.4.4	CSS shall provide specific information to the systems and services to handle incidents that require additional instructions because CSS has the most updated cybersecurity information.

9.7.2	CSS shall transmit System Wide Cybersecurity Status Messages to the HIS, RAS, and VMD.	9.5.4	CSS shall provide system wide cybersecurity status to individual services to coordinate their priorities and decision making.

Vertiport Automation System Message Trace Matrix

Originating VAS Component or External Stakeholder	Message Name	FAA	PSU	Fleet Operator	Flight Crew	RMSS	STS	ACM	SMS	HIS	RAS	VMD	CSS
RMSS Messages													
RMSS	Vertiport Configuration	X	X	X			X	X			X	X	
RMSS	Vertiport Resource Availability Schedule	X	X	X	X		X	X		X	X	X	
RMSS	Vertiport Resource Negotiation Response		X	X									
RMSS	Vertiport Resource Clear		X	X	X			X					
RMSS	Vertiport Demand-Capacity Imbalance									X		X	
RMSS	Vertiport Resource Reservation Summary	X	X	X			X	X		X	X	X	
STS Messages													
STS	4D Surface Trajectory			X	X	X		X		X	X	X	
ACM Messages													
ACM	Airborne Trajectory Conformance Status					X				X		X	
ACM	Surface Trajectory Conformance Status					X				X		X	
ACM	Projected Trajectory Conformance Status					X				X		X	
SMS Messages													
SMS	System Monitoring Alert									X		X	X
HIS Messages													
HIS	Hazard	X	X	X	X						X	X	X
RAS Messages													
RAS	Risk Assessment		X	X		X	X					X	X
RAS	Aggregate Risk Score		X	X								X	
CSS Messages													
CSS	Cybersecurity Advisory									X	X	X	

CSS	System Wide Cybersecurity Status										X	X	X	
PSU Messages														
PSU	Flight Plan						X	X	X		X	X	X	
PSU	Flight Position						X	X	X		X	X	X	
PSU	Flight Status						X	X	X		X	X	X	
PSU	Resource Negotiation						X							
PSU	Airspace Configuration								X				X	
Flight Crew														
Flight Crew	Flight Position										X	X		
Infrastructure Data Connector														
Vertiport Weather Sensor	Vertiport Weather (Wx)										X	X	X	
Vertiport Surveillance	VOA Surveillance						X	X	X		X	X	X	
Vertiport Surveillance	Vertiport Surface Surveillance								X		X	X	X	
Vertiport FOD Detection Sensor	Vertiport FOD Detection										X	X	X	
Vertiport Charging Infrastructure Sensor	Vertiport Charging Infrastructure Status										X	X	X	
Vertiport Noise Monitoring Sensor	Vertiport Noise Monitoring Alert										X	X	X	

2021

VERTIPORT AUTOMATION SYSTEM (VAS)

Software Test Approaches

NUAIR®

MAKING FUTURE SKIES SAFER

Contents

VA-SDSP Interface

1.0.0 VAS shall interface with external systems.

1.1.0 Feature: VA-SDSP Interface shall provide a ground-to-ground interface for transmission of messages to external systems.

1.1.1 Scenario: VA-SDSP Interface shall transmit Resource Availability Schedule Messages to:

- FAA
- PSU
- Fleet Operator
- Flight Crew

Given External stakeholders are connected to the VA-SDSP Interface;

When RMSS transmits Resource Availability Schedule Messages to the VA-SDSP Interface; <2.6.2>

Then VA-SDSP Interface transmits Resource Availability Schedule Messages to the FAA, PSU, Fleet Operator, and Flight Crew.

1.1.2 Scenario: VA-SDSP Interface shall transmit Vertiport Resource Negotiation Response Messages to:

- PSU
- Fleet Operator

Given External stakeholders are connected to the VA-SDSP Interface;

When RMSS transmits Vertiport Resource Request Response Messages to the VA-SDSP Interface; <2.6.3>

Then VA-SDSP Interface transmits Vertiport Resource Negotiation Response Messages to the PSU and Fleet Operator.

1.1.3 Scenario: VA-SDSP Interface shall transmit Vertiport Configuration Messages to:

- FAA
- PSU
- Fleet Operator

Given External stakeholders are connected to the VA-SDSP Interface;

When RMSS transmits Vertiport Configuration Messages to the VA-SDSP Interface; <2.6.1>

Then VA-SDSP Interface transmits Vertiport Configuration Messages to the PSU, Fleet Operator, and FAA.

1.1.4 Scenario: VA-SDSP Interface shall transmit Vertiport Resource Reservation Summary Messages:

- FAA
- PSU
- Fleet Operator

Given External stakeholders are connected to the VA-SDSP Interface;

When RMSS transmits Vertiport Resource Reservation Summary Messages to the VA-SDSP Interface; <2.6.6>

Then VA-SDSP Interface transmits Vertiport Resource Reservation Summary Messages to the PSU, Fleet Operator, and FAA.

1.1.5 Scenario: VA-SDSP Interface shall transmit Vertiport Resource Clear Messages to:

- PSU
- Fleet Operator

Given External stakeholders are connected to the VA-SDSP Interface;

When RMSS transmits Vertiport Resource Clear Messages to the VA-SDSP Interface; <2.6.4>

Then VA-SDSP Interface transmits Vertiport Resource Clear Messages to the PSU and Fleet Operator.

1.1.6 Scenario: VA-SDSP Interface shall transmit Risk Assessment Messages to:

- PSU
- Fleet Operator

Given External stakeholders are connected to the VA-SDSP Interface;

When RAS transmits Risk Assessment Messages to the VA-SDSP Interface; <7.6.1>

Then VA-SDSP Interface transmits Risk Assessment Messages to the PSU and Fleet Operator.

1.1.7 Scenario: VA-SDSP Interface shall transmit Aggregate Risk Score Messages to:

- PSU
- Fleet Operator

Given External stakeholders are connected to the VA-SDSP Interface;

When RAS transmits Aggregate Risk Score Messages to the VA-SDSP Interface; <7.6.2>

Then VA-SDSP Interface transmits Aggregate Risk Score Messages to the PSU and Fleet Operator.

1.1.8 Scenario: VA-SDSP Interface shall transmit 4D Surface Trajectory Messages to the Fleet Operator.

Given External stakeholders are connected to the VA-SDSP Interface;

When STS transmits 4D Surface Trajectory Messages to the VA-SDSP Interface; <3.3.1>

Then VA-SDSP Interface transmits 4D Surface Trajectory Messages to the Fleet Operator.

1.1.9 Scenario: VA-SDSP Interface shall transmit Hazard Messages to:

- FAA
- PSU
- Fleet Operator

Given External stakeholders are connected to the VA-SDSP Interface;

When HIS transmits Hazard Messages to the VA-SDSP Interface; <6.4.1>

Then VA-SDSP Interface transmits Hazard Messages to the PSU, Fleet Operator, and FAA.

1.2.0 Feature: VA-SDSP Interface shall provide a ground-to-ground interface for reception of messages from external systems.

1.2.1 Scenario: VA-SDSP Interface shall receive Resource Negotiation Response Messages from the PSU.

Given External stakeholders are connected to the VA-SDSP Interface;

When PSU transmits Resource Negotiation Response Messages to the VA-SDSP Interface;

Then VA-SDSP Interface receives Resource Negotiation Response Messages;

And VA-SDSP Interface transmits Resource Negotiation Response Messages to the RMSS.

1.2.2 Scenario: VA-SDSP Interface shall receive Flight Plan Messages from PSU.

Given External stakeholders are connected to the VA-SDSP Interface;

When PSU transmits Flight Plan Messages to the VA-SDSP Interface;

Then VA-SDSP Interface receives Flight Plan Messages;

And VA-SDSP Interface transmits Flight Plan Messages to the RMSS, STS, ACM, HIS, and RAS.

1.2.3 Scenario: VA-SDSP Interface shall receive Flight Status Messages from PSU.

Given External stakeholders are connected to the VA-SDSP Interface;

When PSU transmits Flight Status Messages to the VA-SDSP Interface;

Then VA-SDSP Interface receives Flight Status Messages;

And VA-SDSP Interface transmits Flight Status Messages to the RMSS, STS, ACM, HIS, and RAS.

1.2.4 Scenario: VA-SDSP Interface shall receive Flight Position Messages from the PSU.

Given External stakeholders are connected to the VA-SDSP Interface;

When PSU transmits Flight Position Messages to the VA-SDSP Interface;

Then VA-SDSP Interface receives Flight Position Messages;

And VA-SDSP Interface transmits Flight Position Messages to the RMSS, STS, ACM, HIS, and RAS.

1.2.5 Scenario: VA-SDSP Interface shall receive Airspace Configuration Messages from the PSU.

Given External stakeholders are connected to the VA-SDSP Interface;

When PSU transmits Airspace Configuration Messages to the VA-SDSP Interface;

Then VA-SDSP Interface receives Airspace Configuration Messages;

And VA-SDSP Interface transmits Airspace Configuration Messages to the RMSS, STS, ACM, HIS, and RAS.

1.2.6 Scenario: VA-SDSP Interface shall receive Vertiport Weather (Wx) Messages from the Vertiport Infrastructure Data Connectors.

Given Vertiport Infrastructure Data Connectors are connected to the VA-SDSP Interface;

When Vertiport Infrastructure Data Connectors transmits Vertiport Weather (Wx) Messages to the VA-SDSP Interface;

Then VA-SDSP Interface transmits Vertiport Weather (Wx) Messages to the HIS, RAS, and VMD.

1.2.7 Scenario: VA-SDSP Interface shall receive VOA Surveillance Messages from the Vertiport Infrastructure Data Connectors.

Given Vertiport Infrastructure Data Connectors are connected to the VA-SDSP Interface;

When Vertiport Infrastructure Data Connectors transmits VOA Surveillance Messages to the VA-SDSP Interface;

Then VA-SDSP Interface transmits VOA Surveillance Messages to the RMSS, STS, ACM.

1.2.8 Scenario: VA-SDSP Interface shall receive the Vertiport Surface Surveillance Messages from the Vertiport Infrastructure Data Connectors.

Given Vertiport Infrastructure Data Connectors are connected to the VA-SDSP Interface;

When Vertiport Infrastructure Data Connectors transmits Vertiport Surface Surveillance Messages to the VA-SDSP Interface;

Then VA-SDSP Interface transmits Vertiport Surface Surveillance Messages to the HIS, RAS, and VMD.

1.2.9 Scenario: VA-SDSP Interface shall receive the Vertiport FOD Detection Messages from the Vertiport Infrastructure Data Connectors.

Given Vertiport Infrastructure Data Connectors are connected to the VA-SDSP Interface;

When Vertiport Infrastructure Data Connectors transmits Vertiport FOD Detection Messages to the VA-SDSP Interface;

Then VA-SDSP Interface transmits Vertiport FOD Detection Messages to the HIS, RAS, and VMD.

1.2.10 Scenario: VA-SDSP Interface shall receive the Vertiport Charging Infrastructure Status Messages from the Vertiport Infrastructure Data Connectors.

Given Vertiport Infrastructure Data Connectors are connected to the VA-SDSP Interface;

When Vertiport Infrastructure Data Connectors transmits Vertiport Charging Infrastructure Status;

Then VA-SDSP Interface transmits Vertiport Charging Infrastructure Status Messages to the HIS, RAS, and VMD.

1.2.11 Scenario: VA-SDSP Interface shall receive the Vertiport Noise Monitoring Alert Messages from the Vertiport Infrastructure Data Connectors.

Given Vertiport Infrastructure Data Connectors are connected to the VA-SDSP Interface;

When Vertiport Infrastructure Data Connectors Vertiport Noise Monitoring Alert Messages to the VA-SDSP Interface;

Then VA-SDSP Interface transmits Vertiport Noise Monitoring Alert Messages to the HIS, RAS, and VMD.

1.3.0 Feature: VA-SDSP Interface shall provide an air-ground interface for transmission of messages to Flight Crew.

1.3.1 Scenario: VA-SDSP Interface shall transmit Hazard Messages to the Flight Crew.

Given External stakeholders are connected to the VA-SDSP Interface;

When HIS transmits Hazard Messages to the VA-SDSP Interface; <6.4.1>

Then VA-SDSP Interface transmits Hazard Messages to the Flight Crew.

1.3.2 Scenario: VA-SDSP Interface shall transmit Surface Trajectory Messages to the Flight Crew.

Given External stakeholders are connected to the VA-SDSP Interface;

When STS transmits Surface Trajectory Messages to the VA-SDSP Interface; <3.3.1>

Then VA-SDSP Interface transmits Surface Trajectory Messages to the Flight Crew.

1.3.3 Scenario: VA-SDSP Interface shall transmit Vertiport Resource Clear Messages to the Flight Crew.

Given External stakeholders are connected to the VA-SDSP Interface;

When RMSS transmits Vertiport Resource Clear Messages to the VA-SDSP Interface; <2.6.4>

Then VA-SDSP Interface transmits Vertiport Resource Clear Messages to the Flight Crew.

1.3.4 Scenario: VA-SDSP Interface shall transmit Resource Availability Schedule Messages to Flight Crew.

Given External stakeholders are connected to the VA-SDSP Interface;

When RMSS generates a Resource Availability Schedule Messages to the VA-SDSP Interface; <2.6.2>

Then VA-SDSP Interface transmits Resource Availability Schedule Messages to the Flight Crew.

1.4.0 Feature: VA-SDSP Interface shall provide an air-ground interface for reception of messages from Flight Crew.

1.4.1 Scenario: VA-SDSP Interface shall receive Flight Position Messages from Flight Crew.

Given External stakeholders are connected to the VA-SDSP Interface;

When Flight Crew transmits Flight Position Messages to the VA-SDSP Interface;

Then VA-SDSP Interface transmits Flight Position Messages to the HIS, RAS, and VMD.

1.5.0 Feature: VA-SDSP Interface shall be discoverable digitally by operational stakeholders.

1.5.1 Scenario: VA-SDSP Interface shall be discoverable by PSUs.

Given PSU is connected to the same network as the VA-SDSP Interface;

When PSU searches for available Vertiport Automation SDSPs;

Then VA-SDSP Interface responds with a definition of the services available to the PSU.

1.5.2 Scenario: VA-SDSP Interface shall be discoverable by Fleet Operator.

Given Fleet Operator is connected to the same network as the VA-SDSP Interface;

When Fleet Operator searches for available Vertiport Automation SDSPs;

Then VA-SDSP Interface responds with a definition of the services available to the Fleet Operator.

1.5.3 Scenario: VA-SDSP Interface shall be discoverable by Flight Crew.

Given Flight Crew is connected to the same network as the VA-SDSP Interface;

When Flight Crew searches for available Vertiport Automation SDSPs;

Then VA-SDSP Interface responds with a definition of the services available to the Flight Crew.

Resource Management and Scheduling Service (RMSS)

2.0.0 VAS shall manage vertiport resources.

2.1.0 Feature: RMSS shall receive messages.

2.1.1 Scenario: RMSS shall receive the following messages from the PSU:

- Flight Plan
- Flight Position
- Flight Status
- Resource Negotiation

Given VA-SDSP Interface passes Flight Plan, Flight Position, Flight Status, and Resource Negotiation Response Messages from the PSU; <1.2.2> <1.2.4> <1.2.3>

When PSU transmits Flight Plan, Flight Position, Flight Status, and Resource Negotiation Response Messages to the VA-SDSP Interface;

Then RMSS receives Flight Plan Messages from the VA-SDSP Interface;

And RMSS receives Flight Position Messages from the VA-SDSP Interface;

And RMSS receives Flight Status Messages from the VA-SDSP Interface;

And RMSS receives Resource Negotiation Response Messages from the VA-SDSP Interface.

2.1.2 Scenario: RMSS shall receive the VOA Surveillance Messages from the Vertiport Infrastructure Data Connector.

Given VA-SDSP Interface passes VOA Surveillance Messages from the Vertiport Infrastructure Data Connectors; <1.2.7>

When Vertiport Infrastructure Data Connector transmits VOA Surveillance Messages to the VA-SDSP Interface;

Then RMSS receives VOA Surveillance Messages from the VA-SDSP Interface.

2.1.3 Scenario: RMSS shall receive the following messages from the ACM:

- Airborne Trajectory Conformance Status
- Surface Trajectory Conformance Status
- Projected Trajectory Conformance Status

Given VAS manages the flow of data between services;

When ACM transmits Airborne Trajectory Conformance Status, Surface Trajectory Conformance Status, and Projected Trajectory Conformance Status Messages to the RMSS; <4.5.1> <4.5.2> <4.5.3>

Then RMSS receives Airborne Trajectory Conformance Status Messages;

And RMSS receives Surface Trajectory Conformance Status Messages;

And RMSS receives Projected Trajectory Conformance Status Messages.

2.1.4 Scenario: RMSS shall receive Risk Assessment Messages from the RAS.

Given VAS manages the flow of data between services;

When RAS transmits Risk Assessment Messages to the RMSS; <7.6.1>

Then RMSS receives Risk Assessment Messages.

2.2.0 Feature: RMSS shall determine vertiport configuration.

2.2.1 Scenario: RMSS shall construct a 4D (longitude, latitude, altitude, and time) map of vertiport resources fused with vertiport resource performance and sizing information.

Given RMSS has 4D mapping capability;

And VMD defines Vertiport Resource List; <8.3.2>

When VMD updates Vertiport Resource List;

Then RMSS constructs a 4D map of vertiport resources.

2.2.2 Scenario: RMSS shall designate restricted surface volumes on or above the surface of the vertiport from nominal aircraft operations.

Given VMD configures separation buffer criteria; <8.3.2>

And VMD designates passenger and cargo zones; <8.3.2>

When RMSS constructs a 4D map of vertiport resources; <2.2.1>

Then RMSS updates 4D map to include vertiport surface restricted volumes.

2.2.3 Scenario: RMSS shall update resource availability using arrival and departure traffic flow direction.

Given Arrival and departure traffic flow direction are indicated in the Flight Plan; <2.1.1>

And RMSS collaborates with the PSU Network;

And RMSS accounts for local regulations, regional weather conditions, environmental considerations, and operating rules;

When RMSS updates 4D map to include vertiport surface restricted volumes; <2.2.2>

Then RMSS updates 4D map resource availability to match arrival and departure flow directionality.

2.2.4 Scenario: RMSS shall generate Vertiport Configuration Messages.

Given RMSS constructs a 4D map of vertiport resources; <2.2.1>

When RMSS updates 4D map resource availability to match arrival and departure flow directionality; <2.2.3>

Then RMSS generates Vertiport Configuration Messages.

2.3.0 Feature: RMSS shall determine vertiport resource availability, publish resource availability, and negotiate resource reservations.

2.3.1 Scenario: RMSS shall map resource prioritization to the vertiport configuration to configure a resource scheduling prioritization algorithm.

Given RMSS generates Vertiport Configuration Messages; <2.2.4>

When VMD defines resource prioritization rules; <8.3.3>

Then RMSS configures a resource prioritization algorithm.

2.3.2 Scenario: RMSS shall reserve a configurable number and type of vertiport resources to be utilized in an emergency or other high priority situation.

Given VMD has configured a set of rules to be used during periods of emergency or high priority situations; <8.3.3>

And RMSS receives Projected Trajectory Conformance Status; <2.1.3>

When RMSS configures a resource prioritization algorithm; <2.3.1>

Then RMSS reserves a set of resources for emergency conditions.

2.3.3 Scenario: RMSS shall generate Vertiport Resource Availability Schedule Messages at the start of the day of operations and as updates occur.

Given RMSS generates Vertiport Configuration Messages; <2.2.4>

And RMSS configures a resource prioritization algorithm; <2.3.1>

And RMSS reserves a set of resources for emergency conditions; <2.3.2>

When VMD operationalizes VAS systems and services; <8.3.3>

Then RMSS generates Vertiport Resource Availability Schedule Messages.

2.3.4 Scenario: RMSS shall receive and validate resource reservation requests.

Given RMSS generates Vertiport Resource Availability Schedule Messages; <2.3.3>

And Flight Plan includes relevant aircraft sizing and performance characteristics;

When RMSS receives Flight Plan Messages from the VA-SDSP Interface; <8.3.3>

Then RMSS validates resource reservation requests.

2.3.5 Scenario: RMSS shall accept or reject resource reservation requests.

Given VMD transmits Resource Prioritization Rules Message; <8.3.3>

And RMSS receives Projected Trajectory Conformance Status; <2.1.3>

And RMSS generates Vertiport Resource Availability Schedule Messages; <2.3.3>

When RMSS validates resource reservation request; <2.3.4>

Then RMSS accepts or rejects resource reservation requests.

2.3.6 Scenario: RMSS shall generate Vertiport Resource Request Response Messages.

Given RMSS validates resource reservation requests; <2.3.4>

When RMSS accepts or rejects resource reservation requests; <2.3.5>

Then RMSS generates Vertiport Resource Request Response Messages.

2.3.7 Scenario: RMSS shall generate Vertiport Arrival Pad Clear Messages.

Given RMSS receives Airborne Trajectory Conformance Status Messages; <2.1.3>

And RMSS receives Surface Trajectory Conformance Status Messages; <2.1.3>

And RMSS receives Projected Trajectory Conformance Status Messages; <2.1.3>

When Flight Status Message indicates an aircraft is approaching to land; <2.1.1>

Then RMSS generates Vertiport Arrival Pad Clear Messages.

2.3.8 Scenario: RMSS shall generate Vertiport Departure Pad Clear Messages.

Given RMSS receives Airborne Trajectory Conformance Status Messages; <2.1.3>

And RMSS receives Surface Trajectory Conformance Status Messages; <2.1.3>

And RMSS receives Projected Trajectory Conformance Status Messages; <2.1.3>

When Flight Status Message indicate an aircraft is ready to taxi for departure; <2.1.1>

Then RMSS generates Vertiport Departure Pad Clear Messages.

2.4.0 Feature: RMSS shall respond to vertiport resource schedule disruptions.

2.4.1 Scenario: RMSS shall update vertiport resource reservations in response to resource negotiations.

Given RMSS receives Flight Plan Messages from the VA-SDSP Interface; <2.1.1>

And RMSS receives Flight Position Messages from the VA-SDSP Interface; <2.1.1>

And RMSS receives Flight Status Messages from the VA-SDSP Interface; <2.1.1>

And RMSS receives Projected Trajectory Conformance Status; <2.1.3>

When RMSS receives Resource Negotiation Response Message; <2.1.1>

And RMSS receives Airborne Trajectory Conformance Status Messages; <2.1.3>

And RMSS receives Surface Trajectory Conformance Status Messages; <2.1.3>

Then RMSS updates vertiport resource reservations.

2.4.2 Scenario: RMSS shall update vertiport resource reservations in response to RAS and VMD risk mitigation strategies.

Given RMSS receives Flight Plan Messages from the VA-SDSP Interface; <2.1.1>

And RMSS receives Flight Position Messages from the VA-SDSP Interface; <2.1.1>

And RMSS receives Flight Status Messages from the VA-SDSP Interface; <2.1.1>

When RMSS receives Risk Assessment Messages; <2.1.4>

And VMD inputs mitigation strategy; <8.3.3>

Then RMSS updates resource availability.

2.4.3 Scenario: RMSS shall update the vertiport configuration based on updated vertiport resource availability.

Given RMSS generates Vertiport Configuration Messages; <2.2.4>

When RMSS updates resource availability; <2.4.2>

Then RMSS updates the vertiport configuration.

2.5.0 Feature: RMSS shall calculate resource reservation metrics.

2.5.1 Scenario: RMSS shall calculate aggregate resource reservations, approvals, and rejections.

Given RMSS logs historical resource reservation request and response data;

And VMD defines resource reservation metric calculation frequency; <8.3.4>

When RMSS reaches recurring resource reservation metric calculation frequency timestep;

Then RMSS calculates aggregate resource reservations, approvals, and rejections.

2.5.2 Scenario: RMSS shall generate Vertiport Resource Reservation Summary Messages containing:

- Aggregate resource reservations
- Reservation approvals
- Reservation rejections

Given RMSS accepts or rejects resource reservation requests; <2.3.5>

When RMSS calculates aggregate resource reservations, approvals, and rejections; <2.5.1>

Then RMSS generates Vertiport Resource Reservation Summary Messages.

2.5.3 Scenario: RMSS shall calculate projected vertiport resource demand.

Given RMSS features a demand projection algorithm;

And RMSS generates Vertiport Configuration Messages; <2.2.4>

And RMSS calculates aggregate resource reservations, approvals, and rejections; <2.5.1>

And VMD defines resource reservation metric calculation frequency; <8.3.4>

When RMSS reaches recurring resource reservation metric calculation frequency timestep;

Then RMSS calculates projected vertiport resource demand.

2.5.4 Scenario: RMSS shall calculate vertiport resource demand-capacity balance.

Given RMSS receives Surface Trajectory Conformance Status Messages; <2.1.3>

And RMSS generates Vertiport Configuration Messages; <2.2.4>

When RMSS calculates projected vertiport resource demand; <2.5.3>

Then RMSS calculates vertiport resource demand-capacity balance.

2.5.5 Scenario: RMSS shall generate Vertiport Demand-Capacity Imbalance Messages.

Given RMSS calculates a demand-capacity balance that exceeds pre-configured thresholds;

And VMD defines demand-capacity balance criteria; <8.3.4>

When RMSS calculates vertiport resource demand-capacity balance; <2.5.4>

Then RMSS generates Vertiport Demand-Capacity Imbalance Messages.

2.6.0 Feature: RMSS shall transmit the following messages.

2.6.1 Scenario: RMSS shall transmit Vertiport Configuration Messages to the STS, ACM, RAS, and VMD.

Given VA-SDSP Interface passes Vertiport Configuration Messages to the PSU, Fleet Operator, and the FAA; <1.1.3>

And VAS manages the flow of data between services;

When RMSS generates Vertiport Configuration Messages; <2.2.4>

Then RMSS transmits Vertiport Configuration Messages to the VA-SDSP Interface;

And RMSS transmits Vertiport Configuration Messages to the STS, ACM, RAS, and VMD.

2.6.2 Scenario: RMSS shall transmit Vertiport Resource Availability Schedule Messages to the STS, ACM, HIS, RAS, and VMD.

Given VA-SDSP Interface passes Vertiport Resource Availability Schedule Messages to the PSU, Fleet Operator, Flight Crew, and FAA; <1.1.1>

And VAS manages the flow of data between services;

When RMSS generates Vertiport Resource Availability Schedule Messages; <2.3.3>

Then RMSS transmits Vertiport Resource Availability Schedule Messages to the VA-SDSP Interface;

And RMSS transmits Vertiport Resource Availability Schedule Messages to the STS, ACM, HIS, RAS, and VMD.

2.6.3 Scenario: RMSS shall transmit Vertiport Resource Negotiation Response Messages.

Given VA-SDSP Interface passes Vertiport Resource Negotiation Response Messages to the PSU and Fleet Operator; <1.1.2>

When RMSS generates Vertiport Resource Request Response Messages; <2.3.6>

Then RMSS transmits Vertiport Resource Negotiation Response Messages to the VA-SDSP Interface.

2.6.4 Scenario: RMSS shall transmit Vertiport Resource Clear Messages to the ACM.

Given VA-SDSP Interface passes Vertiport Resource Clear Messages to the PSU, Fleet Operator, and Flight Crew; <1.1.5>

And VAS manages the flow of data between services;

When RMSS generates Vertiport Arrival Pad Clear Messages; <2.3.7>

And RMSS generates Vertiport Departure Pad Clear Messages; <2.3.8>

Then RMSS transmits Vertiport Resource Clear Messages to the VA-SDSP Interface;

And RMSS transmits Vertiport Resource Clear Messages to the ACM.

2.6.5 Scenario: RMSS shall transmit Vertiport Demand-Capacity Imbalance Messages to the HIS and VMD.

Given VAS manages the flow of data between services;

When RMSS generates Vertiport Demand-Capacity Imbalance Messages; <2.5.5>

Then RMSS transmits Vertiport Demand-Capacity Imbalance Messages to the HIS and VMD.

2.6.6 Scenario: RMSS shall transmit Vertiport Resource Reservation Summary Messages to the STS, ACM, HIS, RAS, and VMD.

Given VA-SDSP Interface passes Vertiport Resource Reservation Summary Messages to the PSU, Fleet Operator, and the FAA; <1.1.4>

And VAS manages the flow of data between services;

When RMSS generates Vertiport Resource Reservation Summary Messages; <2.5.2>

Then RMSS transmits Vertiport Resource Reservation Summary Messages to the VA-SDSP Interface;

And RMSS transmits Vertiport Resource Reservation Summary Messages to the STS, ACM, HIS, RAS, and VMD.

Surface Trajectory Service (STS)

3.0.0 VAS shall manage surface trajectories.

3.1.0 Feature: STS shall receive messages.

3.1.1 Scenario: STS shall receive the following messages from the PSU:

- Flight Plan
- Flight Position
- Flight Status

Given VA-SDSP Interface passes Flight Plan, Flight Position, and Flight Status Messages from the PSU; <1.2.2> <1.2.4> <1.2.3>

When PSU transmits Flight Plan, Flight Position, and Flight Status Messages to the VA-SDSP Interface;

Then STS receives Flight Plan Messages from the VA-SDSP Interface;

And STS receives Flight Position Messages from the VA-SDSP Interface;

And STS receives Flight Status Messages from the VA-SDSP Interface.

3.1.2 Scenario: STS shall receive the following messages from the RMSS:

- Vertiport Configuration
- Vertiport Resource Availability Schedule
- Vertiport Resource Reservation Summary

Given VAS manages the flow of data between services;

When RMSS transmits Vertiport Configuration Messages to the STS; <2.6.1>

And RMSS transmits Vertiport Resource Availability Schedule Messages to the STS; <2.6.2>

And RMSS transmits Vertiport Resource Reservation Summary Messages to the STS; <2.6.6>

Then STS receives Vertiport Configuration Messages;

And STS receives Vertiport Resource Availability Schedule Messages;

And STS receives Vertiport Resource Reservation Summary Messages.

3.1.3 Scenario: STS shall receive Risk Assessment Messages from the RAS.

Given VAS manages the flow of data between services;

When RAS transmits Risk Assessment Messages to the STS; <7.6.1>

Then STS receives Risk Assessment Messages.

3.2.0 Feature: STS shall construct 4D surface trajectories for aircraft and ground vehicles.

3.2.1 Scenario: STS shall construct a 3D map containing:

- Vertiport resource configuration

- Vertiport resource availability
- Taxi pathways

Given STS receives Vertiport Resource Reservation Summary Messages; <3.1.2>

And STS receives Vertiport Resource Availability Schedule Messages; <3.1.2>

And STS has 3D mapping capability;

When STS receives Vertiport Configuration Messages; <3.1.2>

Then STS constructs a 3D map of vertiport surface taxi pathways.

3.2.2 Scenario: STS shall construct the 3D (longitude, latitude, altitude) surface trajectory connecting origin to destination.

Given STS receives Vertiport Resource Availability Schedule Messages; <3.1.2>

And STS constructs a 3D map of vertiport surface taxi pathways; <3.2.1>

When Flight Status Message indicate an aircraft is ready to taxi for departure; <3.1.1>

Then STS constructs a notional 3D surface trajectory.

3.2.3 Scenario: STS shall calculate the origin to destination expected timing for the 3D surface trajectory to construct a 4D (time) surface trajectory.

Given STS receives Vertiport Resource Availability Schedule Messages; <3.1.2>

And STS constructs a 3D map of vertiport surface taxi pathways; <3.2.1>

When STS constructs a notional 3D surface trajectory; <3.2.2>

Then STS calculates the origin to destination expected timing;

And STS constructs a notional 4D surface trajectory.

3.2.4 Scenario: STS shall provide strategic deconfliction of surface trajectories to balance demand against surface capacity.

Given STS receives Vertiport Resource Reservation Summary Messages; <3.1.2>

And STS receives Vertiport Resource Availability Schedule Messages; <3.1.2>

And STS receives digital 3D vertiport diagram; <3.2.1>

When STS constructs a notional 4D surface trajectory; <3.2.3>

Then STS checks for strategic deconfliction of surface trajectories;

And STS calculates the most efficient 4D surface trajectory.

3.2.5 Scenario: STS shall generate 4D Surface Trajectory Messages.

Given Flight Status Message indicate an aircraft is ready to taxi for departure; <3.1.1>

When STS calculates the most efficient 4D surface trajectory; <3.2.4>

Then STS generates 4D Surface Trajectory Messages.

3.2.6 Scenario: STS shall regenerate 4D surface trajectories in response to RAS mitigations.

Given a hazard has been identified with an unacceptable risk level which results in a mitigation action affecting a surface trajectory;

When STS receives Risk Assessment Messages; <3.1.3>

Then STS shall regenerate 4D surface trajectories.

3.3.0 Feature: STS shall transmit messages.

3.3.1 Scenario: STS shall transmit 4D Surface Trajectory Messages to the RMSS, ACM, HIS, RAS, and VMD.

Given VA-SDSP Interface passes 4D Surface Trajectory Messages to the Fleet Operator and Flight Crew; <1.1.7>

And VAS manages the flow of data between services;

When STS generates 4D Surface Trajectory Messages; <3.2.5>

Then STS transmits 4D Surface Trajectory Messages to the VA-SDSP Interface;

And STS transmits 4D Surface Trajectory Messages to the RMSS, ACM, HIS, RAS, and VMD.

Aircraft Conformance Monitor (ACM)

4.0.0 VAS shall monitor aircraft and ground vehicle conformance to trajectories.

4.1.0 Feature: ACM shall receive messages.

4.1.1 Scenario: ACM shall receive the following messages from the PSU:

- Flight Plan
- Flight Position
- Flight Status
- Airspace Configuration

Given VA-SDSP Interface passes Flight Plan, Flight Position, Flight Status, and Airspace Configuration Messages from the PSU; <1.2.2> <1.2.4> <1.2.3>

When PSU transmits Flight Plan, Flight Position, Flight Status, and Airspace Configuration Messages to the VA-SDSP Interface;

Then ACM receives Flight Plan Messages from the VA-SDSP Interface;

And ACM receives Flight Position Messages from the VA-SDSP Interface;

And ACM receives Flight Status Messages from the VA-SDSP Interface;

And ACM receives Airspace Configuration Messages from the VA-SDSP Interface.

4.1.2 Scenario: ACM shall receive the following messages from the Vertiport Infrastructure Data Connectors:

- VOA Surveillance
- Vertiport Surface Surveillance

Given VA-SDSP Interface passes VOA Surveillance and Vertiport Surface Surveillance Messages from the Vertiport Infrastructure Data Connectors; <1.2.6>

When Vertiport Infrastructure Data Connector transmits VOA Surveillance and Vertiport Surface Surveillance Messages to the VA-SDSP Interface;

Then ACM receives VOA Surveillance Messages from the VA-SDSP Interface;

And ACM receives Vertiport Surface Surveillance Messages from the VA-SDSP Interface.

4.1.3 Scenario: ACM shall receive the following messages from the RMSS:

- Vertiport Configuration
- Vertiport Resource Availability Schedule
- Vertiport Resource Clear
- Vertiport Resource Reservation Summary

Given VAS manages the flow of data between services;

When RMSS transmits Vertiport Configuration Messages to the ACM; <2.6.1>

And RMSS transmits Vertiport Resource Availability Schedule Messages to the ACM; <2.6.2>

And RMSS transmits Vertiport Resource Clear Messages to the ACM; <2.6.4>

And RMSS transmits Vertiport Resource Reservation Summary Messages to the ACM; <2.6.6>

Then ACM receives Vertiport Configuration Messages;

And ACM receives Vertiport Resource Availability Schedule Messages;

And ACM receives Vertiport Resource Clear Messages;

And ACM receives Vertiport Resource Reservation Summary Messages.

4.1.4 Scenario: ACM shall receive 4D Surface Trajectory Messages from the STS.

Given VAS manages the flow of data between services;

When STS transmits 4D Surface Trajectory Messages to the ACM; <3.3.1>

Then ACM receives 4D Surface Trajectory Messages.

4.2.0 Feature: ACM shall identify non-conforming airborne aircraft.

4.2.1 Scenario: ACM shall continuously predict aircraft arrival times.

Given ACM receives Flight Position Messages; <4.1.1>

And ACM receives Flight Status Messages; <4.1.1>

And ACM receives VOA Surveillance Messages; <4.1.2>

And ACM receives Vertiport Configuration Messages; <4.1.3>

And ACM receives Vertiport Resource Reservation Summary Messages; <4.1.3>

When ACM receives Flight Plan Messages; <4.1.1>

Then ACM generates predicted arrival time for aircraft;

And ACM continuously updates predicted arrival time for aircraft.

4.2.2 Scenario: ACM shall identify airborne aircraft in non-conformance with landing pad reservation window.

Given VMD configures reservation window conformance tolerances; <8.5.2>

And ACM receives Flight Plan Messages; <4.1.1>

And ACM receives Flight Position Messages; <4.1.1>

And ACM receives Flight Status Messages; <4.1.1>

And ACM receives VOA Surveillance Messages; <4.1.2>

And ACM receives Vertiport Configuration Messages; <4.1.3>

And ACM receives Vertiport Resource Reservation Summary Messages; <4.1.3>

When ACM generates a prediction of aircraft arrival time; <4.2.1>

And ACM predicted arrival time for an aircraft is outside of the aircraft arrival pad reservation tolerance;

Then ACM identifies non-conforming aircraft.

4.2.3 Scenario: ACM shall monitor aircraft location in relation to VOA and VPV airspace boundaries.

Given ACM receives Airspace Configuration Messages; <4.1.1>

And ACM receives Flight Plan Messages; <4.1.1>

And ACM receives Flight Position Messages; <4.1.1>

And ACM receives Flight Status Messages; <4.1.1>

And ACM receives Vertiport Configuration Messages; <4.1.3>

And ACM receives Vertiport Resource Reservation Summary Messages; <4.1.3>

When ACM receives VOA Surveillance Messages; <4.1.2>

Then ACM compares aircraft current position against airspace boundaries.

4.2.4 Scenario: ACM shall identify airborne aircraft in non-conformance with VOA and VPV airspace boundaries.

Given VMD configures airspace boundaries and conformance tolerances; <8.5.2>

And ACM receives Airspace Configuration Messages; <4.1.1>

And ACM receives Flight Plan Messages; <4.1.1>

And ACM receives Flight Position Messages; <4.1.1>

And ACM receives Flight Status Messages; <4.1.1>

And ACM receives VOA Surveillance Messages; <4.1.2>

And ACM receives Vertiport Configuration Messages; <4.1.3>

And ACM receives Vertiport Resource Reservation Summary Messages; <4.1.3>

When ACM compares aircraft current position against airspace boundaries; <4.2.3>

Then ACM identifies non-conforming aircraft.

4.2.5 Scenario: ACM shall generate Airborne Trajectory Conformance Status Messages.

Given ACM monitors airborne aircraft;

When ACM identifies non-conforming aircraft; <4.2.2>

Then ACM generates Airborne Trajectory Conformance Status Messages.

4.3.0 Feature: ACM shall identify non-conforming surface aircraft or ground vehicles.

4.3.1 Scenario: ACM shall monitor surface aircraft or ground vehicle location in relation to surface trajectories issued by STS.

Given ACM receives Flight Position Messages; <4.1.1>

And ACM receives Flight Status Messages; <4.1.1>

And ACM receives Vertiport Configuration Messages; <4.1.3>

And ACM receives 4D Surface Trajectory Messages; <4.1.4>

When ACM receives Vertiport Surface Surveillance Messages; <4.1.2>

Then ACM compares aircraft location against surface trajectory.

4.3.2 Scenario: ACM shall identify if surface aircraft or ground vehicles in non-conformance with surface trajectory issued by the STS.

Given VMD configures acceptable surface trajectory conformance tolerances; <8.5.2>

And ACM receives Flight Position Messages; <4.1.1>

And ACM receives Flight Status Messages; <4.1.1>

And ACM receives Vertiport Surface Surveillance Messages; <4.1.2>

And ACM receives Vertiport Configuration Messages; <4.1.3>

And ACM receives 4D Surface Trajectory Messages; <4.1.4>

When ACM compares aircraft location against surface trajectory; <4.3.1>

And Aircraft or ground vehicles are outside of acceptable surface trajectory conformance tolerances;

Then ACM identifies surface trajectory non-conforming aircraft or ground vehicles.

4.3.3 Scenario: ACM shall monitor surface aircraft or ground vehicle location in relation to other surface aircraft or ground vehicles.

Given ACM receives Flight Position Messages; <4.1.1>

And ACM receives Flight Status Messages; <4.1.1>

When ACM receives Vertiport Surface Surveillance Messages; <4.1.2>

Then ACM compares aircraft location against location of other aircraft or ground vehicles on the surface.

4.3.4 Scenario: ACM shall identify if aircraft or ground vehicles are in non-conformance with vehicle-to-vehicle separation.

Given VMD configures acceptable vehicle-to-vehicle separation conformance tolerances; <8.5.2>

And ACM receives Flight Position Messages; <4.1.1>

And ACM receives Flight Status Messages; <4.1.1>

And ACM receives Vertiport Surface Surveillance Messages; <4.1.2>

And ACM receives Vertiport Configuration Messages; <4.1.3>

And ACM receives 4D Surface Trajectory Messages; <4.1.4>

When ACM compares aircraft location against location of other aircraft or ground vehicles on the surface.

And Aircraft or ground vehicles are outside of acceptable vehicle-to-vehicle separation conformance tolerances;

Then ACM identifies vehicle-to-vehicle separation non-conforming aircraft or ground vehicles.

4.3.5 Scenario: ACM shall continuously predict aircraft departure times.

Given ACM receives Flight Position Messages; <4.1.1>

And ACM receives Flight Status Messages; <4.1.1>

And ACM receives Vertiport Configuration Messages; <4.1.3>

And ACM receives Vertiport Resource Reservation Summary Messages; <4.1.3>

When ACM receives Flight Plan Messages; <4.1.1>

Then ACM predicts departure time for aircraft;

And ACM continuously updates predicted arrival time for aircraft.

4.3.6 Scenario: ACM shall identify surface aircraft in non-conformance with departure pad reservation window.

Given VMD configures reservation window conformance tolerances; <8.5.2>

And ACM receives the Flight Plan Message; <4.1.1>

And ACM receives the Flight Status Message; <4.1.1>

And ACM receives Vertiport Configuration Messages; <4.1.3>

And ACM receives Vertiport Resource Reservation Summary Messages; <4.1.3>

When ACM generates a prediction of aircraft departure time; <4.3.5>

And ACM predicted departure time for an aircraft is outside of the aircraft departure pad reservation tolerance;

Then ACM identifies departure pad reservation window non-conforming aircraft.

4.3.7 Scenario: ACM shall generate Surface Trajectory Conformance Status Messages.

Given ACM monitors aircraft on the surface and ground vehicles;

When ACM identifies surface trajectory non-conforming aircraft or ground vehicles; <4.3.1>

And ACM identifies vehicle-to-vehicle separation non-conforming aircraft or ground vehicles; <4.3.2>

And ACM identifies departure pad reservation window non-conforming aircraft; <4.3.3>

Then ACM generates Surface Trajectory Conformance Status Messages.

4.4.0 Feature: ACM shall predict aircraft 4D trajectory non-conformance.

4.4.1 Scenario: ACM shall identify aircraft future non-conformance.

Given ACM logs aircraft state vectors and conformance status;

And VMD defines trajectory non-conformance prediction frequency; <8.5.2>

When ACM reaches recurring trajectory non-conformance prediction frequency timestep;

Then ACM predicts future aircraft 4D airborne trajectory conformance;

And ACM predicts future aircraft 4D surface trajectory conformance.

4.4.2 Scenario: ACM shall improve aircraft future non-conformance prediction through experience and use of historical data.

Given ACM logs aircraft state vectors and conformance status;

And ACM contains non-conformance prediction model based on historical data;

When ACM predicts future aircraft 4D airborne trajectory conformance; <4.4.1>

And ACM predicts future aircraft 4D surface trajectory conformance; <4.4.1>

Then ACM non-conformance prediction model uses historical data to improve aircraft future non-conformance prediction.

4.4.3 Scenario: ACM shall calculate projected aircraft 4D airborne and surface trajectory conformance probabilities.

Given ACM logs aircraft state vectors and conformance status;

And ACM receives Vertiport Resource Availability Schedule Messages; <4.1.3>

And ACM non-conformance prediction model uses historical data to improve aircraft future non-conformance prediction; <4.4.2>

When ACM predicts future aircraft 4D airborne trajectory conformance; <4.4.1>

And ACM predicts future aircraft 4D surface trajectory conformance; <4.4.1>

Then ACM identifies aircraft non-conformance in the future.

4.4.4 Scenario: ACM shall generate Projected Trajectory Conformance Status Messages.

Given ACM predicts future aircraft 4D airborne trajectory conformance; <4.4.1>

And ACM predicts future aircraft 4D surface trajectory conformance; <4.4.1>

When ACM identifies aircraft non-conformance in the future; <4.4.3>

Then ACM generates Projected Airborne Trajectory Conformance Status Messages.

4.5.0 Feature: ACM shall transmit messages.

4.5.1 Scenario: ACM shall transmit Airborne Trajectory Conformance Status Messages to the RMSS, HIS, and VMD.

Given VAS Manages the flow of data between services;

When ACM generates Airborne Trajectory Conformance Status Message; <4.2.3>

Then ACM transmits Airborne Trajectory Conformance Status Messages to the RMSS, HIS, and VMD.

4.5.2 Scenario: ACM shall transmit Surface Trajectory Conformance Status Messages to the RMSS, HIS, and VMD.

Given VAS Manages the flow of data between services;

When ACM generates Surface Trajectory Conformance Status Messages; <4.3.4>

Then ACM transmits Surface Trajectory Conformance Status Messages to the RMSS, HIS, and VMD.

4.5.3 Scenario: ACM shall transmit Projected Trajectory Conformance Status Messages to the RMSS, HIS, and VMD.

Given VAS Manages the flow of data between services;

When ACM generates Projected Airborne Trajectory Conformance Status Messages; <4.4.4>

Then ACM transmits Projected Trajectory Conformance Status Messages to the RMSS, HIS, and VMD.

System Monitoring Service (SMS)

5.0.0 The VAS shall monitor vertiport infrastructure and software.

5.1.0 Feature: SMS shall monitor VAS services.

5.1.1 Scenario: SMS shall detect VAS service exceptions and faults.

Given VMD defines the internal VAS services to monitor; <8.6.2>

And VMD configures the parameters to monitor for internal VAS services; <8.6.2>

And VMD configures SMS monitoring frequency; <8.6.2>

When SMS reaches recurring SMS monitoring frequency timestep;

And exception or fault occurs in VAS service;

Then SMS detects exceptions and faults.

5.1.2 Scenario: SMS shall monitor VAS service logs and detect errors.

Given VMD defines the internal VAS services to monitor; <8.6.2>

And VMD configures the parameters to monitor for errors; <8.6.2>

And VMD configures SMS monitoring frequency; <8.6.2>

When SMS reaches recurring SMS monitoring frequency timestep;

And error is written to VAS service log;

Then SMS detects errors in VAS service logs.

5.1.3 Scenario: SMS shall generate a System Monitoring Alert Message.

Given exception or fault occurs in VAS service;

And error is written to VAS service log;

When SMS detects exception or fault within internal VAS services; <5.1.1>

And SMS detects error in VAS service logs; <5.1.2>

Then SMS generates System Monitoring Alert Messages.

5.2.0 Feature: SMS shall monitor VAS Infrastructure.

5.2.1 Scenario: SMS shall monitor VAS digital storage and detect when the usage exceeds a configurable threshold.

Given VMD configures the digital storage parameters to be monitored; <8.6.3>

And VMD configures the alerting threshold for digital storage usage; <8.6.3>

And VMD configures SMS monitoring frequency; <8.6.3>

When SMS reaches recurring SMS monitoring frequency timestep;

And Storage usage exceeds configurable threshold;

Then SMS detects low storage level.

5.2.2 Scenario: SMS shall monitor VAS digital memory and detect when usage exceeds a configurable threshold.

Given VMD configures the digital memory parameters to be monitored; <8.6.3>

And VMD configures the alerting threshold for digital memory usage; <8.6.3>

And VMD configures SMS monitoring frequency; <8.6.3>

When SMS reaches recurring SMS monitoring frequency timestep;

And memory usage exceeds configurable threshold;

Then SMS detects low memory level.

5.2.3 Scenario: SMS shall monitor VAS processing usage and detect when load exceeds a configurable threshold.

Given VMD configures the processing parameters to be monitored; <8.6.3>

And VMD configures the alerting threshold for processing usage; <8.6.3>

And VMD configures SMS monitoring frequency; <8.6.3>

When SMS reaches recurring SMS monitoring frequency timestep;

And processing load exceeds configurable threshold;

Then SMS detects high processing load.

5.2.4 Scenario: The SMS shall monitor VAS radio communication infrastructure and detect when interference exceeds the configurable threshold.

Given VMD configures the radio communication infrastructure to be monitored;

And VMD configures the alerting threshold for interference; <8.6.3>

And VMD configures SMS monitoring frequency; <8.6.3>

When SMS reaches recurring SMS monitoring frequency timestep;

And radio interference exceeds configurable threshold;

Then SMS detects radio interference.

5.2.5 Scenario: SMS shall monitor the VAS networking infrastructure and detect any faults or failures.

Given VMD configures the networking infrastructure to be monitored; <8.6.3>

And VMD configures the parameters to monitor for faults or failures; <8.6.3>

And VMD configures SMS monitoring frequency; <8.6.3>

When SMS reaches recurring SMS monitoring frequency timestep;

And networking infrastructure encounters a fault or failure;

Then SMS detects networking fault or failure.

5.2.6 Scenario: SMS shall monitor VAS sensors and detect any faults are failures.

Given VMD configures the VAS sensors to be monitored; <8.6.3>

And VMD configures the parameters to monitor for faults or failures; <8.6.3>

And VMD configures SMS monitoring frequency; <8.6.3>

When SMS reaches recurring SMS monitoring frequency timestep;

And VAS sensor encounters a fault or failure;

Then SMS detects sensor fault or failure.

5.2.7 Scenario: SMS shall monitor networking infrastructure used to provide connectivity to external stakeholders and detect faults or failures.

Given VMD configures the networking infrastructure to be monitored; <8.6.3>

And VMD configures the parameters to monitor for faults or failures; <8.6.3>

And VMD configures SMS monitoring frequency; <8.6.3>

When SMS reaches recurring SMS monitoring frequency timestep;

And networking infrastructure encounters a fault or failure;

Then SMS detects networking fault or failure.

5.2.8 Scenario: SMS shall generate System Monitoring Alert Messages.

Given VAS Infrastructure is experiencing low storage, memory, high processing load, radio interference, fault, or failure;

When SMS detects the fault or failure; <5.2.5> <5.2.6> <5.2.7>

Then SMS generates System Monitoring Alert Messages.

5.3.0 Feature: SMS shall transmit messages.

5.3.1 Scenario: SMS shall transmit System Monitoring Alert Message to the HIS, VMD, and CSS.

Given VAS manages the flow of data between services;

When SMS generates System Monitoring Alert Messages; <5.2.8>

Then SMS transmits System Monitoring Alert Messages to the HIS, VMD, and CSS.

Hazard Identification Service (HIS)

6.0.0 VAS shall identify hazards.

6.1.0 Feature: HIS shall receive messages.

6.1.1 Scenario: HIS shall receive the following messages from the PSU:

- Flight Plan
- Flight Position
- Flight Status

Given VA-SDSP Interface passes Flight Plan, Flight Position, and Flight Status Messages from the PSU; <1.2.2> <1.2.4> <1.2.3>

When PSU transmits Flight Plan, Flight Position, and Flight Status Messages to the VA-SDSP Interface;

Then HIS receives Flight Plan Messages from the VA-SDSP Interface;

And HIS receives Flight Position Messages from the VA-SDSP Interface;

And HIS receives Flight Status Messages from the VA-SDSP Interface;

6.1.2 Scenario: HIS shall receive Flight Position Messages from the Flight Crew.

Given VA-SDSP Interface passes Flight Position Messages from the Flight Crew; <1.2.4>

When Flight Crew transmits Flight Position Messages to the VA-SDSP Interface;

Then HIS receives Flight Position Messages from the VA-SDSP Interface.

6.1.3 Scenario: HIS shall receive the following messages from the Vertiport Infrastructure Data Connectors:

- Vertiport Weather (Wx)
- VOA Surveillance
- Vertiport Surface Surveillance
- Vertiport FOD Detection
- Vertiport Charging Infrastructure Status
- Vertiport Noise Monitoring Alert

Given VA-SDSP Interface passes Vertiport Weather (Wx), VOA Surveillance, Vertiport Surface Surveillance, Vertiport FOD Detection, Vertiport Charging Infrastructure Status, Vertiport Noise Monitoring Alert Messages from the Vertiport Infrastructure Data Connectors; <1.2.6> <1.2.7> <1.2.8> <1.2.9> <1.2.10> <1.2.11>

When Vertiport Infrastructure Data Connectors transmits Vertiport Weather (Wx), VOA Surveillance, Vertiport Surface Surveillance, Vertiport FOD Detection, Vertiport Charging Infrastructure Status, Vertiport Noise Monitoring Alert Messages to the VA-SDSP Interface;

Then HIS receives Vertiport Weather (Wx) Messages from the VA-SDSP Interface;

And HIS receives VOA Surveillance Messages from the VA-SDSP Interface;

And HIS receives Vertiport Surface Surveillance Messages from the VA-SDSP Interface;

And HIS receives Vertiport FOD Detection Messages from the VA-SDSP Interface;

And HIS receives Vertiport Charging Infrastructure Status Messages from the VA-SDSP Interface;

And HIS receives Vertiport Noise Monitoring Alert Messages from the VA-SDSP Interface.

6.1.4 Scenario: HIS shall receive the following messages from the RMSS:

- Vertiport Resource Availability Schedule
- Vertiport Demand-Capacity Imbalance
- Vertiport Resource Reservation Summary

Given VAS manages the flow of data between services;

When RMSS transmits Vertiport Resource Availability Schedule Messages to the HIS; <2.6.2>

And RMSS transmits Vertiport Demand-Capacity Imbalance Messages to the HIS; <2.6.5>

And RMSS transmits Vertiport Resource Reservation Summary Messages to the HIS; <2.6.6>

Then HIS receives Vertiport Resource Reservation Summary Messages;

And HIS receives Vertiport Demand-Capacity Imbalance Messages;

And HIS receives Vertiport Resource Availability Schedule Messages.

6.1.5 Scenario: HIS shall receive 4D Surface Trajectory Messages from the STS.

Given VAS manages the flow of data between services;

When STS transmits 4D Surface Trajectory Messages to the HIS; <3.3.1>

Then HIS receives 4D Surface Trajectory Messages.

6.1.6 Scenario: HIS shall receive the following messages from the ACM:

- Airborne Trajectory Conformance Status
- Surface Trajectory Conformance Status
- Projected Trajectory Conformance Status

Given VAS manages the flow of data between services;

When ACM transmits Airborne Trajectory Conformance Status Messages to the HIS; <4.5.1>

And ACM transmits Surface Trajectory Conformance Status Messages to the HIS; <4.5.2>

And ACM transmits Projected Trajectory Conformance Status Messages to the HIS; <4.5.3>

Then HIS receives Airborne Trajectory Conformance Status Messages;

And HIS receives Surface Trajectory Conformance Status Messages;

And HIS receives Projected Trajectory Conformance Status Messages.

6.1.7 Scenario: HIS shall receive System Monitoring Alert Message from the SMS.

Given VAS manages the flow of data between services;

When SMS transmits System Monitoring Alert Messages to the HIS; <5.3.1>

Then HIS receives System Monitoring Alert Messages.

6.1.8 Scenario: HIS shall receive the following messages from the CSS:

- Cybersecurity Advisory
- System Wide Cybersecurity Status

Given VAS manages the flow of data between services;

When CSS transmits Cybersecurity Advisory Messages to the HIS; <9.7.1>

And CSS transmits System Wide Cybersecurity Status Messages to the HIS; <9.7.2>

Then CSS receives Cybersecurity Advisory Messages;

And CSS receives System Wide Cybersecurity Status Messages.

6.2.0 Feature: HIS shall detect anomalies.

6.2.1 Scenario: HIS shall detect vertiport infrastructure sensor data anomalies.

Given VMD defines anomaly detection rules; <8.7.2>

When HIS receives Vertiport Weather (Wx) Messages; <6.1.3>

When HIS receives VOA Surveillance Messages; <6.1.3>

And HIS receives Vertiport Surface Surveillance; <6.1.3>

And HIS receives Vertiport FOD Detection Messages; <6.1.3>

And HIS receives Vertiport Charging Infrastructure Status Messages; <6.1.3>

And HIS receives Vertiport Noise Monitoring Alert Messages; <6.1.3>

Then HIS detects vertiport infrastructure sensor anomalies.

6.2.2 Scenario: HIS shall detect external data source anomalies that could impact vertiport operations.

Given VMD defines anomaly detection rules; <8.7.2>

When HIS receives external data;

Then HIS detects external sensor anomalies.

6.2.3 Scenario: HIS shall determine the location of the anomaly.

Given vertiport infrastructure or external sensor data contains sufficient information to determine the location of the anomaly;

When HIS detects vertiport infrastructure and external sensor anomalies; <6.2.1> <6.2.2>

Then HIS determines the location of the anomaly.

6.2.4 Scenario: HIS shall determine if the anomaly is moving and in which direction and speed.

Given anomalies are objects that are moving;

When HIS detects vertiport infrastructure and external sensor anomalies; <6.2.1> <6.2.2>

Then HIS determines the direction and speed the anomaly is moving.

6.2.5 Scenario: HIS shall identify any aircraft which could be affected by identified anomalies.

Given HIS receives Flight Position Messages; <6.1.1>

And HIS detects vertiport infrastructure and external sensor anomalies; <6.2.1> <6.2.2>

And HIS determines the location of the anomaly; <6.2.3>

When HIS determines the direction and speed the anomaly is moving; <6.2.4>

And HIS compares current anomaly location against current and projected aircraft locations;

Then HIS identifies aircraft affected by anomalies.

6.3.0 Feature: HIS shall identify hazards.

6.3.1 Scenario: HIS shall analyze each anomaly to determine if it is a hazard.

Given VMD defines hazard detection rules; <8.7.3>

And HIS receives Vertiport Demand-Capacity Imbalance Messages; <6.1.4>

And HIS receives Vertiport Resource Reservation Summary Messages; <6.1.4>

And HIS receives 4D Surface Trajectory Messages; <6.1.5>

And HIS receives Airborne, Surface, and Projected Trajectory Conformance Status Messages; <6.1.6>

And HIS receives System Monitoring Alert Messages; <6.1.7>

And HIS detects vertiport infrastructure and external sensor anomalies; <6.2.1> <6.2.2>

When HIS detects an anomaly; <6.2.1> <6.2.2>

And Anomaly matches hazard detection rules defined by VMD; <8.7.3>

Then HIS identifies hazards.

6.3.2 Scenario: HIS shall improve hazard identification through experience and use of historical data.

Given HIS logs anomaly and hazard data;

And HIS detects vertiport infrastructure and external sensor anomalies; <6.2.1> <6.2.2>

When HIS identifies hazards; <6.3.1>

Then HIS improves hazard identification using historical data.

6.3.3 Scenario: HIS shall generate Hazard Messages.

Given HIS detects vertiport infrastructure and external sensor anomalies; <6.2.1> <6.2.2>

When HIS identifies hazards; <6.3.1>

Then HIS generates Hazard Messages.

6.4.0 Feature: HIS shall transmit messages.

6.4.1 Scenario: HIS shall transmit Hazard Messages to the RAS, VMD, and CSS.

Given VA-SDSP Interface passes Hazard Messages to the PSU, Fleet Operator, FAA, and Flight Crew; <1.1.8>

And VAS manages the flow of data between services;

When HIS generates Hazard Messages; <6.3.3>

Then HIS transmits Hazard Messages to the VA-SDSP Interface;

And HIS transmits Hazard Messages to the RAS, VMD, and CSS.

Risk Assessment Service (RAS)

7.0.0 VAS shall assess operational risk.

7.1.0 Feature: RAS shall receive messages.

7.1.1 Scenario: RAS shall receive the following messages from the PSU:

- Flight Plan
- Flight Position
- Flight Status

Given VA-SDSP Interface passes Flight Plan, Flight Position, and Flight Status Messages from the PSU; <1.2.2> <1.2.4> <1.2.3>

When PSU transmits Flight Plan and Flight Position, and Flight Status Messages to the VA-SDSP Interface;

Then RAS receives Flight Plan Messages from the VA-SDSP Interface;

And RAS receives Flight Position, and Flight Status Messages from the VA-SDSP Interface.

7.1.2 Scenario: RAS shall receive Flight Position Messages from the Flight Crew.

Given VA-SDSP Interface passes Flight Position Messages from the Flight Crew; <1.4.1>

When Flight Crew transmits Flight Position Messages to the VA-SDSP Interface;

Then RAS receives Flight Position Messages from the VA-SDSP Interface.

7.1.3 Scenario: RAS shall receive the following messages from the Vertiport Infrastructure Data Connectors:

- Vertiport Weather (Wx)
- VOA Surveillance
- Vertiport Surface Surveillance
- Vertiport FOD Detection
- Vertiport Charging Infrastructure Status
- Vertiport Noise Monitoring Alert

Given VA-SDSP Interface passes Vertiport Weather (Wx), VOA Surveillance, Vertiport Surface Surveillance, Vertiport FOD Detection, Vertiport Charging Infrastructure Status, and Vertiport Noise Monitoring Alert Messages from the Vertiport Infrastructure Data Connectors; <1.2.6> <1.2.7> <1.2.8> <1.2.9> <1.2.10> <1.2.11>

When Vertiport Infrastructure Data Connectors transmits Vertiport Weather (Wx), VOA Surveillance, Vertiport Surface Surveillance, Vertiport FOD Detection, Vertiport Charging Infrastructure Status, and Vertiport Noise Monitoring Alert Messages to the VA-SDSP Interface;

Then RAS receives Vertiport Weather (Wx) Messages from the VA-SDSP Interface;

And RAS receives VOA Surveillance Messages from the VA-SDSP Interface;

And RAS receives Vertiport Surface Surveillance Messages from the VA-SDSP Interface;

And RAS receives Vertiport FOD Detection Messages from the VA-SDSP Interface;

And RAS receives Vertiport Charging Infrastructure Status Messages from the VA-SDSP Interface;

And RAS receives Vertiport Noise Monitoring Alert Messages from the VA-SDSP Interface.

7.1.4 Scenario: RAS shall receive the following messages from the RMSS:

- Vertiport Configuration
- Vertiport Resource Availability Schedule
- Vertiport Resource Reservation Summary

Given VAS manages the flow of data between services;

When RMSS transmits Vertiport Configuration Messages to the RAS; <2.6.1>

And RMSS transmits Vertiport Resource Availability Schedule Messages to the RAS; <2.6.2>

And RMSS transmits Vertiport Resource Reservation Summary Messages to the RAS; <2.6.6>

Then RAS receives Vertiport Configuration Messages;

And RAS receives Vertiport Resource Availability Schedule Messages;

And RAS receives Vertiport Resource Reservation Summary Messages.

7.1.5 Scenario: RAS shall receive 4D Surface Trajectory Messages from the STS.

Given VAS manages the flow of data between services;

When STS transmits 4D Surface Trajectory Messages to the RAS; <3.3.1>

Then RAS receives 4D Surface Trajectory Messages.

7.1.6 Scenario: RAS shall receive Hazard Messages from the HIS.

Given VAS manages the flow of data between services;

When HIS transmits Hazard Messages to the RAS; <6.4.1>

Then RAS receives Hazard Messages.

7.2.0 Feature: RAS shall determine the probability of a hazard causing material loss or harm.

7.2.1 Scenario: RAS shall receive the necessary data to determine the probability of a hazards occurring.

Given VMD configures the hazard probability data elements and attributes; <8.8.2>

And RAS receives Vertiport Configuration Messages; <7.1.4>

And RAS receives Vertiport Resource Availability Schedule Messages; <7.1.4>

And RAS receives Vertiport Resource Reservation Summary Messages; <7.1.4>

And RAS receives 4D Surface Trajectory Messages; <7.1.5>

When RAS receives Hazard Messages from the HIS; <7.1.6>

Then RAS retrieves the data to be used to determine probability.

7.2.2 Scenario: RAS shall calculate the probability of a hazard occurrence as a series of values.

Given VMD defines series of probability values for each known hazard; <8.8.2>

When RAS receives data used to determine probability; <7.2.1>

Then RAS calculates the probability of the hazard occurring.

7.2.3 Scenario: RAS shall improve probability calculation through experience and use of historical data.

Given A hazard is identified; <6.3.1>

And RAS logs hazard and probability data in a historical repository;

And Historical hazard and probability repository exists and is populated;

When RAS calculated the probability of a hazard occurring; <7.2.2>

Then RAS uses historical data to improve probability calculation.

7.2.4 Scenario: RAS shall recalculate the probability of a hazard occurrence after the implementation of a mitigation strategy.

Given RAS calculates initial probability of hazard occurring; <7.2.2>

When VMD implements risk mitigation; <8.8.4>

Then RAS calculates post-mitigation probability of hazard occurring.

7.3.0 Feature: RAS shall determine the potential severity of loss or harm caused by a hazard occurring.

7.3.1 Scenario: RAS shall receive the necessary data to determine the severity of a hazards occurring.

Given VMD configures the severity calculation data elements and attributes; <8.8.3>

And RAS receives Vertiport Configuration Messages; <7.1.4>

And RAS receives Vertiport Resource Availability Schedule Messages; <7.1.4>

And RAS receives Vertiport Resource Reservation Summary Messages; <7.1.4>

And RAS receives 4D Surface Trajectory Messages; <7.1.5>

When RAS receives Hazard Messages from the HIS; <7.1.6>

Then RAS retrieves the data to be used to determine severity.

7.3.2 Scenario: RAS shall calculate the severity of a hazard occurrence as a series of categories defined by the VMD.

Given VMD defines categories of severity for each known hazard; <8.8.3>

And RAS receives Hazard Messages from the HIS; <7.1.6>

When RAS receives the data to be used to determine severity; <7.2.1>

Then RAS calculates the severity of the hazard occurring.

7.3.3 Scenario: RAS shall improve severity calculation through experience and use of historical data.

Given A hazard is identified; <6.3.1>

And RAS logs hazard and severity data;

When RAS calculated the severity of the hazard occurring; <7.3.2>

Then RAS uses historical data to improve severity calculation.

7.3.4 Scenario: RAS shall recalculate the severity of a hazard occurrence after the implementation of a mitigation strategy.

Given RAS calculates initial severity of hazard occurring; <7.3.2>

When VMD implements risk mitigation; <8.8.4>

Then RAS calculates post-mitigation severity of hazard occurring.

7.4.0 Feature: RAS shall determine mitigation strategy and calculate the effectiveness of recommended risk mitigation strategies.

7.4.1 Scenario: RAS shall match the appropriate mitigation strategies to a specific hazard.

Given VMD configures hazard and mitigation mapping; <8.8.4>

When RAS receives Hazard Messages from the HIS; <7.1.6>

Then RAS matches the correct mitigation with the hazard.

7.4.2 Scenario: RAS shall generate Risk Assessment Messages.

Given VMD configures hazard and mitigation mapping; <8.8.4>

When RAS calculates the probability of the hazard occurring; <7.2.2>

And RAS calculates the severity of the hazard occurring; <7.3.2>

And RAS matches the correct mitigation with the hazard; <7.4.1>

Then RAS generates Risk Assessment Messages.

7.4.3 Scenario: RAS shall calculate the reduction in probability and severity of a hazard after the application of a mitigation strategy, known as effectiveness.

Given RAS calculates the probability of the hazard occurring; <7.2.2>

And RAS calculates the severity of the hazard occurring; <7.3.2>

And VMD implements risk mitigation; <8.8.4>

When RAS calculates post-mitigation probability of hazard occurring; <7.2.4>

And RAS calculates post-mitigation severity of hazard occurring; <7.3.4>

Then RAS calculates the post-mitigation effectiveness.

7.4.4 Scenario: RAS shall track and calculate average effectiveness of risk mitigation strategies.

Given historical repository containing hazards, associated mitigations, and their effectiveness exists;

When RAS calculates the post-mitigation effectiveness; <7.4.3>

Then RAS calculates the average effectiveness of mitigations applied to hazards.

7.5.0 Feature: RAS shall determine an aggregate risk score for the vertiport.

7.5.1 Scenario: RAS shall estimate the aggregate risk score for the vertiport.

Given VMD configures vertiport risk calculation parameters; <8.8.5>

And VMD defines aggregate risk score calculation frequency; <8.8.5>

When RAS reaches recurring aggregate risk score calculation frequency timestep;

Then RAS calculates aggregate risk score.

7.5.2 Scenario: RAS shall generate Aggregate Risk Score Messages.

Given VMD configures vertiport risk calculation parameters; <8.8.5>

And VMD defines aggregate risk score calculation frequency; <8.8.5>

When RAS calculates aggregate risk score; <7.5.1>

Then RAS generates Aggregate Risk Score Messages.

7.6.0 Feature: RAS shall transmit messages.

7.6.1 Scenario: RAS shall transmit Risk Assessment Messages to the RMSS, STS, VMD, and CSS.

Given VA-SDSP Interface passes Risk Assessment Messages to the PSU and Fleet Operator;

And VAS manages the flow of data between services;

When RAS generates Risk Assessment Messages; <7.4.2>

Then RAS transmits Risk Assessment Messages to the VA-SDSP Interface;

And VAS transmits Risk Assessment Messages to the RMSS, STS, VMD, and CSS.

7.6.2 Scenario: RAS shall transmit Aggregate Risk Score Messages to the VMD.

Given VA-SDSP Interface passes Aggregate Risk Score Messages to the PSU and Fleet Operator;

And VAS manages the flow of data between services;

When RAS generates Aggregate Risk Score Messages; <7.5.2>

Then RAS transmits Aggregate Risk Score Messages to the VA-SDSP Interface;

And VAS transmits Aggregate Risk Score Messages to the VMD.

Vertiport Manager Display (VMD)

8.0.0 VAS shall provide a physical user interface.

8.1.0 Feature: VMD shall receive messages.

8.1.1 Scenario: VMD shall receive the following messages from PSU:

- Flight Plan
- Flight Position
- Flight Status
- Airspace Configuration

Given VA-SDSP Interface passes Flight Plan, Flight Position, Flight Status, and Airspace Configuration Messages from PSU; <1.2.2> <1.2.4> <1.2.3>

When PSU transmits Flight Plan, Flight Position, Flight Status, and Resource Negotiation Response Messages to VA-SDSP Interface;

Then VMD receives Flight Plan Messages from VA-SDSP Interface;

And VMD receives Flight Position Messages from VA-SDSP Interface;

And VMD receives Flight Status Messages from VA-SDSP Interface;

And VMD receives Airspace Configuration Messages from VA-SDSP Interface.

8.1.2 Scenario: VMD shall receive the following messages from Vertiport Infrastructure Data Connectors:

- Vertiport Weather (Wx)
- VOA Surveillance
- Vertiport Surface Surveillance
- Vertiport FOD Detection
- Vertiport Charging Infrastructure Status
- Vertiport Noise Monitoring Alert

Given VA-SDSP Interface passes Vertiport Weather (Wx), VOA Surveillance, Vertiport Surface Surveillance, Vertiport FOD Detection, Vertiport Charging Infrastructure Status, Vertiport Noise Monitoring Alert Messages from Vertiport Infrastructure Data Connectors; <1.2.6> <1.2.7> <1.2.8> <1.2.9> <1.2.10> <1.2.11>

When Vertiport Infrastructure Data Connectors transmits Vertiport Weather (Wx), VOA Surveillance, Vertiport Surface Surveillance, Vertiport FOD Detection, Vertiport Charging Infrastructure Status, Vertiport Noise Monitoring Alert Messages to VA-SDSP Interface;

Then VMD receives Vertiport Weather (Wx) Messages from VA-SDSP Interface;

And VMD receives VOA Surveillance Messages from VA-SDSP Interface;

And VMD receives Vertiport Surface Surveillance Messages from VA-SDSP Interface;

And VMD receives Vertiport FOD Detection Messages from VA-SDSP Interface;

And VMD receives Vertiport Charging Infrastructure Status Messages from VA-SDSP Interface;

And VMD receives Vertiport Noise Monitoring Alert Messages from VA-SDSP Interface.

8.1.3 Scenario: VMD shall receive the following messages from RMSS:

- Vertiport Configuration
- Vertiport Resource Availability Schedule
- Vertiport Demand-Capacity Imbalance
- Vertiport Resource Reservation Summary

Given VAS manages the flow of data between services;

When RMSS transmits Vertiport Configuration, Vertiport Resource Availability Schedule, Vertiport Demand-Capacity Imbalance, Vertiport Resource Reservation Summary Messages to VMD; <2.6.1> <2.6.2> <2.6.5> <2.6.6>

Then VMD receives Vertiport Configuration Messages;

And VMD receives Vertiport Resource Availability Schedule Messages;

And VMD receives Vertiport Demand-Capacity Imbalance Messages;

And VMD receives Vertiport Resource Reservation Summary Messages.

8.1.4 Scenario: VMD shall receive 4D Surface Trajectory Messages from STS.

Given VAS manages the flow of data between services;

When STS transmits 4D Surface Trajectory Messages to the VMD; <3.3.1>

Then VMD receives 4D Surface Trajectory Messages.

8.1.5 Scenario: VMD shall receive the following messages from the ACM:

- Airborne Trajectory Conformance Status
- Surface Trajectory Conformance Status
- Projected Trajectory Conformance Status

Given VAS manages the flow of data between services;

When ACM transmits Airborne Trajectory Conformance Status, Surface Trajectory Conformance Status, and Projected Trajectory Conformance Status Messages to VMD; <4.5.1> <4.5.2> <4.5.3>

Then VMD receives Airborne Trajectory Conformance Status Messages;

And VMD receives Surface Trajectory Conformance Status Messages;

And VMD receives Projected Trajectory Conformance Status Messages.

8.1.6 Scenario: VMD shall receive System Monitoring Alert Messages from SMS.

Given VAS manages the flow of data between services;

When SMS transmits System Monitoring Alert Messages to VMD; <5.3.1>

Then VMD receives System Monitoring Alert Messages.

8.1.7 Scenario: VMD shall receive Hazard Messages from HIS.

Given VAS manages the flow of data between services;

When HIS transmits Hazard Messages to VMD; <6.4.1>

Then VMD receives Hazard Messages.

8.1.8 Scenario: VMD shall receive the following messages from the RAS:

- Risk Assessment
- Aggregate Risk Score

Given VAS manages the flow of data between services;

When RAS transmits Risk Assessment and Aggregate Risk Score Messages to VMD; <7.6.1> <7.6.2>

Then VMD receives Risk Assessment Messages;

And VMD receives Aggregate Risk Score Messages.

8.1.9 Scenario: VMD shall receive the following messages from the CSS:

- Cybersecurity Advisory
- System Wide Cybersecurity Status

Given VAS manages the flow of data between services;

When CSS transmits Cybersecurity Advisory and System Wide Cybersecurity Messages to VMD; <9.7.1> <9.7.2>

Then VMD receives Cybersecurity Advisory Messages from CSS;

And VMD receives System Wide Cybersecurity Status Messages from CSS.

8.2.0 Feature: VMD shall provide a VA-SDSP Interface user interface.

8.2.1 Scenario: VMD shall display performance data and metrics from VA-SDSP Interface.

Given VAS manages the flow of data between services;

And CSS implements authentication and authorization for identity management and access control; <9.3.1>

When External stakeholders are connected to the VA-SDSP Interface;

Then VMD presents VA-SDSP Interface information.

8.2.2 Scenario: VMD shall provide VA-SDSP Interface management capabilities.

Given VAS manages the flow of data between services;

And CSS implements authentication and authorization for identity management and access control; <9.3.1>

When VMD presents VA-SDSP Interface user interface to Vertiport Manager

Then Vertiport Manager manages VA-SDSP Interface service capabilities.

8.3.0 Feature: VMD shall provide a RMSS Vertiport Manager Interface.

8.3.1 Scenario: VMD shall display configuration, availability, capacity, demand, and reservation status information received from RMSS for all vertiport resources, including:

- TLOF pads
- Passenger gates
- Cargo gates
- Short term parking
- Long term parking
- Charging stations
- Vertiport ramp areas

Given VAS manages the flow of data between services;

And CSS shall implement authentication and authorization for identity management and access control; <9.3.1>

When VMD receives Vertiport Configuration Messages; <8.1.2>

And VMD receives Vertiport Resource Availability Schedule Messages; <8.1.2>

And VMD receives Vertiport Demand-Capacity Imbalance Messages; <8.1.2>

And VMD receives Vertiport Resource Reservation Summary Messages; <8.1.2>

Then VMD presents RMSS information.

8.3.2 Scenario: VMD shall provide vertiport resource configuration management capability.

Given VAS manages the flow of data between services;

And CSS implements authentication and authorization for identity management and access control; <9.3.1>

When VMD presents a RMSS user interface to Vertiport Manager; <8.3.1>

Then VMD defines vertiport resources list;

And VMD configures separation buffer criteria;

And VMD designates passenger and cargo zones.

8.3.3 Scenario: VMD shall provide vertiport resources reservation management capability.

Given VAS manages the flow of data between services;

And CSS implements authentication and authorization for identity management and access control; <9.3.1>

When VMD presents a RMSS user interface to Vertiport Manager; <8.3.1>

Then VMD configures resource prioritization rules;

And VMD configures resources emergency reserve limits;

And VMD operationalizes VAS systems and services;

And VMD inputs mitigation strategy.

8.3.4 Scenario: VMD shall provide a resource reservation metrics management capability.

Given VAS manages the flow of data between services;

And CSS implements authentication and authorization for identity management and access control; <9.3.1>

When VMD presents a RMSS user interface to Vertiport Manager; <8.3.1>

Then VMD configures resources reservation metrics calculation frequency;

And VMD configures demand-capacity balance criteria.

8.3.5 Scenario: VMD shall provide RMSS performance analytics.

Given VAS manages the flow of data between services;

And CSS implements authentication and authorization for identity management and access control; <9.3.1>

When VMD presents a RMSS user interface to Vertiport Manager; <8.3.1>

Then Vertiport Manager can review vertiport resource management and scheduling performance analytics.

8.4.0 Feature: VMD shall display an STS user interface.

8.4.1 Scenario: VMD shall display surface 3D map, aircraft surface trajectory, and ground vehicle surface trajectory information received from STS.

Given VAS manages the flow of data between services;

And CSS shall implement authentication and authorization for identity management and access control; <9.3.1>

When VMD receives Vertiport Surface Surveillance Messages from VA-SDSP Interface; <8.1.2>

Then VMD presents STS information.

8.5.0 Feature: VMD shall provide an ACM user interface.

8.5.1 Scenario: VMD shall display the current and predicted non-conformance information for airborne aircraft, surface aircraft, and ground vehicles received from ACM.

Given VAS manages the flow of data between services;

And CSS implements authentication and authorization for identity management and access control; <9.3.1>

When VMD receives Airborne Trajectory Conformance Status Messages; <8.1.5>

And VMD receives Surface Trajectory Conformance Status Messages; <8.1.5>

And VMD receives Projected Trajectory Conformance Status Messages. <8.1.5>

Then VMD presents ACM information.

8.5.2 Scenario: VMD shall provide a conformance tolerance management capability.

Given VAS manages the flow of data between services;

And CSS implements authentication and authorization for identity management and access control; <9.3.1>

When VMD presents ACM user interface to Vertiport Manager; <8.5.1>

Then VMD configures reservation window tolerances;

And VMD configures airspace boundaries and conformance tolerances;

And VMD configures surface trajectory conformance tolerances;

And VMD configures vehicle-to-vehicle separation conformance tolerances;

And VMD configures trajectory non0conformance prediction frequency.

8.5.3 Scenario: VMD shall provide aircraft conformance performance analytics.

Given VAS manages the flow of data between services;

And CSS implements authentication and authorization for identity management and access control; <9.3.1>

When VMD presents ACM user interface to Vertiport Manager; <8.5.1>

Then Vertiport Manager can review aircraft conformance performance analytics.

8.6.0 Feature: VMD shall provide a SMS user interface.

8.6.1 Scenario: VMD shall display system monitoring alert information received from SMS.

Given VAS manages the flow of data between services;

And CSS implements authentication and authorization for identity management and access control; <9.3.1>

When VMD receives System Monitoring Alert Messages. <8.1.6>

Then VMD presents SMS information.

8.6.2 Scenario: VMD shall provide a VAS service monitoring management capability.

Given VAS manages the flow of data between services;

And CSS implements authentication and authorization for identity management and access control; <9.3.1>

When VMD presents SMS user interface to Vertiport Manager; <8.6.1>

Then VMD configures which VAS services are monitored;

And VMD configures which VAS service parameters are monitored;

And VMD configures frequency of VAS service monitoring.

8.6.3 Scenario: VMD shall provide a VAS infrastructure monitoring management capability.

Given VAS manages the flow of data between services;

And CSS implements authentication and authorization for identity management and access control; <9.3.1>

When VMD presents SMS user interface to Vertiport Manager; <8.6.1>

Then VMD configures which VAS infrastructure components are monitored;

And VMD configures which VAS infrastructure parameters are monitored;

And VMD configures alerting thresholds for monitored VAS infrastructure parameter;

And VMD configures monitoring frequency of VAS infrastructure.

8.6.4 Scenario: VMD shall display system monitoring data and metrics.

Given VAS manages the flow of data between services;

And CSS implements authentication and authorization for identity management and access control; <9.3.1>

When VMD presents SMS user interface to Vertiport Manager; <8.6.1>

Then Vertiport Manager can review system monitoring data and metrics.

8.7.0 Feature: VMD shall provide a HIS user interface.

8.7.1 Scenario: VMD shall display hazard information received from HIS.

Given VAS manages the flow of data between services;

And CSS implements authentication and authorization for identity management and access control; <9.3.1>

When VMD receives Hazard Messages. <8.1.7>

Then VMD presents HIS information.

8.7.2 Scenario: VMD shall provide an anomaly detection management interface.

Given VAS manages the flow of data between services;

And CSS implements authentication and authorization for identity management and access control; <9.3.1>

When VMD presents HIS user interface to Vertiport Manager; <8.7.1>

Then VMD configures anomaly detection rules.

8.7.3 Scenario: VMD shall provide a hazard detection management interface.

Given VAS manages the flow of data between services;

And CSS implements authentication and authorization for identity management and access control; <9.3.1>

When VMD presents HIS user interface to Vertiport Manager; <8.7.1>

Then VMD configures hazard detection rules.

Then Vertiport Manager can review active and historic anomalies.

8.7.4 Scenario: VMD shall display active and historic hazards.

Given VAS manages the flow of data between services;

And CSS implements authentication and authorization for identity management and access control; <9.3.1>

When VMD presents HIS user interface to Vertiport Manager; <8.7.1>

Then Vertiport Manager can review active and historic hazards.

8.7.5 Scenario: VMD shall provide hazard data and trend analytics.

Given VAS manages the flow of data between services;

And CSS implements authentication and authorization for identity management and access control; <9.3.1>

When VMD presents HIS user interface to Vertiport Manager; <8.7.1>

Then Vertiport Manager can review hazard data and trend analytics.

8.8.0 Feature: VMD shall provide a RAS user interface.

8.8.1 Scenario: VMD shall display risk assessment and aggregate risk scores received from RAS.

Given VAS manages the flow of data between services;

And CSS implements authentication and authorization for identity management and access control; <9.3.1>

When VMD receives Risk Assessment Messages; <8.1.8>

And VMD receives Aggregate Risk Score Messages; <8.1.8>

Then VMD presents RAS information.

8.8.2 Scenario: VMD shall provide a hazard probability management interface.

Given VAS manages the flow of data between services;

And CSS implements authentication and authorization for identity management and access control; <9.3.1>

When VMD presents RAS user interface to Vertiport Manager; <8.8.1>

Then VMD configures probability data elements and attributes for each hazard;

And VMD configures probability values for each hazard.

8.8.3 Scenario: VMD shall provide a hazard severity management interface.

Given VAS manages the flow of data between services;

And CSS implements authentication and authorization for identity management and access control; <9.3.1>

When VMD presents RAS user interface to Vertiport Manager; <8.8.1>

Then VMD configures severity data elements and attributes for each hazard;

And VMD configures severity values for each hazard.

8.8.4 Scenario: VMD shall provide a risk mitigation management interface.

Given VAS manages the flow of data between services;

And CSS implements authentication and authorization for identity management and access control; <9.3.1>

When VMD presents RAS user interface to Vertiport Manager; <8.8.1>

Then VMD configures mapping of mitigation for each hazard.

8.8.5 Scenario: VMD shall provide an aggregate risk score management interface.

Given VAS manages the flow of data between services;

And CSS implements authentication and authorization for identity management and access control; <9.3.1>

When VMD presents RAS user interface to Vertiport Manager; <8.8.1>

Then VMD configures vertiport risk calculation parameters;

And VMD configures aggregate risk score calculation frequency.

8.8.6 Scenario: VMD shall display active and historic risks.

Given VAS manages the flow of data between services;

And CSS implements authentication and authorization for identity management and access control; <9.3.1>

When VMD presents RAS user interface to Vertiport Manager; <8.8.1>

Then Vertiport Manager can review active and historic vertiport risks.

8.8.7 Scenario: VMD shall provide risk mitigation performance analytics.

Given VAS manages the flow of data between services;

And CSS implements authentication and authorization for identity management and access control; <9.3.1>

When VMD presents RAS user interface to Vertiport Manager; <8.8.1>

Then Vertiport Manager can review vertiport risk mitigation performance analytics.

8.9.0 Feature: VMD shall provide a CSS user interface.

8.9.1 Scenario: VMD shall display cybersecurity advisories and system wide cybersecurity status received from CSS.

Given VAS manages the flow of data between services;

And CSS implements authentication and authorization for identity management and access control; <9.3.1>

When VMD receives System Wide Cybersecurity Messages from CSS; <8.1.9>

And VMD receives Cybersecurity Advisory Messages from CSS; <8.1.9>

Then VMD presents CSS information.

8.9.2 Scenario: VMD shall provide a cybersecurity protection management interface.

Given VAS manages the flow of data between services;

And CSS implements authentication and authorization for identity management and access control; <9.3.1>

When VMD presents CSS user interface to Vertiport Manager; <8.9.1>

Then VMD configures VAS systems, users, assets, data, and capabilities that support critical function.

8.9.3 Scenario: VMD shall provide a cybersecurity incident detection management interface.

Given VAS manages the flow of data between services;

And CSS implements authentication and authorization for identity management and access control; <9.3.1>

When VMD presents CSS user interface to Vertiport Manager; <8.9.1>

Then VMD configures anomaly detection criteria;

And VMD configures scanning frequency.

8.9.4 Scenario: VMD shall provide a cybersecurity incident response management interface.

Given VAS manages the flow of data between services;

And CSS implements authentication and authorization for identity management and access control; <9.3.1>

When VMD presents CSS user interface to Vertiport Manager; <8.9.1>

Then VMD configures response plan.

8.9.5 Scenario: VMD shall provide a cybersecurity incident recovery management interface.

Given VAS manages the flow of data between services;

And CSS implements authentication and authorization for identity management and access control; <9.3.1>

When VMD presents CSS user interface to Vertiport Manager; <8.9.1>

Then VMD configures recovery plan.

8.9.6 Scenario: VMD shall display cybersecurity risks and mitigation strategies.

Given VAS manages the flow of data between services;

And CSS implements authentication and authorization for identity management and access control; <9.3.1>

When VMD presents CSS user interface to Vertiport Manager; <8.9.1>

Then Vertiport Manager can review vertiport cybersecurity risks and mitigation strategies.

8.9.7 Scenario: VMD shall provide cybersecurity data analytics.

Given VAS manages the flow of data between services;

And CSS implements authentication and authorization for identity management and access control; <9.3.1>

When VMD presents CSS user interface to Vertiport Manager; <8.9.1>

Then Vertiport Manager can review cybersecurity data analytics.

8.10.0 Feature: VMD shall comply with the FAA Human Factors Design Standard, HF-STD-001 [Ahlstrom, V., & Longo, K. (2003). Human Factors Design Standard (HF-STD-001). Atlantic City International Airport, NJ: Federal Aviation Administration William J. Hughes Technical Center].

8.10.1 Scenario: The system shall comply with general requirements of the FAA Human Factors Design Standard, HF-STD-001, to consider:

- Basic Design Elements
- Simplicity
- Consistency
- Standardization
- Safety
- Vertiport Manager-centered Perspective
- Support
- Maintenance

Given VAS in operational state;

When Vertiport Manager interfaces with VAS (through visual, aural, cognitive, and psychomotor channels);

Then System complies with general FAA human factors design standards.

8.10.2 Scenario: Provide a fail-safe design. A fail-safe design shall be provided for systems in which failure could cause catastrophic damage, injury to personnel, or inadvertent operation of equipment. [Per HF-STD-001 Safety 4.5.2]

Given VAS in operational state;

When Component xyz fails;

Then Vertiport Manager does not suffer injury nor operate equipment in unintended manners.

8.10.3 Scenario: The system should comply with specific requirements of the FAA Human Factors Design Standard, HF-STD-001, to consider:

- Automation
- Design for Maintenance
- Displays and Printers
- Controls and Visual Indicators
- Alarms, Audio, and Voice Communications
- Computer-Human Interface
- Keyboards and Input Devices
- Workstation and Workplace Design
- System Security
- Personnel Safety
- Environment
- Anthropometry and Biomechanics
- Vertiport Manager Documentation

Given VAS in operational state;

When Vertiport Manager interfaces with VAS (through visual, aural, cognitive, and psychomotor channels);

Then System complies with specific FAA human factors design standards.

8.10.4 Scenario: An automated system should:

- Provide sufficient information to keep the Vertiport Manager informed of its operating mode, intent, function, and output;
- Inform the Vertiport Manager of automation failure or degradation;
- Inform the Vertiport Manager if potentially unsafe modes are manually selected;
- Not interfere with manual task performance; and
- Allow for manual override. [Per HF-STD-001 5.1.1.1 Minimum automation human factors requirements]

Given VAS in operational state;

When Vertiport Manager interfaces with VAS automation (through visual, aural, cognitive, and psychomotor channels);

Then System complies with specific FAA automation human factors requirements.

8.11.0 Feature: VMD shall provide an aircraft surveillance interface.

8.11.1 Scenario: VMD shall display past, current, and planned aircraft surveillance data received from PSU, and Vertiport Infrastructure Data Connectors.

Given VAS manages the flow of data between services;

And CSS implements authentication and authorization for identity management and access control; <9.3.1>

When VMD receives Flight Position Messages from the VA-SDSP Interface; <8.1.1>

And VMD receives VOA Surveillance Messages from the VA-SDSP Interface; <8.1.2>

And VMD receives Vertiport Surface Surveillance Messages from the VA-SDSP Interface; <8.1.2>

Then VMD presents aircraft surveillance information.

8.11.2 Scenario: VMD shall display current position of surface aircraft.

Given VAS manages the flow of data between services;

And CSS implements authentication and authorization for identity management and access control; <9.3.1>

When VMD presents aircraft surveillance user interface to Vertiport Manager; <8.11.1>

Then Vertiport Manager can review current position of surface aircraft.

8.11.3 Scenario: VMD shall display historic path of surface aircraft.

Given VAS manages the flow of data between services;

And CSS implements authentication and authorization for identity management and access control; <9.3.1>

When VMD presents aircraft surveillance user interface to Vertiport Manager; <8.11.1>

Then Vertiport Manager can review historic positions of surface aircraft.

8.11.4 Scenario: VMD shall display planned path of surface aircraft.

Given VAS manages the flow of data between services;

And CSS implements authentication and authorization for identity management and access control; <9.3.1>

When VMD presents aircraft surveillance user interface to Vertiport Manager; <8.11.1>

Then Vertiport Manager can review planned positions/path of surface aircraft.

8.11.5 Scenario: VMD shall display current position of airborne aircraft within x nmi from the vertiport.

Given VAS manages the flow of data between services;

And CSS implements authentication and authorization for identity management and access control; <9.3.1>

When VMD presents aircraft surveillance user interface to Vertiport Manager; <8.11.1>

Then Vertiport Manager can review current position of airborne aircraft within x nmi from the vertiport.

8.11.6 Scenario: VMD shall display historic path (i.e., the trail) of active airborne aircraft within x nm from the vertiport.

Given VAS manages the flow of data between services;

And CSS implements authentication and authorization for identity management and access control; <9.3.1>

When VMD presents aircraft surveillance user interface to Vertiport Manager; <8.11.1>

Then Vertiport Manager can review historic position of airborne aircraft within x nmi from the vertiport.

8.11.7 Scenario: VMD shall display the planned path of active airborne aircraft within x nmi from the vertiport.

Given VAS manages the flow of data between services;

And CSS implements authentication and authorization for identity management and access control; <9.3.1>

When VMD presents aircraft surveillance user interface to Vertiport Manager; <8.11.1>

Then Vertiport Manager can review planned position/path of airborne aircraft within x nmi from the vertiport.

8.11.8 Scenario: VMD shall display current status of all pertinent aircraft.

Given VAS manages the flow of data between services;

And CSS implements authentication and authorization for identity management and access control; <9.3.1>

When VMD presents aircraft surveillance user interface to Vertiport Manager; <8.11.1>

Then Vertiport Manager can review current state of pertinent aircraft (vertiport surface and airborne aircraft within x nmi of vertiport).

8.12.0 Feature: VMD shall provide a weather interface.

8.12.1 Scenario: VMD shall display weather data received from PSU, VOA Surveillance, and Surface Surveillance.

Given VAS manages the flow of data between services;

And CSS implements authentication and authorization for identity management and access control; <9.3.1>

When VMD receives Vertiport Weather (Wx) Messages from the VA-SDSP Interface; <8.1.2>

Then VMD presents weather information.

Cybersecurity Service (CSS)

9.0.0 VAS shall deter and mitigate hostile digital acts.

9.1.0 Feature: CSS shall receive messages.

9.1.1 Scenario: CSS shall receive System Monitoring Alert Messages from the SMS.

Given VAS manages the flow of data between services;

When SMS transmits System Monitoring Alert Messages to the CSS; <5.3.1>

Then CSS receives System Monitoring Alert Messages.

9.1.2 Scenario: CSS shall receive Hazard Messages from the HIS.

Given VAS manages the flow of data between services;

When HIS transmits Hazard Messages to the CSS; <6.4.1>

Then CSS receives Hazard Messages.

9.1.3 Scenario: CSS shall receive Risk Assessment Messages from the RAS.

Given VAS manages the flow of data between services;

When RMS transmits Risk Assessment Messages to the CSS; <7.6.1>

Then CSS receives Risk Assessment Messages.

9.2.0 Feature: CSS shall identify the systems, users, assets, data, and capabilities that support critical functions for the purpose of cybersecurity protection.

9.2.1 Scenario: CSS shall identify the systems that support critical functions for purpose of cybersecurity protection.

Given VMD defines VAS systems, users, assets, data, and capabilities that support critical function; <8.9.2>

When VMD updates VAS systems, users, assets, data, and capabilities that support critical function; <8.9.2>

Then CSS identifies critical function systems and the required cybersecurity protection.

9.2.2 Scenario: CSS shall identify the users that support critical functions in operating scenarios for purpose of cybersecurity protection.

Given VMD defines VAS systems, users, assets, data, and capabilities that support critical function; <8.9.2>

When VMD updates VAS systems, users, assets, data, and capabilities that support critical function; <8.9.2>

Then CSS identifies critical users and the required cybersecurity protection.

9.2.3 Scenario: CSS shall identify the assets that support critical functions in operating scenarios for purpose of cybersecurity protection.

Given VMD defines VAS systems, users, assets, data, and capabilities that support critical function; <8.9.2>

When VMD updates VAS systems, users, assets, data, and capabilities that support critical function; <8.9.2>

Then CSS identifies critical assets and the required cybersecurity protection.

9.2.4 Scenario: CSS shall identify the data that support critical functions in operating scenarios for purpose of cybersecurity protection.

Given VMD defines VAS systems, users, assets, data, and capabilities that support critical function; <8.9.2>

When VMD updates VAS systems, users, assets, data, and capabilities that support critical function; <8.9.2>

Then CSS identifies critical data and the required cybersecurity protection.

9.2.5 Scenario: CSS shall identify the capabilities that support critical functions in operating scenarios for purpose of cybersecurity protection.

Given VMD defines VAS systems, users, assets, data, and capabilities that support critical function; <8.9.2>

When VMD updates VAS systems, users, assets, data, and capabilities that support critical function; <8.9.2>

Then CSS identifies critical capabilities and the required cybersecurity protection.

9.3.0 Feature: CSS shall protect VAS systems, data, assets, and capabilities from digital attacks to ensure delivery of the required critical services.

9.3.1 Scenario: CSS shall implement authentication and authorization for identity management and access control.

Given CSS identifies the systems, users, assets, data, and capabilities that support critical functions for the purpose of cybersecurity protection; <9.2.1> <9.2.2> <9.2.3> <9.2.4> <9.2.5>

When External stakeholders connect to the VA-SDSP Interface;

And Users log into the VMD;

Then CSS implements identity-based authentication;

And CSS implements identity-based authorization.

9.3.2 Scenario: CSS shall implement data at-rest protection.

Given CSS identifies critical data and the required cybersecurity protection; <9.2.4>

When VAS stores data;

Then CSS implements data at-rest protection.

9.3.3 Scenario: CSS shall implement data in-transit protection.

Given CSS identifies critical data and the required cybersecurity protection; <9.2.4>

When VAS manages the flow of data between services;

And VA-SDSP Interface passes messages from VAS to external stakeholders;

Then CSS implements data in-transit protection.

9.3.4 Scenario: CSS shall protect against data leaks and unauthorized access.

Given CSS identifies critical data and the required cybersecurity protection; <9.2.4>

When There is access on the identified data;

Then CSS protects against data leaks and unauthorized access to the data.

9.3.5 Scenario: CSS shall monitor system redundancy for critical systems, components, and services.

Given CSS identifies the systems, users, assets, data, and capabilities that support critical functions for the purpose of cybersecurity protection; <9.2.1> <9.2.2> <9.2.3> <9.2.4> <9.2.5>

When CSS receives System Monitoring Alert Messages; <9.1.1>

And CSS receives Hazard Messages; <9.1.2>

And CSS receives Risk Assessment Messages; <9.1.3>

Then CSS monitors the operating redundancy for such critical systems, components, and services.

9.3.6 Scenario: CSS shall implement system integrity checking mechanisms for self-correctness and self-consistency verification.

Given CSS identifies the systems, users, assets, data, and capabilities that support critical functions for the purpose of cybersecurity protection; <9.2.1> <9.2.2> <9.2.3> <9.2.4> <9.2.5>

When VAS manages the flow of data between services;

And VA-SDSP Interface passes messages from VAS to external stakeholders;

Then CSS implements integrity checking to ensure the correctness and consistency of the shared information among these system entities.

9.4.0 Feature: CSS shall detect the occurrence of a cybersecurity incident with the traceability required to respond and mitigate.

9.4.1 Scenario: CSS shall establish and manage a baseline of operations and expected outcome and data.

Given CSS identifies the systems, users, assets, data, and capabilities that support critical functions for the purpose of cybersecurity protection; <9.2.1> <9.2.2> <9.2.3> <9.2.4> <9.2.5>

When External stakeholders connect to the VA-SDSP Interface;

And Users log into the VMD;

Then CSS establishes a baseline of the expected operation outcome and data.

9.4.2 Scenario: CSS shall monitor VAS for anomalies against the baseline behaviors.

Given CSS establishes a baseline of the expected operation outcome and data; <9.4.1>

And VMD defines cybersecurity scanning frequency; <8.9.3>

And CSS receives System Monitoring Alert Messages; <9.1.1>

When CSS reaches recurring cybersecurity scanning frequency timestep;

Then CSS monitors for baseline operation anomalies.

9.4.3 Scenario: CSS shall detect anomalies compared against the baseline operation and outcome.

Given VMD defines anomaly detection criteria; <8.9.3>

And CSS monitors for baseline operation anomalies; <9.4.2>

When CSS establishes a baseline of the expected operation outcome and data; <9.4.1>

Then CSS detects baseline operation anomalies.

9.4.4 Scenario: CSS shall generate Cybersecurity Advisory Messages for each incident that requires IT security handling with specific handling instructions.

Given CSS identifies the systems, users, assets, data, and capabilities that support critical functions for the purpose of cybersecurity protection; <9.2.1> <9.2.2> <9.2.3> <9.2.4> <9.2.5>

When CSS detects baseline operation anomalies; <9.4.3>

Then CSS generates Cybersecurity Advisory Messages.

9.4.5 Scenario: CSS shall improve detection mechanism and policies through experience and use of historical data.

Given Historical repository of cybersecurity incidents exists;

When CSS generates Cybersecurity Advisory Messages; <9.4.4>

Then CSS uses historical data to improve the detection mechanism and policies.

9.5.0 Feature: CSS shall respond to detected cybersecurity incidents with a defined set of actions according to security and privacy policies and procedures.

9.5.1 Scenario: CSS shall execute a response plan upon a cybersecurity incident.

Given VMD defines a cybersecurity response plan; <8.9.4>

When CSS generates Cybersecurity Advisory Messages; <9.4.4>

Then CSS executes the cybersecurity response plan.

9.5.2 Scenario: CSS shall define stakeholder roles and actions during a cybersecurity incident.

Given VMD defines a cybersecurity response plan; <8.9.4>

When CSS generates Cybersecurity Advisory Messages; <9.4.4>

Then CSS specifies stakeholder cybersecurity response plan roles and actions.

9.5.3 Scenario: CSS shall contain and mitigate a cybersecurity incident.

Given VMD defines a cybersecurity response plan; <8.9.4>

When CSS generates Cybersecurity Advisory Messages; <9.4.4>

Then CSS contains the incident impact according to the cybersecurity response plan;

And CSS mitigates the incident impact according to the cybersecurity response plan.

9.5.4 Scenario: CSS shall generate System Wide Cybersecurity Status Messages for each incident containing the following information:

- Nature of the incident
- Severity of the incident
- Response status

Given CSS generates Cybersecurity Advisory Messages; <9.4.4>

When CSS mitigates the incident impact according to the cybersecurity response plan; <9.5.3>

Then CSS generates System Wide Cybersecurity Status Messages.

9.5.5 Scenario: CSS shall improve its cybersecurity response plan through experience and use of historical data.

Given Historical repository of cybersecurity response plans exists;

When CSS mitigates the incident impact according to the cybersecurity response plan; <9.5.3>

Then CSS uses historical data to improve the cybersecurity response plan.

9.6.0 Feature: CSS shall recover from a cybersecurity incident to maintain critical services.

9.6.1 Scenario: CSS shall execute a pre-defined cybersecurity recovery plan during and after a cybersecurity incident to maintain critical services.

Given CSS generates Cybersecurity Advisory Messages; <9.4.4>

And VMD defines a cybersecurity recovery plan; <8.9.5>

When CSS mitigates the incident impact according to the cybersecurity response plan; <9.5.3>

Then CSS executes the cybersecurity recovery plan maintain mission critical services;

And CSS executes the recovery plan after the cybersecurity incident to restore full VAS services.

9.6.2 Scenario: CSS shall improve its cybersecurity recovery plan through experience and use of historical data.

Given Historical repository of cybersecurity recovery plans exists;

When CSS executes the recovery plan after the cybersecurity incident to restore full VAS services; <9.6.1>

Then CSS uses historical data to improve the cybersecurity recovery plan.

9.7.0 Feature: CSS shall transmit messages.

9.7.1 Scenario: CSS shall transmit Cybersecurity Advisory Messages to the HIS, RAS, and VMD.

Given VAS manages the flow of data between services;

When CSS generates Cybersecurity Advisory Messages; <9.4.4>

Then CSS transmits Cybersecurity Advisory Messages to the HIS, RAS, and VMD.

9.7.2 Scenario: CSS shall transmit System Wide Cybersecurity Status Messages to the HIS, RAS, and VMD.

Given VAS manages the flow of data between services;

When CSS generates System Wide Cybersecurity Status Messages; <9.5.4>

Then CSS transmits System Wide Cybersecurity Status Messages to the HIS, RAS, and VMD.

2021

VERTIPORT AUTOMATION SYSTEM (VAS)

Software Trade Study

NUAIR®

MAKING FUTURE SKIES SAFER

Contents

Software Trade Study

The following trade study breaks down the software architecture for the Vertiport Automation System (VAS) by component and present some existing products and solutions that can be used in part or with modifications to fulfill the functionality of the system component. The focus of this section is on commercial off the shelf (COTS), government off the shelf (GOTS) non-developmental items (NDI), and certain ongoing projects and demonstrations are also considered.

1.1 Vertiport Automation System Components

The VAS consists of multiple systems which manage or enable vertiport operations. There are multiple off the shelf solutions that possess certain VAS capabilities and could be modified or used in a limited capacity as a part of the larger software package. This section will highlight existing platforms and concepts, their potential uses in the VAS, and suggestions on how they could be adapted for use in the VAS.

1.1.1 VA-SDSP Interface

The VA-SDSP Interface sends and receives data to connected operational stakeholders, continuously updates vertiport data to describe current and future vertiport operational status and establish a direct transmission link to aircraft operating in the vertiport volume (VPV).

1.1.1.1 Potentially Applicable Commercial Products

uAvionix MicroLink beyond visual line of sight (BVLOS) C2 datalink radio is designed for long-range UAS operations.[1] MicroLink's versatility allows integration with nearly any serial connected autopilot to enable commanding aircraft and the mission monitor application enables critical decision making before a lost link occurs. MicroLink has two radios, and natively supports frequency hopping to minimize external interference. Applicable capabilities include:

- Meets American Society for Testing and Materials (ASTM) Standard F3002-14a.
- Uses GPS Coordinated Universal Time (UTC) timing to enable high levels of precision in frequency hopping.

Solace's PubSub+ Platform enables real-time ecosystem management across both modern and legacy devices. [2] The platform augments the basic event processing infrastructure that most organizations have to provide mission management, operational metrics, and portal design tools. Applicable capabilities include:

- Built in security measures including authentication, authorization, and encryption.
- Representation state transfer (REST) application programming interface (API) for seamless integration and management.

MuleSoft's Anypoint Platform supports development, deployment, management, security, and reuse of APIs and integration assets.[3] Anypoint is deployable either directly on premises, on the cloud, or in a hybrid method to ensure maximum flexibility. Applicable capabilities include:

---

[1] "Microlink," uAvionics, https://uavionix.com/products/microlink/
[2] "PubSub+ Platform," Solace, https://solace.com/products/platform/
[3] "Anypoint Platform," MuleSoft, https://www.mulesoft.com/platform/enterprise-integration

- Out-of-the-box compliance with International Organization for Standardization (ISO) 27001, Service Organization Control (SOC) 2, Payment Card Industry Data Security Standard (PCI DSS), and General Data Protection Regulation (GDPR).
- Support for both prebuilt and custom control access policies.
- Automatic data transformation with machine learning (ML) based recommendations.

1.1.1.2 Potentially Applicable Non-Developmental Item

Collins Aerospace Control and Non-Payload Communications-1000 (CNPC-1000) UAS Command and Control Data Link can be installed directly in the aircraft or in the control station.[4] While it is optimized for sUAS, it can also support larger aircraft. CNPC-1000 allows networked communication in addition to point-to-point transmission. Applicable capabilities include:

- Capable of providing higher bandwidth services such as control, telemetry, weather radar, and video downlink.
- Is not authorized by the Federal Communications Commission (FCC) and may not be sold until that authorization is obtained.

1.1.1.3 Potentially Applicable Open-Source Solution

The Fuser technology used in ATD-2compiles flight data from stakeholders (FAA, airlines, and 3rd parties) into a single database.[5] Flight files are updated in real time as the information is received, and it is organized by unique flights. The Fuser database allows ATD-2 components to gather data for use from multiple origin points with a single interface, rather than requiring a separate interface with each stakeholder. Applicable capabilities include:

- Continuous flight file updates as information are received.
- Traceable monitoring of flight information using the Globally Unique Flight Identifier (GUFI).

1.1.2 Resource Management and Scheduling Service

The RMSS is responsible for scheduling and sequencing of vertiport resources, calculating total current and future capacity, monitoring resource demand, and tracking vertiport status. Additionally, RMSS facilitates negotiation and reservation of vertiport resources with fleet operators and providers of service for Urban Air Mobility (PSUs) via the VA-SDSP Interface.

1.1.2.1 Potentially Applicable Commercial Products

The Aerobahn collaborative decision making (CDM) Suite provides decision making tools to airlines, airport operators, and air navigation service providers (ANSPs) to enable CDM at airports to reduce delays and costs while improving safety.[6] One direct benefit Aerobahn provides to air traffic control (ATC) and ANSPs is real-time information of the impact of surface conditions on traffic management initiatives. Applicable capabilities include:

- Calculations on resource capacity and availability.
- Support for collaboration between entities on decisions.

---

[4] "CNPC-1000 UAS Command and Control Data Link," Collins Aerospace, https://www.collinsaerospace.com/en/what-we-do/Military-And-Defense/Communications/Tactical-Data-Links/Cnpc-1000-Uas-Command-And-Control-Data-Link

[5] "ATD-2 Industry Workshop Documentation Outline," NASA, https://aviationsystems.arc.nasa.gov/atd2-industry-workshop/fuser/ATD-2-Industry-Workshop-Documentation-Outline_81565170.html

[6] "Collaborative Decision Making," SAAB, https://www.saab.com/products/collaborative-decision-making-and-efficiency-platform

The L3Harris Orthogon Coupled Arrival Manager-Departure Manager (AMAN-DMAN) identifies time gaps in runway usage at airports and inserts additional departures resulting in increased efficiency.[7] The coupling of AMAN and DMAN systems enable improved capacity and predictability at runways. Applicable capabilities include:

- Estimations on aircraft arrival and departure times.
- Schedule optimization for capacity-constrained airports.

PASSUR Surface Management provides key decision support information allowing airports to maximize throughput and availability of resources.[8] The platform focuses on sequencing flights based on priority and reducing events that reflect negatively on an airport such as long taxi queues and diversions. Applicable capabilities include:

- Estimations on aircraft arrival and departure times.
- Schedule optimization for capacity-constrained airports.

1.1.2.2 Potentially Applicable Government Demonstration

Portions of NASA's Airspace Technology Demonstration 2 (ATD-2) project have applications in RMSS. The tactical scheduler design sub-project creates an optimized departure plan based on real-time estimates of aircraft departure and taxi times.[9] The integration of dynamic resource buffers at choke points in the system (such as runways in aviation or takeoff and landing pads for vertiports) will enable maximum throughput at a vertiport.[10] Use of machine learning for model tuning will enable better predictions on aircraft taxi times, thus improving the accuracy of the schedule.[11] Applicable capabilities include:

- Optimization of departures based on aircraft and environmental characteristics.
- Supports continuously updated 3D (x,y,t) surface trajectories with integrated arrival / departure/ surface (IADS) prediction, scheduling, and management system.

1.1.3 Surface Trajectory Service

The STS ingests relevant surface surveillance of obstruction detection data, predicts aircraft arrival times at locations on the vertiport surface, generates 4-D surface trajectories (latitude, longitude, altitude, and time) routing aircraft, monitors conformance to surface trajectories, and issues alerts if an aircraft approaching known foreign object debris (FOD).

1.1.3.1 Potentially Applicable Commercial Products

Saab-Sensis' Advanced Surface Movement Guidance and Control (A-SMGCS) presents a variety of information to the controller such as maps, safety alert indicators, picture of movements on the airport surface and control volume, and system status.[12] A-SMGCS is modular and scalable supporting multiple functions such as routing and guidance of inbound and outbound aircraft. Applicable capabilities include:

- Surface trajectory generation based on runway configuration and constraints.

---

[7] "Orthogon Coupled AMAN-DMAN," L3Harris, https://www.l3harris.com/all-capabilities/orthogon-coupled-aman-dman
[8] "Surface Management," PASSUR, https://www.passur.com/solutions/airports/surface-management/
[9] "Assessing Tactical Scheduling Options for Time-Based Surface Metering," NASA, https://aviationsystems.arc.nasa.gov/publications/atd2/tech-transfers/3_Technical_Publications/3.1-12%20DASC2017_Zelinski.pdf
[10] "Queue Buffer Sizing for Efficient and Robust Integrated Departure Scheduling," NASA, https://aviationsystems.arc.nasa.gov/publications/atd2/tech-transfers/3_Technical_Publications/3.1-17%20AIAA2016_Idris.pdf
[11] "Taxi-Out Time Prediction for Departures at Charlotte Airport Using Machine Learning Techniques," NASA, https://aviationsystems.arc.nasa.gov/publications/atd2/tech-transfers/3_Technical_Publications/3.1-18%20AIAA2016_Lee.pdf
[12] "Advanced Surface Movement Guidance and Control (A-SMGCS)," SAAB, https://www.saab.com/products/a-smgcs

- Alerting on possible safety hazards.

1.1.4 Aircraft Conformance Monitor

ACM monitors current and projected conformance status of aircraft to detect anomalies that could create a disruption in vertiport operations. The vertiport manager defines VOA and VPV airspace along with conformance boundaries and tolerances for ACM monitoring. ACM will routinely report on current status and future projects to ensure operations are proceeding as expected.

1.1.4.1 Potentially Applicable Commercial Products

Saab's VL-1090 allows ATC to see MLAT or ADS-B equipped aircraft via a surface surveillance system.[13] The VL-1090 transmits its location on 1090 MHz directly to any cooperative surface surveillance system at an airport enabling instant display to controllers. Applicable capabilities include:

- Support for both temporary and permanent installation due to USB-C connectivity.
- Detection via ADS-B and MLAT.

Saab's VL-4G is a similar piece of technology that uses commercial cellular networks and is even more portable than the VL-1090. Applicable capabilities include:

- Compliant with numerous FCC and ICAO standards.
- Support for integration with Saab's Aerobahn platform to be a part of the wider CDM ecosystem.

1.1.5 System Monitoring Service

The SMS continually monitors the VAS infrastructure and software and detects and degradation in the availability or quality of the data of information generated. Each VAS component will self-monitor and generate warnings or alerts if a potential or actual issue has been detected. SMS will collect this information for analysis and escalation to the HIS if an anomaly is detected. Additionally, this service will provide its own level of monitoring of VAS infrastructure and software to detect any degradation in service that has not been alerted to by the affected service.

1.1.5.1 Potentially Applicable Commercial Products

ANRA's Mission Manager supports flight planning for small unmanned aircraft systems (sUAS) or UAM aircraft, automated notifications and authorizations, automated data collection, and autonomous execution.[14] Additionally, the platform is built around collaboration with support for data sharing and integration with enterprise systems. Applicable capabilities include:

- Information sharing with external entities.
- Automatic data collection based on real-time sensor data.

1.1.6 Hazard Identification Service

The HIS provides automated hazard identification. HIS analysis vertiport data to identify anomalies and determine if those anomalies pose hazards to vertiport infrastructure, passengers, flight crew, or other entities at the vertiport. Once HIS identifies a hazard, HIS transmits the appropriate information for risk analysis and mitigation to RAS.

1.1.6.1 Potentially Applicable Commercial Products

Although obstruction detection is focused on physical infrastructure at the vertiport, existing framework laid out by Optimal Synthesis Inc. to enable vision-based surveillance systems at airports has applications

---

[13] "Airport Vehicle Tracking," SAAB, https://www.saab.com/products/airport-vehicle-tracking

[14] "MissionManager – Drone Operations Platform," ANRA Technologies, https://www.anratechnologies.com/home/drone-oss-platform/

to vertiport operations.[15] The model is used for tracking aircraft, rather than obstructions, but the use of only vision-based surveillance rather than GPS, radar, or ADS-B may eventually allow for obstruction detection and mitigation without sophisticated infrastructure. Applicable capabilities include:

- Centroid tracking of aircraft.
- Distinguishing between aircraft and other objects in a cluttered ramp area.

1.1.7 Risk Assessment Service

The RAS supports the vertiport safety management system (SMS) program by automating parts the Safety Risk Management process through the identification of potential hazards and estimation of the associated risk. This information is provided to the VMD for further review and analysis. Additionally, RAS supports the SMS Safety Assurance program through the continual monitoring of establish risk mitigation strategies and generates reports detailing their effectiveness. Other functionality includes providing access to Safety Policy documentation such as the Emergency Response Plan which can be automatically triggered when needed.

1.1.7.1 Potentially Applicable Commercial Products

Vistair's RiskNet risk management solution supports both flexible and high-volume risk assessments through hazard identification and quantification. RiskNet also supports mitigation management based on the risk assessment.[16] Applicable capabilities include:

- Built in project management capabilities.
- Dashboard for mitigation management reporting.

SMS Pro provides a centralized solution centralized solution to manage SMS programs for International Civil Aviation Organization (ICAO) compliance.[17] The central database aggregates data in one location to make report compiling easier while also supporting backup data storage locations. Applicable capabilities include:

- Immediate feedback based on user submitted reports.
- Immediate notification of issues to safety managers.

1.1.8 Vertiport Manager Display

The VMD is the physical interface allowing a vertiport manager to facilitate ground-to-air operations at the vertiport, manage VAS configuration, override VAS automation during off-nominal or emergency conditions, communicate directly to aircraft, flight crews, PSUs, or fleet operators, and manually divert aircraft if needed. VMD also visually depicts the real time status of vertiport resources and aircraft locations and alerts the manager to off-nominal conditions.

1.1.8.1 Potentially Applicable Commercial Products

Saab-Sensis' Electronic Flight Strips (EFS) enables efficient distribution of flight data to tower positions and ATM systems through a configurable, visual interface that organizes flights depending on phase of flight and flight ownership.[18] Applicable capabilities include:

- Situational awareness capabilities such as runway incursion notifications and prevention.

---

[15] "Multiple-Target Tracking Framework for Aircraft in Airport Ramp Area," Optimal Synthesis Inc, https://www.optisyn.com/research/publications/2016/AIAA-2016-1493.pdf

[16] "RiskNet," Vistair, https://www.vistair.com/aviation-management-software/aviation-sms-software/risknet/

[17] "National and Regional SMS Data Management Challenges," SMS Pro, https://www.asms-pro.com/Products/SSPProStateSafetyProgram.aspx

[18] "Electronic Flight Strips (EFS)," SAAB, https://www.saab.com/products/electronic-flight-strips-EFS

- Customization based on specific airports and the role of ATC.

Digital Tower, also by Saab-Sensis, supports the use of remote tower services through specific equipment installed at the airport along with a Visual Presentation (VP) that displays full 360° views to the Digital Tower Center (DTC).[19] Applicable capabilities include:

- Graphical overlays for intuitive presentation of key information.
- Support for integration with automation tools for larger airports.

Sabre's Flight Explorer Professional is a map-based tool allowing airlines to track aircraft and use weather overlays for monitoring and alerting aircraft of inclement weather.[20] Additionally, Flight Explorer Professional integrates with aircraft communications addressing and reporting system (ACARS) and automatic dependent surveillance – broadcast (ADS-B) allowing seamless use of position reports and flight plans. Applicable capabilities include:

- Support for a desktop interface.
- Integration with 3rd party weather data providers to create overlays on the display.

L3Harris's Weather and Radar Processing (WARP) generates radar data for ATC displays and is designed to support FAA NextGen Network Enabled Weather (NNEW).[21] Applicable capabilities include:

- Flexible hardware to support integration with legacy and future technology.
- Generation of radar data for display to controllers.

Existing UAS service suppliers' (USS) applications from entities such as Avision could fill the role of a VMD with modifications and tailoring towards vertiport operations.[22] Avision's application is FAA certified and connects directly into UAS Traffic Management (UTM) to supply operators with advisories and authorizations. Additionally, Avision's integration with FAA Low Altitude Authorization and Notification Capability (LAANC) allows real-time airspace reservation. Applicable capabilities include:

- Support for airspace analytics and 3D (x,y,z) flight simulation.
- Real-time monitoring and activity logbooks for flight data.

1.1.9 Cybersecurity Service

The CSS will monitor for cyber-attacks, detect security breaches, verify identities of stakeholders connected to the VA-SDSP Interface, and enforce access controls based on role and privileges.

1.1.9.1 Potentially Applicable Commercial Products

Datiphy's DatiDNA secures databases by mapping data transactions to immediately report potential data breech events.[23] The mapping capabilities contextualize a user's behavior to their activity to provide database threat insight. Applicable capabilities include:

- Compliance assessment for SOC 2, GDPR, PCI, and other standards.
- Investigative tools mapping patterns during and after an incident or data breach.

[19] "Digital Tower (r-TWR)," SAAB, https://www.saab.com/products/digital-tower
[20] "Flight Explorer Professional," Sabre, https://www.sabre.com/products/flight-explorer-professional/
[21] "Weather and Radar Processing (WARP)," L3Harris, https://www.l3harris.com/all-capabilities/weather-and-radar-processing-warp
[22] "Airspace Management for Drones," Avision, https://avision.io/
[23] "Datiphy Solutions," Datiphy, https://www.datiphy.com/

Neovera's Cybersecurity Monitoring Services use artificial intelligence (AI) and ML automation for continuous risk reduction and increased visibility on security events and threats.[24] Applicable capabilities include:

- Compliance assessment for SOC 2, GDPR, PCI, and other standards.
- Clear breakdown of responsibility based on user needs to ensure proper protection of data.

1.2 Vertiport Infrastructure Components

Many off the shelf solutions for airport infrastructure could be used at vertiports with limited or no modification. This section will investigate some of these solutions, their possible uses in high density vertiport operations, and potential modifications needed. While some existing solutions may not have direct implications on software used at the vertiport, an analysis of the capabilities and features will provide insight for vertiport software needed to support the infrastructure.

1.2.1 Weather Sensors

1.2.1.1 Potentially Applicable Commercial Products

DTN offers multiple solutions build around providing real-time and accurately forecasted weather data to airlines and airports.[25] DTN's AviationSentry provides 4D flight alerting and live route recommendations based on meteorological data. Additional services such as DTN Aircraft IceGuard supports decision making by suppling accurate measurements and forecasts on wing temperature.[26] Applicable capabilities include:

- Solutions designed specifically for each airport and have Enhanced Weather Information Services certification.
- Projects how weather events will impact operations and business.

TruWeather Solutions offers multiple services built around UAS, but they also have applications to UAM operations.[27] Their TruFlite Micro service interpolates existing and proprietary data to capture local climate effects. They also offer multiple evaluation tools including RouteCAST, which provides risk feedback based on user inputs, and MissionCAST which delivers a "Go" or "No Go" on missions based on user inputs. Applicable capabilities include:

- Color coded risk indicator on graphical interface based on projected winds.
- Terrain mapping to ensure adequate clearance for both VLOS and BVLOS operations.

1.2.2 Surface Tracking

1.2.2.1 Potentially Applicable Commercial Products

XSight Systems' RunWize platform is composed of multiple tools: FODetect, BirdWize, SnowWize, and ViewWize to address various runway safety hazards.[28] The infrastructure is often collocated with runway edge lights and leverages the fusion of millimeter-wave radar with electro-optical high-definition imaging for detection of runway threats. Applicable capabilities include:

- Use of automation and AI to improve efficiency and capacity.

[24] "Cybersecurity Monitoring Services," Neovera, https://www.neovera.com/cybersecurity/cybersecurity-monitoring/
[25] "Airline Products," DTN, https://www.dtn.com/weather/airlines/
[26] "Aircraft IceGuard," DTN, https://www.dtn.com/weather/airlines/aircraft-iceguard/
[27] "Subscription Services," TruWeather Solutions, https://truweathersolutions.com/subscription-services/
[28] "RunWize," XSight Systems, https://www.xsightsys.com/index.php/runwize/

- Supports continuous monitoring of runway surfaces to reduce risk.

L3Harris's Airfield Radar System (ARS) uses wide beam radar and camera systems can to specific areas and differentiate between threats.[29] ARS supports placement of user defined routes to reduce false alarms and can cover up to one mile in each direction. Applicable capabilities include:

- Offers protection for the entire airfield rather than just a portion or the perimeter.
- Interfaces with legacy airport and modern systems.

1.2.3 FOD Detection

1.2.3.1 Potentially Applicable Commercial Products

Moog Aircraft Group's Tarsier Automatic Runway FOD Detection System guarantees runway inspection even in zero visibility conditions.[30] Tarsier identifies and confirms debris through advances digital signal processing to eliminate false alarms and displays status information to operators in a graphical display. Applicable capabilities include:

- 100% detection at a range of 3,168 feet.
- Live video feeds to verify the object before dispatching personnel.
- Event log for historical analysis and compliance.

1.2.4 GPS Integrity

1.2.4.1 Potentially Applicable Commercial Products

Swift Navigation's Skylark is a cloud based Global Navigation Satellite System (GNSS) corrections service designed for self-driving cars that is hardware agnostic.[31] It is specifically designed to give cars lane-level positioning, and also supports state of the art security and enterprise management to promote compatibility with existing equipment. When coupled with their Precision GNSS Module (PGM), it can deliver GPS / GNSS accuracy within 10 centimeters.[32] The PGM is a dual frequency GPS receiver designed specifically for areas such as urban canyons and parking lots. Applicable capabilities include:

- Initialization times in seconds rather than minutes.
- Support for enterprise management features and state-of-the-art security.

1.2.5 Charging Station

1.2.5.1 Potentially Applicable Commercial Products

Beta Technologies' eVTOL Charging Station is designed to be an independent facility; however, some capabilities have applications at larger vertiports.[33] The station features a rapid recharge center that includes 500kWh of repurposed aircraft batteries. Beta Technologies states that the batteries no longer meeting flight standards will be used in the recharge center. Using this design enables the recharging station to draw power from the local power grid, augment power delivery when needed, and briefly operate independently from the grid if needed. Applicable capabilities include:

- 250kW AC/DC inverter and stepdown transformers for 480v, 208v, and 120v.

[29] "Airfield Radar System (ARS)," L3Harris, https://www.l3harris.com/all-capabilities/airfield-radar-system-ars
[30] "Tarsier Automatic Runway FOD Detection System," MOOG Aircraft Group, https://www.tarsierfod.com/
[31] "Skylark Precise Positioning Services, Swift Navigation, https://www.swiftnav.com/skylark
[32] "Swift Navigation introduces PCIe product to bring high-precision GNSS to industrial, last-mile, and IoT Platforms," Geospatial World, https://www.geospatialworld.net/news/swift-navigation-introduces-pcie-product-to-bring-high-precision-gnss-to-industrial-last-mile-and-iot-platforms/
[33] "Beta reveals new modular eVTOL power pad," eVTOL News, https://evtol.com/features/beta-reveals-evtol-charging-station/

- Built in solar panels to augment the power grid providing energy for the station.

1.2.6 Noise Sensors

1.2.6.1 Potentially Applicable Commercial Products

Noise sensors are typically included as part of a wider infrastructure solution. One example is the EnvironmentalVue application from L3Harris.[34] EnvironmentalVue uses multiple surveillance feeds such as ADS-B to provide a view of airborne assets and airport surface traffic data to allow users to track and manage compliance. Airports can create regular or ad hoc reports through the EnvironmentalVue application and publish them to public information portals. Applicable capabilities include:

- Web-based system supporting real-time monitoring.
- 2D and 3D geographic information system (GIS) platform for simple map uploads.

Symphony Suite, also by L3Harris, is an aviation management platform composed of multiple applications (including EnvironmentalVue) that provide tools to assist surface operations management operations, airfield and perimeter safety, noise monitoring, and gate management.[35] Applicable capabilities include:

- Maintains analytics information on the airport.
- Supports aircraft tracking and billing.

1.2.7 Voice Radio

1.2.7.1 Potentially Applicable Commercial Products

L3Harris offers multiple solutions for voice communications such as Voice over Internet Protocol Communications Enterprise (VOICE) Control and Control (C2) – Voice Communication Control Systems (VCCS). VOICE C2 presents users a single graphical interface and enables access to control radio, telephony, intercoms, and paging systems.[36] Applicable capabilities include:

- Supports local and remote access for faster response times.
- Highly configurable touchscreen interface allowing users to control their communications environment.

VOICE ATM improves communication between aviation stakeholders by modernizing traditional communications systems.[37] VOICE ATM enables centralization of operations and remote tower capabilities through IP-based communications infrastructure. Applicable capabilities include:

- Seamless integration with communications systems.
- Meets air traffic management (ATM) safety standards.

VCS21, another system in L3Harris's Voice over Internet Protocol (VoIP) suite, takes a network-centric approach to modernizing voice communications to reduce dependence on traditional point-to-point communications.[38] VCS21 supports both modern and legacy systems, enabling ATM modernization and supporting operations of any complexity. Applicable capabilities include:

- Support for business planning and asset sharing.

---

[34] "EnvironmentalVue," L3Harris, https://www.l3harris.com/all-capabilities/environmentalvuer
[35] "Symphony for Airports," L3Harris, https://www.l3harris.com/all-capabilities/symphony-airports
[36] "VOICE C2 – VCCS," L3Harris, https://www.l3harris.com/all-capabilities/voice-c2-vccs
[37] "VOICE ATM – VCCS," L3Harris, https://www.l3harris.com/all-capabilities/voice-atm-vccs
[38] "VCS21," L3Harris, https://www.l3harris.com/all-capabilities/vcs21tm

1.2.8 Digital Communication

1.2.8.1 Potentially Applicable Commercial Products

L3Harris FAA Data Comm will increase airport throughput, airspace safety, and allow the NAS to handle higher levels of traffic.[39] Data Comm will reduce readback/hearback errors that occur in voice communications. Also, Data Comm supports capabilities such as continuous descent approaches and dynamic weather rerouting to increase flight efficiency and operational safety. Applicable capabilities include:

- Support for trajectory-based operations

[39] "FAA Data Comm," L3Harris, https://www.l3harris.com/all-capabilities/faa-data-comm

CLIN 3

Vertiport Automation System
UI Design Concepts and Examples

TOPICS

- Software feature overview
- Human factors considerations
- Core displays
  1. Resource Manager (RM)
  2. Arrival and Departure Scheduler (ADS)
  3. Weather Display (WD)
  4. System Performance Dashboard (SPD)
- Future concepts
- Workstation layout

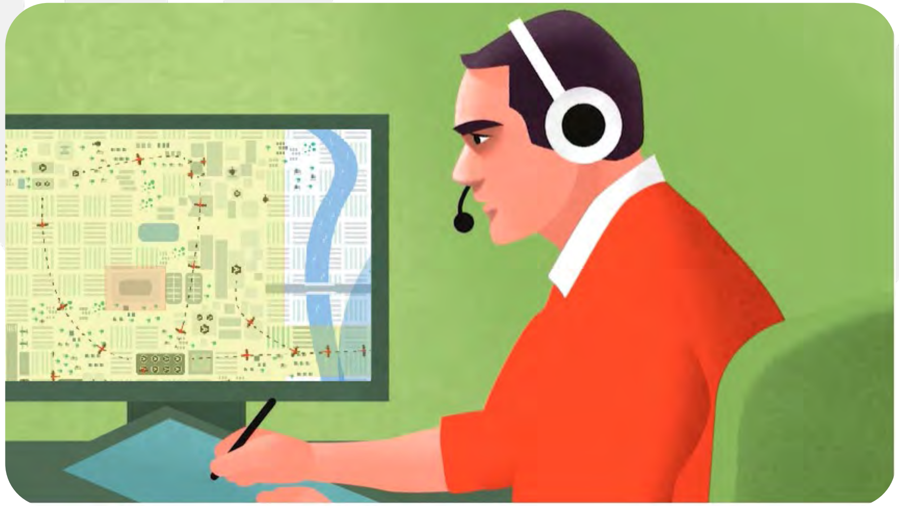
VERTIPORT AUTOMATION SYSTEM

Enterprise operations management software

General Features

- Resource management - Takeoff/Landing pads, passenger/cargo gates, short & long-term parking, charging/refueling station status, schedule
- Operation intent management - Arrivals, departures, on-site servicing schedule
- Taxi planning - 4D surface trajectory generation
- Surveillance system - Situational awareness of surface and airborne traffic
- Weather system - Current and forecast weather
- Conformance monitoring - Approach, departure, and surface trajectory compliance
- Risk management - Hazard identification and mitigation plans
- Health and status - Live system and subsystems status
- Communications - Text and audio

Vertiport Manager (VM)



System-wide design considerations:

- Automation
- Cybersecurity
- Human Factors Engineering
- Multi-vertiport operations/remote towers
- Off-nominal operations
- Exception handling and logging
- Data governance and management

UML - 4 Requires High Levels of Automation

VERTIPORT AUTOMATION SYSTEM
Human factors consideration

- The purpose of this brief is to share UI design concepts and examples for the vertiport automation system. It is by no means a comprehensive human factors design.
- The examples draw from a variety of different FAA, NASA, and industry systems and displays. As such, colors, fonts, and user experience (UX)/interaction are inconsistent.
- A comprehensive design would promote consistency and unity throughout the VAS, including standard:
  - Symbology
  - Color coding
  - Font, including type, pitch, and character discrimination (e.g., letter l/number 1, letter Z/number 2, Letter O and number 0)
  - UX/interaction
  - Button size, behavior, appearance

VERTIPORT AUTOMATION SYSTEM

Four core operational displays

#	Display Name	Description
1	**Resource Manager (RM)**	• Takeoff/Landing Pad Monitor • Arrival/Departure Displays • Surface Manager • Passenger Gate/Cargo Loading Zone Monitor • Charging/Refueling Station Monitor • Short-term Staging/Long-term Parking Monitor • Deicing Manager
2	**Arrival and Departure Scheduler (ADS)**	• Arrival Timeline • Departure Scheduler • Slot Reservation System • Trajectory Modeling and Conformance Monitor
3	**Weather Display (WD)**	• NEXRAD Weather Radar • Corridor Integrated Weather Service (CIWS) • Terminal Aerodrome Forecast (TAF) • Vertiport Information Display System (V-IDS)
4	**System Performance Dashboard (SPD)**	• System Operability • Connectivity • Cybersecurity • Risk Assessment/Safety Risk Management • Operational metrics

Features and capabilities overlap for redundant display of information (e.g., Pad availability is conveyed on multiple displays)

VERTIPORT AUTOMATION SYSTEM

Resource Manager (RM)

The Resource Manager (RM) is a system of displays that support all Vertiport Manager (VM) functions, similar to Ground Control Positions at ATC Towers, or Non-ATC Ramp Tower/Ramp Controller functions. The RM uses a combination of surveillance radar, live video, and electronic sensors to display the current status of all vertiport resources.

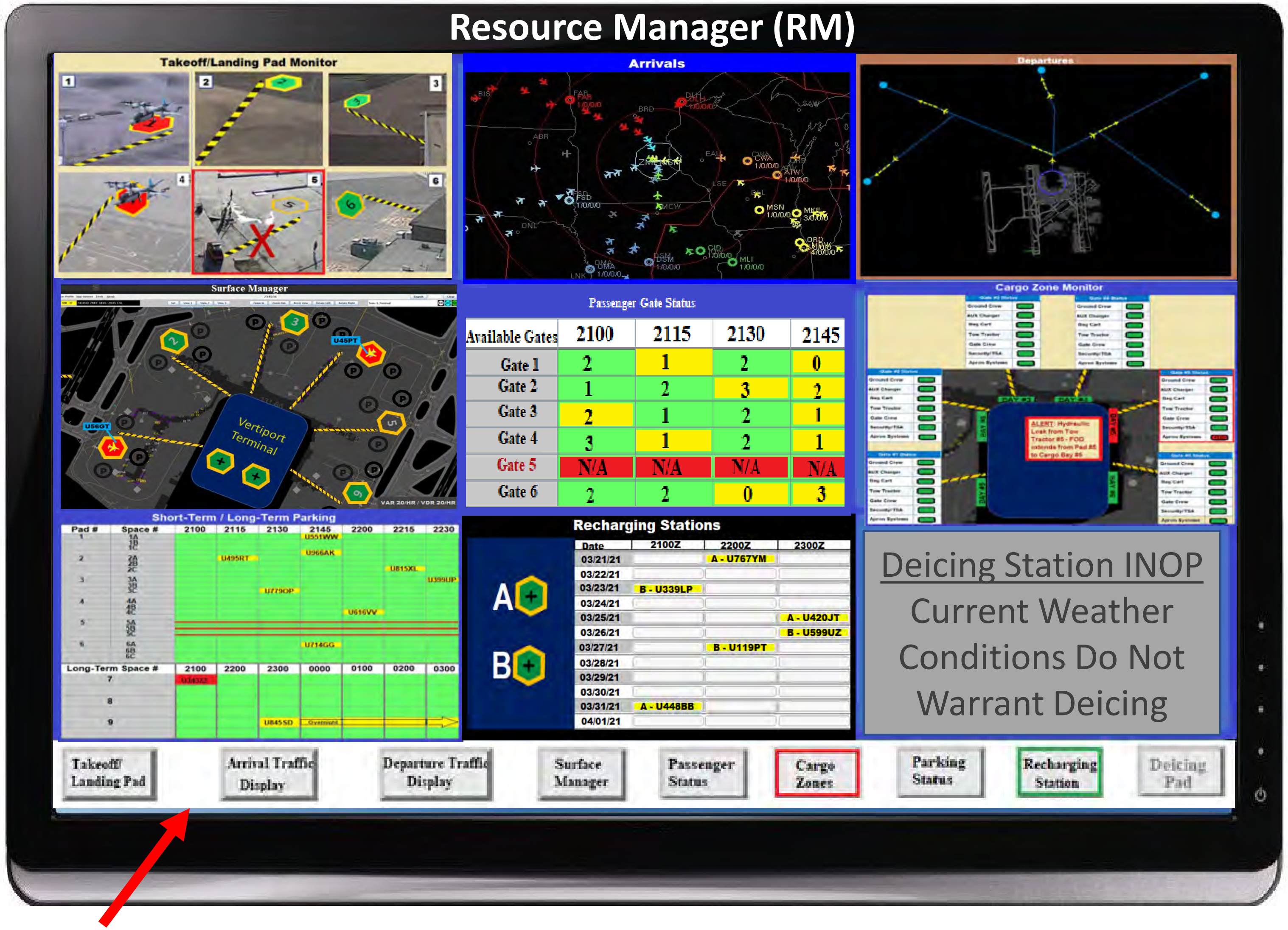
RM components include:

A. Takeoff/Landing Pad Monitor - Displays takeoff/landing pad occupancy status
B. Arrival/Departure Displays - Displays location of arrivals and departures
C. Surface Manager - Uses surveillance monitors to display the status of all vertiport surface activities, including: takeoff/landing pads, taxiways, passenger/baggage/cargo loading zones, aircraft staging and parking pads, recharging/refueling stations, and deicing pads
D. Passenger Gate/Cargo Loading Zone Monitors Display schedule and status of passenger gates, passenger/flight crew readiness, and cargo bay/ground crew availability
E. Charging/Refueling Station Monitor - Displays the schedule and current status (i.e. estimated occupancy time) of all charging/refueling stations.
F. Short-term Staging/Long-term Parking Monitor - Displays status of short-term staging areas and long-term parking spaces used by aircraft that need to wait, but are not allowed to occupy active takeoff/landing pads
G. Deicing Manager - Displays status and schedule during de-icing operations

- *Note: Resource availability will be depicted using a color-coding system:* either **red = occupied**, **green = open**, or yellow – in transition or reserved

The **Resource Manager (RM)** workstation consists of multiple displays. The VM maintains situational awareness through scanning and enlarging any display for closer review. RM component examples shown here include:

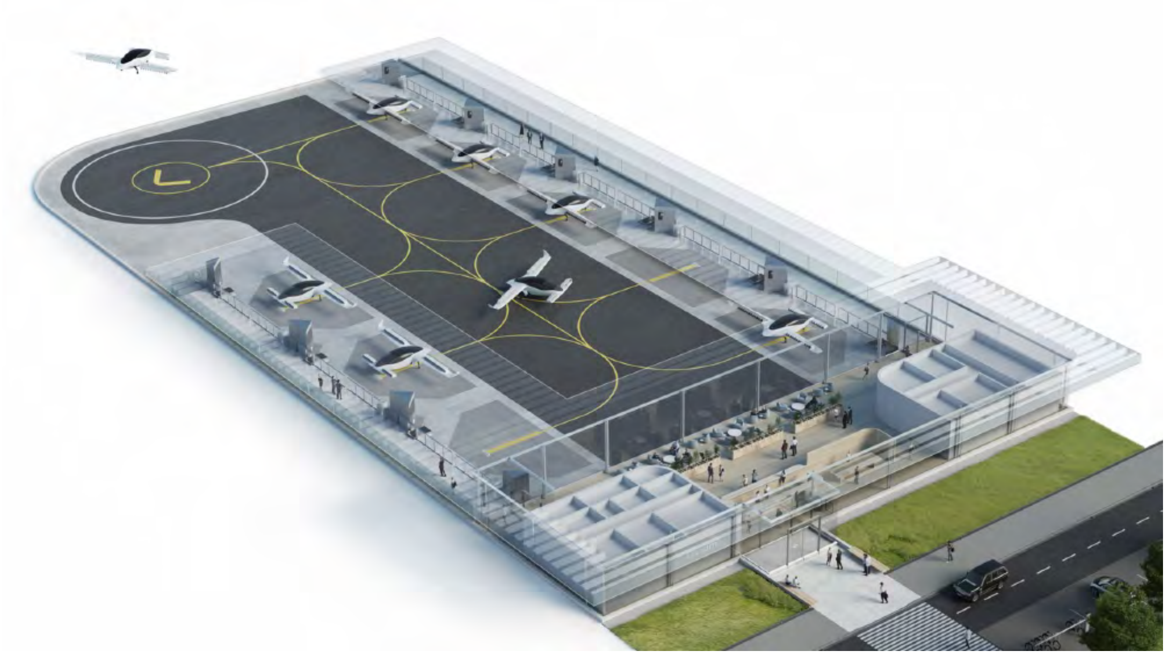
1. Takeoff/Landing Pad Monitor - displays video surveillance of each takeoff and landing pad
2. Arrival Traffic Display - depicts inbound flight position and status. The display shown here leverages the FAA's Traffic Situation Display (TSD). Flights are color coded according to assigned arrival route.
3. Departure Traffic Display - depicts outbound flight position and status. Flights would be color coded by departure route.
4. Surface Manager - depicts vertiport resource and surface aircraft position and status. Discussed in more detail on next slide
5. Passenger Gate Status - displays passenger gate readiness
6. Cargo Zone Monitor - displays status of cargo zone equipment and crew availability
7. Parking Manager - displays status of all short-term and long term parking spaces
8. Recharging Manager - displays status and schedule for all recharging stations
9. Deicing Manager - depicts deicing information. Discussed in more detail later in briefing.



The **Workspace Switcher** toolbar is used to enlarge and toggle between the various RM displays. Color-coding (red/green/yellow) is used to convey status. Flashing is used to increase salience and alert the user to any active warnings, cautions, or advisories. Aural tones are used in conjunction with visual cues to alert the user to warnings, cautions, advisories and other events.

VERTIPORT AUTOMATION SYSTEM

Design Considerations for Surface Manager



Lilium 1:M Pad to Bay Concept

- Increases pad to parking transfer time
- Surface trajectories overlap
- Limited exposure to FATO (AC more protected)

Uber/Gannett Fleming Paw Concept

- Reduces pad to parking transfer time
- Surface trajectories conflict free
- Higher exposure to FATO area

RM: Surface Manager

Notional Vertiport Design:

- 6 take off/landing pads
- 3 parking spots per pad
- 2 recharging stations ("+")

VM would use the Surface Manager to monitor the status of takeoff/landing pads, taxiways, passenger transition zones, baggage/cargo loading zones, aircraft staging and parking pads, recharging/refueling stations, and deicing pads

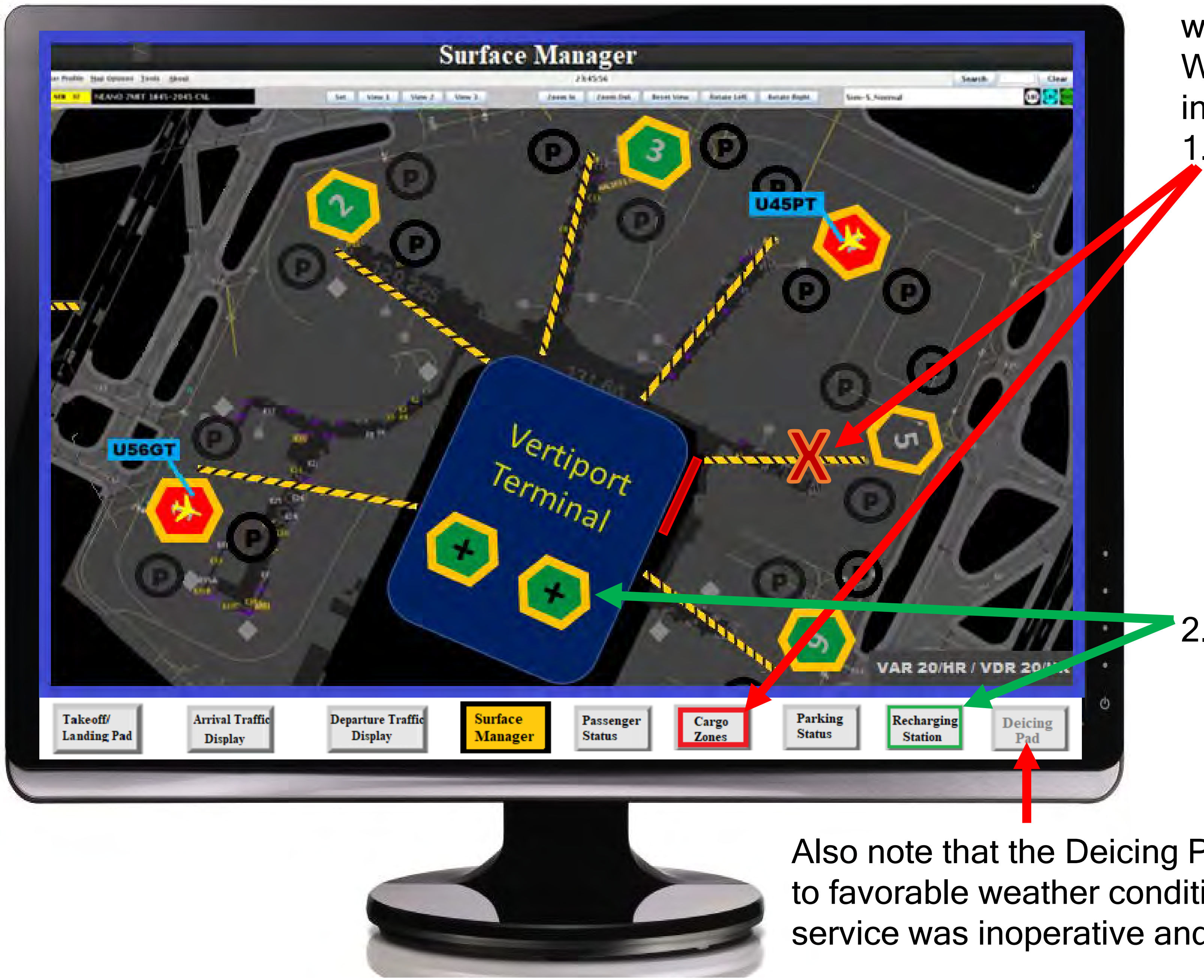
Surface Manager shows: 3 vacant pads (green), 2 occupied pads (red), 1 inactive pad (gray), and 2 vacant recharging stations (green)

Note: Mock-up superimposed onto an ATD-2 Ramp Traffic Console (RTC) graphic.

The ATD-2 graphic uses colored icons and labels to represent ramp activities. The VAS Surface Manager would follow similar conventions.

Note: Recharging is available at all Takeoff/ Landing Pads, but only if the schedule permits. Auxiliary recharging stations ("+") are available if necessary.

RM: Surface Manager

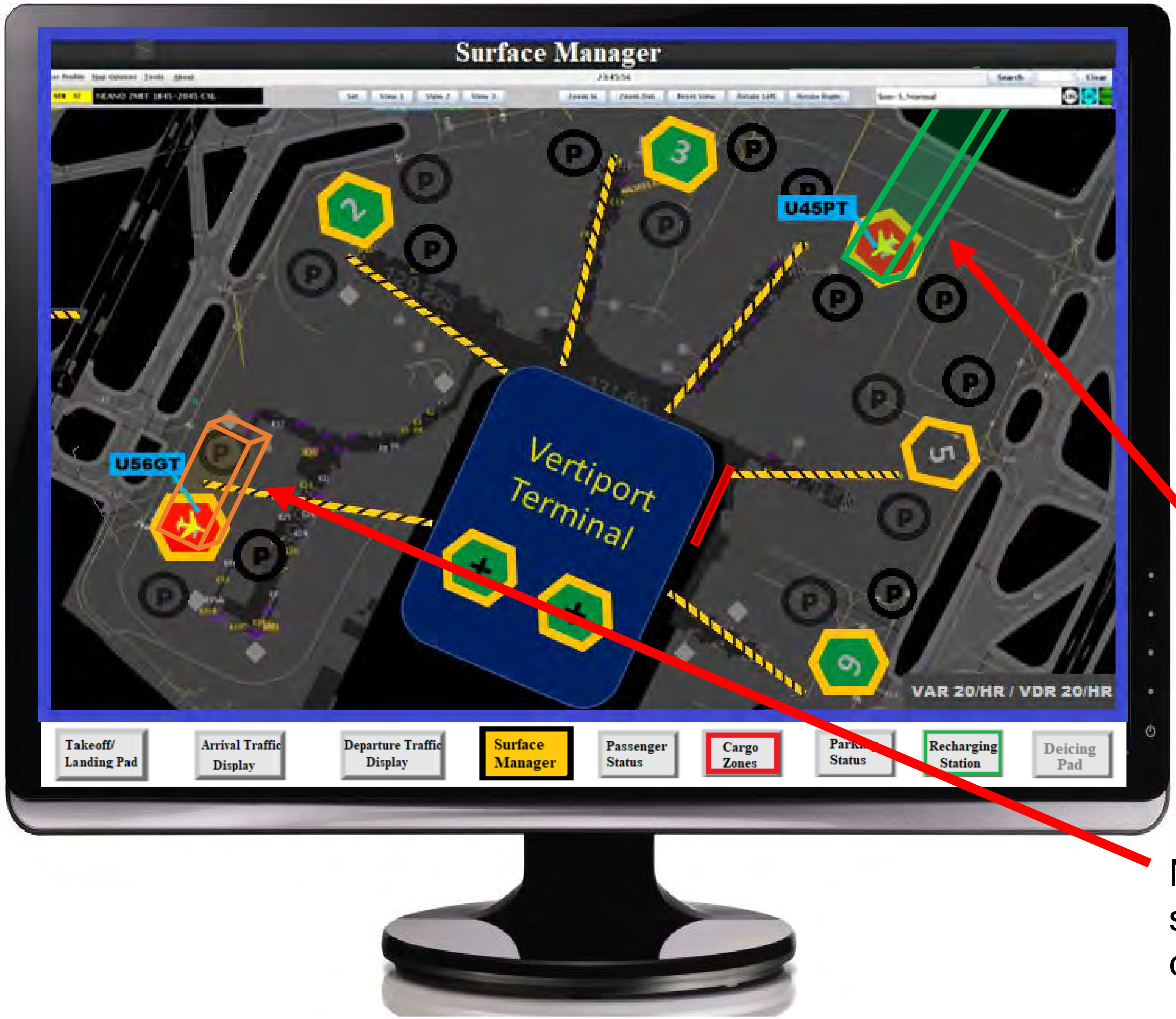


While completing a scan of all VAS workstations the VM notices that two Workstation Switcher buttons are highlighted in green and red indicating:

1. Red indicates an issue in the cargo zone that needs investigating - the red might even be flashing depending on severity. Toggling this button would open the Cargo Zone display. Upon further review the VM learns that due to an equipment malfunction and a hydraulic leak, pad #5 is now inoperative. After learning of the inoperative pad, the VM would:
   - Reallocate traffic to a contingency pad
   - Notify the PSU network of the change
   - Initiate cleanup
2. Green indicates that both auxiliary recharging stations are currently available. Toggling this button would open the Recharging Station display and schedule.

Also note that the Deicing Pad button is grayed out indicating that, due to favorable weather conditions, deicing is not needed. If the deicing service was inoperative and/or unavailable, this button would be red.

RM: Surface Manager



The Surface Manager GUI will also allow the user to:

- Zoom
- Pan
- Rotate
- Filter certain features:
  - Arrival/Departure Operation Intent
  - Surface trajectories
  - Aircraft
    - Arrivals only
    - Departures only
  - Cargo/luggage activities
  - Service activities

Notional departure Operation Intent shown. Green indicates aircraft is conforming with current flight plan.

Notional surface trajectory Operation Intent shown. Orange indicates aircraft is not in conformance with surface trajectory.

VERTIPORT AUTOMATION SYSTEM

Arrival and Departure Scheduler (ADS)

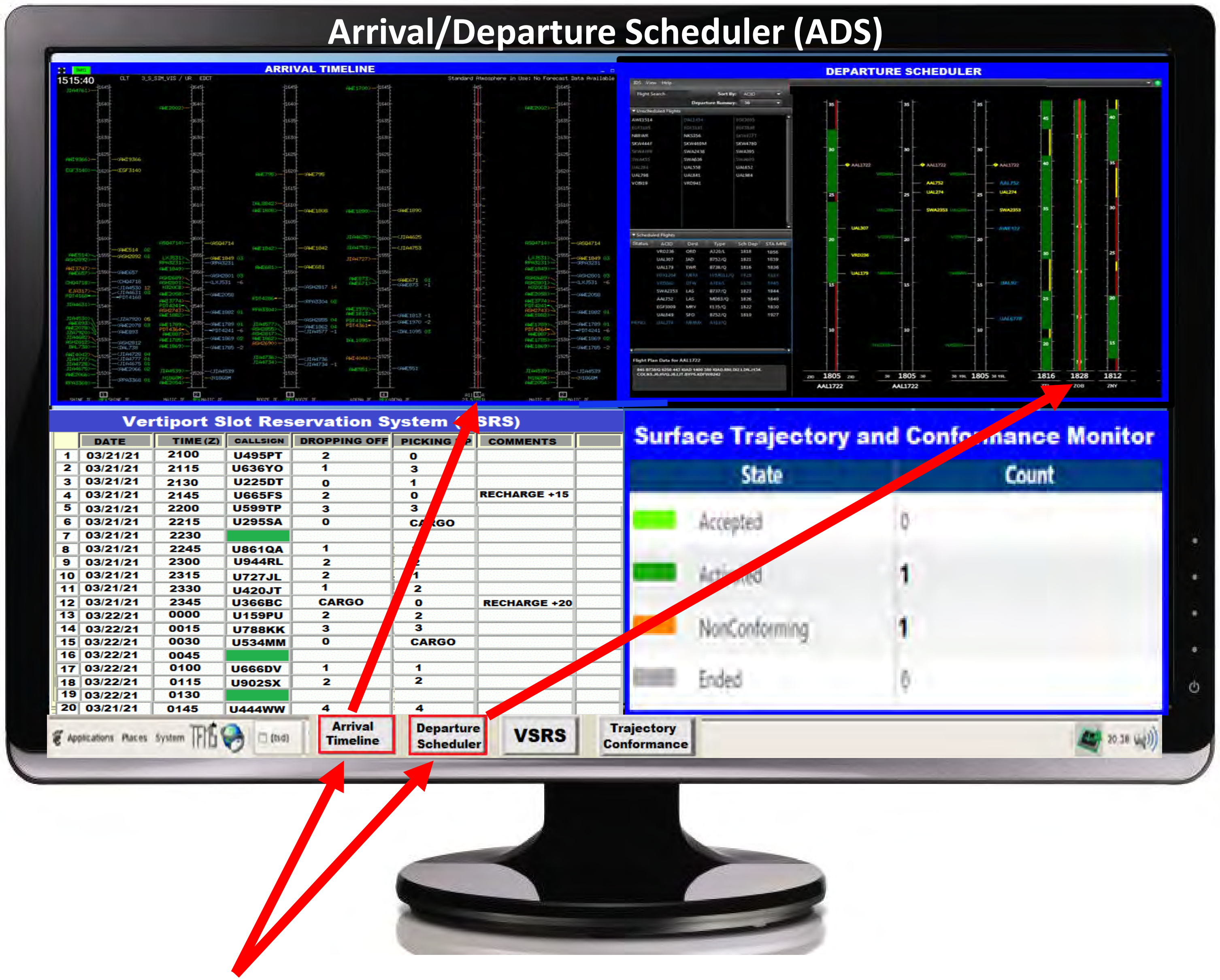
The ADS display, which mirrors the FAA's TBFM metering system, supports arrival and departure scheduling functions. The ADS also contains a landing slot reservation display and a trajectory modeling/conformance monitor.

ADS components include:

A. Vertiport Arrival Timeline (VAT) – Displays all inbound traffic scheduled to arrive at their assigned time slots
B. Vertiport Departure Scheduler (VDS) – Lists all proposed flight plans and displays all scheduled outbound traffic on the departure timeline
C. Vertiport Slot Reservation System (VSRS) – Displays all vertiport arrival and departure reservations. Patterned after FAA's Electronic Special Traffic Management Program (E-STMP) program, the VSRS is an automated way to reserve these vertiport slots
D. Trajectory Modeling and Conformance Monitor (TMCM) – Models and displays all aircraft trajectories, and monitors aircraft conformance to trajectories

The **Arrival/Departure Scheduler (ADS)** workstation shown here consists of several timeline configurations and scheduling components that the VM would use to review arrival and departure times to all vertiport aircraft. (Graphics courtesy of the FAA's Time Based Flow Management System (TBFM)). ADS includes:

1. Arrival Timeline GUI - shows aircraft call signs, arrival time slots, and any assigned delays that are necessary to meet the arrival schedule.
2. Departure Scheduler - lists all proposed flight plans and provides the VM with the capability of scheduling each flight into available time slots, if necessary, otherwise automated.
3. Vertiport Slot Reservation System (VSRS) - lists all slots reservations made by aircraft, used to populate the arrival timeline.
4. Trajectory Modeling and Conformance Monitor - Shows conformance of relevant aircraft, allows user to help with trajectory modeling, if necessary.



Note the Arrival and Departure Timeline buttons are highlighted in red. Upon further review, the VM can see that no arrivals or departures can be assigned to Pad #5 because it is inoperative.

VERTIPORT AUTOMATION SYSTEM

Weather Display (WD)

The WD displays all current and forecast weather relevant to the operation of the vertiport. Automated alerts will notify the VM when conditions change, and may include increasing levels of alerts when conditions become hazardous for vertiport ground movement and flight.

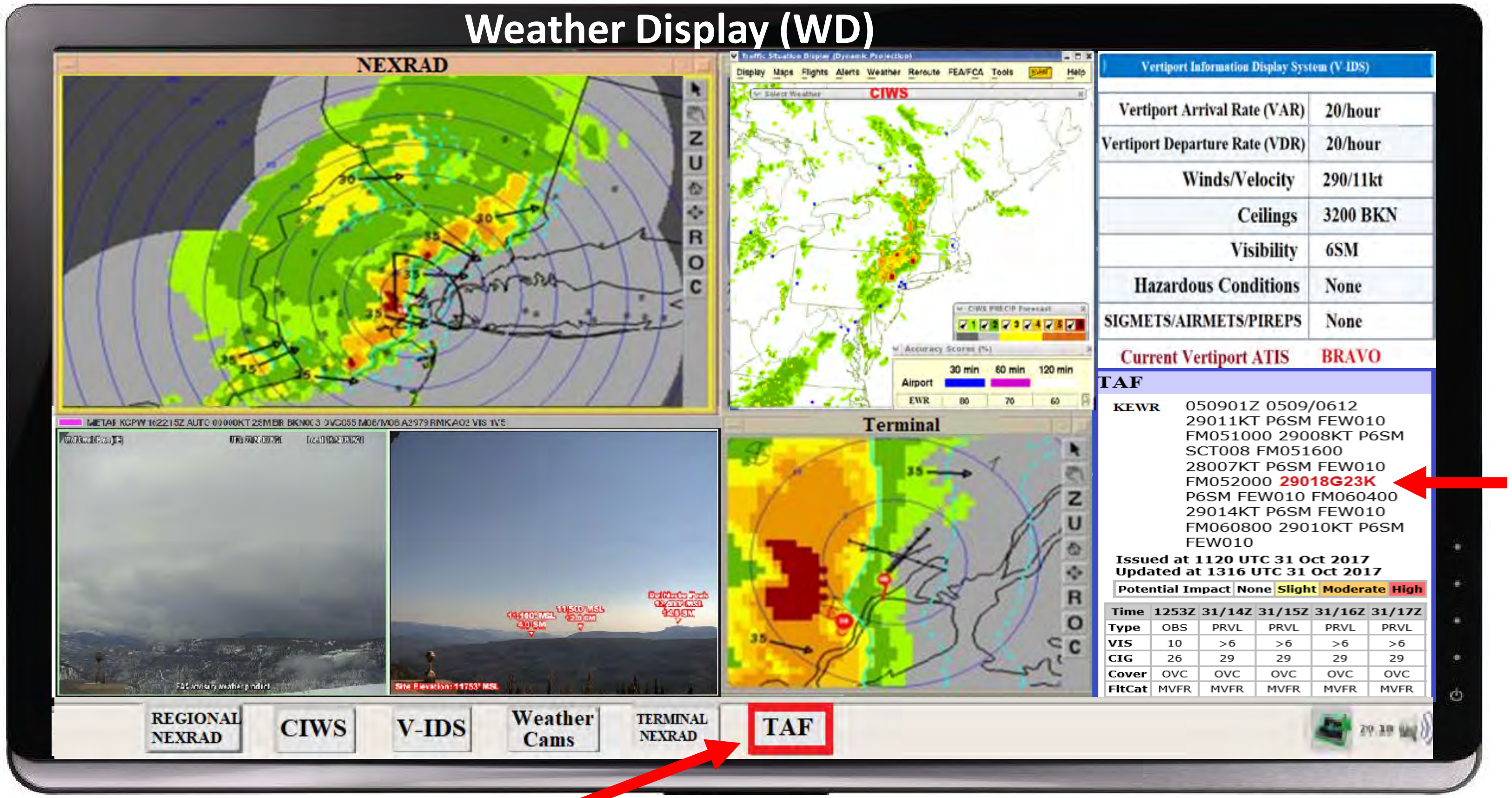
WD components include:

A. NEXRAD Weather Radar – Displays live weather radar with zoom features to view regional and local weather
B. Corridor Integrated Weather Service (CIWS) – provides past, current, and forecast movement of local weather systems impacting the vertiport. CIWS also displays an accuracy indicator that is based off past forecast performance.
C. Vertiport Information Display System (V-IDS) – The V-IDS is a status board used to update the VM on current conditions, including vertiport arrival and departure rates (VAR/VDR), wind/ceiling/visibility, hazardous weather (precipitation/hail/icing/lightning/wind shear/turbulence, etc.), SIGMETS/AIRMETS/PIREPS. The V-IDS also lists the name of the current Automated Terminal Information Service (ATIS) recording.
D. WeatherCams – Live video feeds of vertiport areas of interest (e.g., approach and departure routes)
E. Terminal Weather – Local and on-site weather status (e.g., pad surface temperature)
F. Terminal Aerodrome Forecast (TAF) – Displays forecast winds, ceilings, visibility information

The mock-up of the **Weather Display (WD)** workstation shown here consists of several National Weather Service (NWS) products that the VM would use to monitor the weather conditions impacting the vertiport operation. Examples include:

1. NEXRAD display - used to monitor approaching weather systems
2. CIWS display - used to show past, current and forecast weather system movement
3. V-IDS - shows the current arrival/ departure rates at the vertiport, and displays the current weather conditions and ATIS report in use
4. WeatherCams - Live camera feeds of vertiport areas of interest (e.g., approach routes)
5. Terminal display - used to view local weather impacting the vertiport
6. TAF - displays forecast winds, ceilings and visibility information

User can orient the window location and size, as appropriate. For example, regional weather could be reduced in size and terminal weather (e.g., 1 nmi around vertiport) enlarged.



Note that the TAF button is red. It might be flashing and accompanied by an aural alarm. Upon further review the VM discovers that the latest TAF update contains a forecast wind gust of 23 kts, which exceeds vertiport safety parameters and is key information for planning purposes.

VERTIPORT AUTOMATION SYSTEM

System Performance Dashboard (SPD)

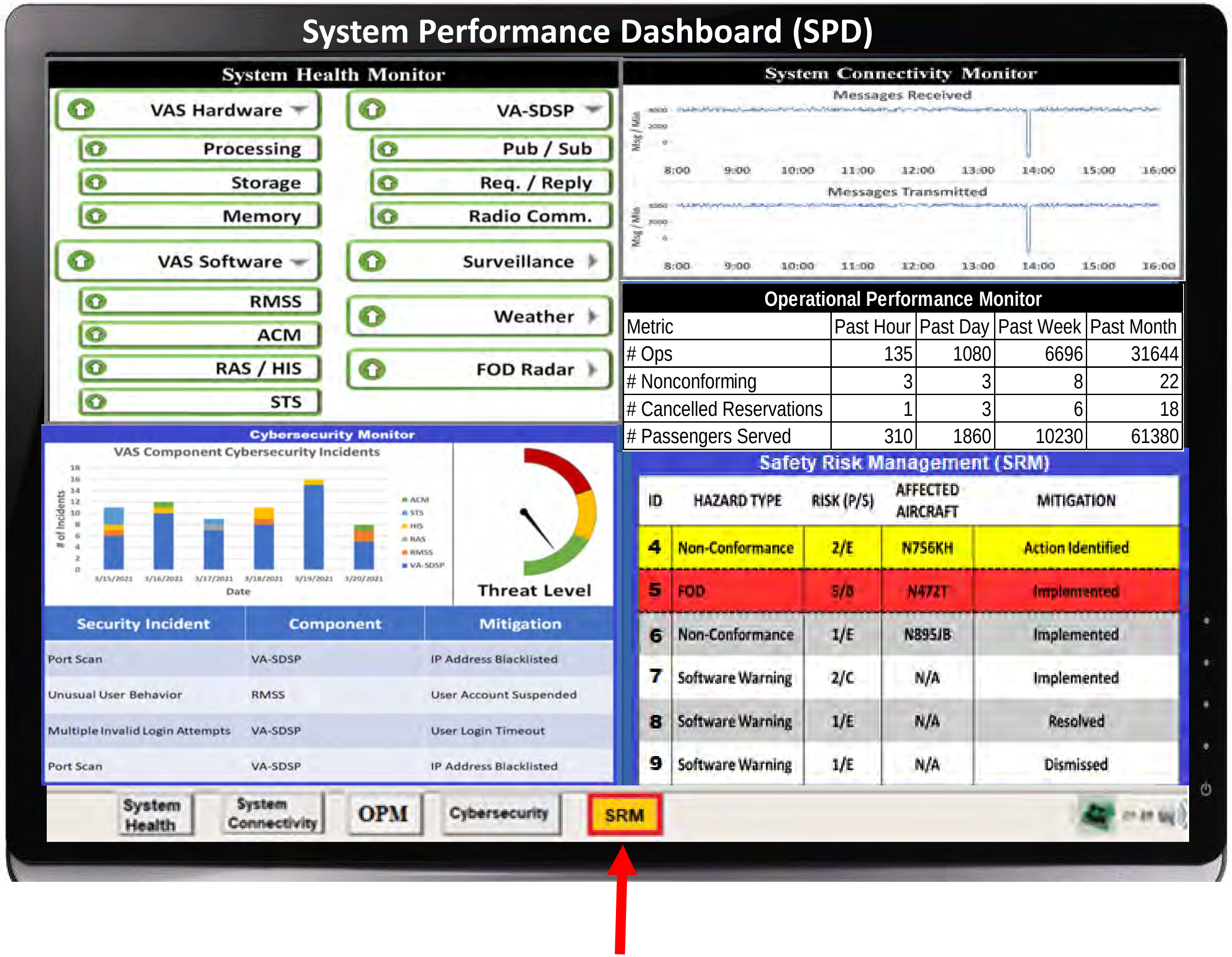
The System Performance Dashboard (SPD) monitors and displays the status of all vertiport hardware, software, surveillance, and communication systems. The SPD will also alert the VM when anomalies or failures are detected. The SPD will utilize standard color-coding to convey system status, where green = good (normal OPs), yellow = caution (anomaly or forecast trend detected), and red = warning (malfunction/offline/failure). The alerting system will provide personnel with a quick overview of VAS system status, and will also use audible alarms to draw the VM's attention when critical events need immediate resolution. Safety Risk Management assessment and mitigation strategies will also be displayed and equipped with SPD alerting functionality.

SPD components include:

A. System Health Monitor – provides status of all hardware, software, surveillance, comm (e.g., GPS integrity)
B. System Connectivity Monitor – provides interconnectivity status between all hardware, software, surveillance, and communication systems
C. Operational Performance Monitor – displays current and recent operational performance metrics (e.g., number of taxiway incursions over the past *t* hours)
D. Cybersecurity Monitor – provides hardware, software, surveillance, comm cybersecurity details
E. Safety Risk Manager (SRM) Monitor – displays current and forecast vertiport hazards and risks, including risk mitigation strategies

This mock-up of a System Performance Dashboard (SPD) contains 4 monitors that display the status of all vertiport hardware, software, surveillance, and communication systems. The SPD will also alert the VM when anomalies or failures are detected, along with SRM mitigation strategies. This SPD includes:

A. System Health Monitor - provides status of all hardware, software, surveillance, comm
B. System Connectivity Monitor - provides interconnectivity status between all hardware, software, surveillance, and communication systems
C. Operation Performance Monitor (OPM) - displays current and recent operational performance metrics
D. Cybersecurity Monitor - provides hardware, software, surveillance, comm cybersecurity details
E. Safety Risk Manager (SRM) Monitor - displays current and forecast vertiport hazards and risks, including risk mitigation strategies



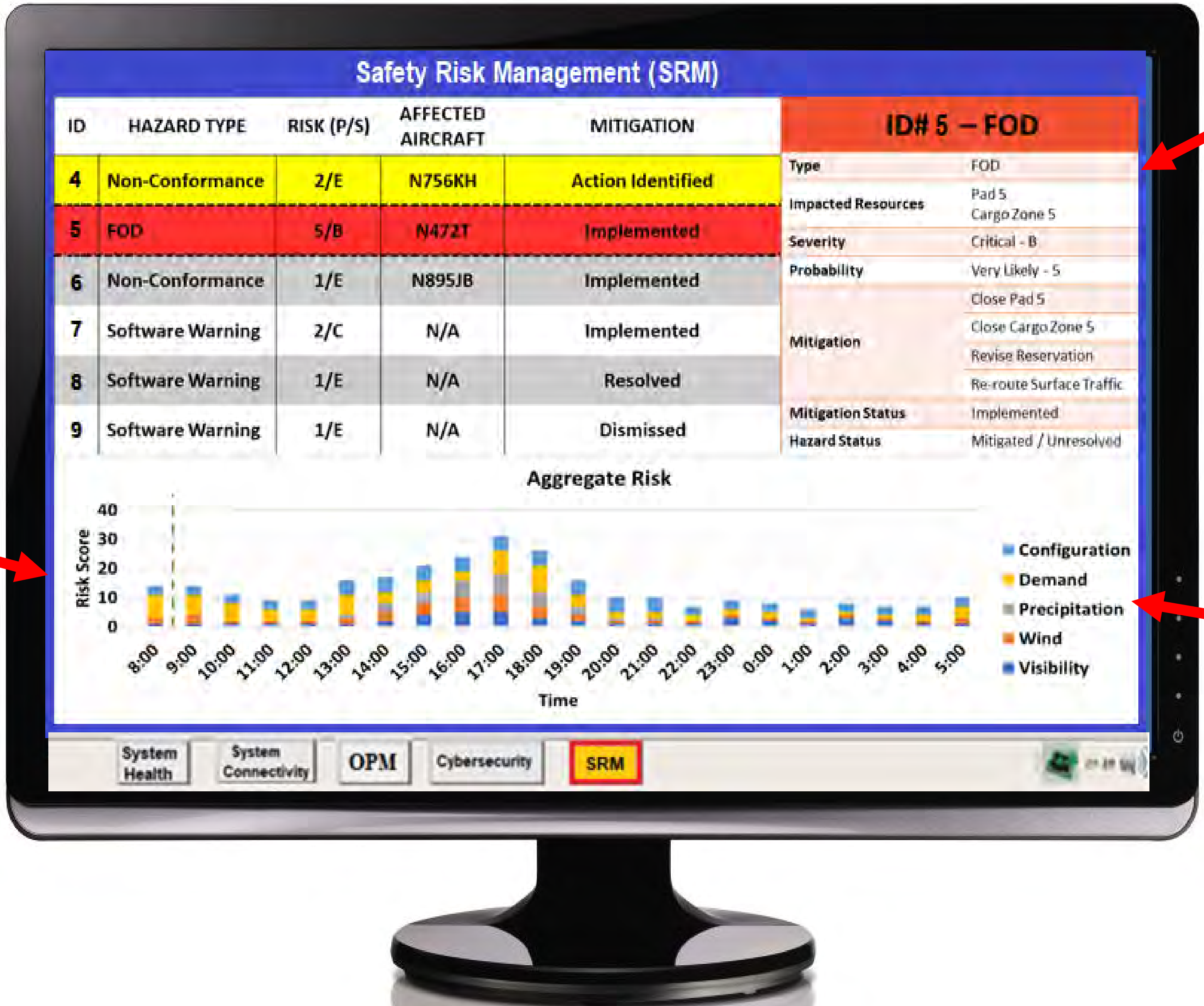
The VM can investigate the Ramp #5 closure issue by selecting the SRM button

VERTIPORT AUTOMATION SYSTEM

Safety Risk Manager (SRM) Monitor

Table showing identified hazards, their associated risks, and status of mitigation actions

Forecasted aggregate risk level for the entire vertiport.



ID	HAZARD TYPE	RISK (P/S)	AFFECTED AIRCRAFT	MITIGATION
4	Non-Conformance	2/E	N756KH	Action Identified
5	FOD	5/B	N472T	Implemented
6	Non-Conformance	1/E	N895JB	Implemented
7	Software Warning	2/C	N/A	Implemented
8	Software Warning	1/E	N/A	Resolved
9	Software Warning	1/E	N/A	Dismissed

ID# 5 – FOD	
Type	FOD
Impacted Resources	Pad 5 Cargo Zone 5
Severity	Critical - B
Probability	Very Likely - 5
Mitigation	Close Pad 5 Close Cargo Zone 5 Revise Reservation Re-route Surface Traffic
Mitigation Status	Implemented
Hazard Status	Mitigated / Unresolved

Drill down window expanding on the details of ID # 5.

The user can select other hazards from the table to view the details of each.

Factors contributing to the forecasted aggregate risk level for the entire vertiport.

NUAIR
MAKING FUTURE SKIES SAFER

VERTIPORT AUTOMATION SYSTEM

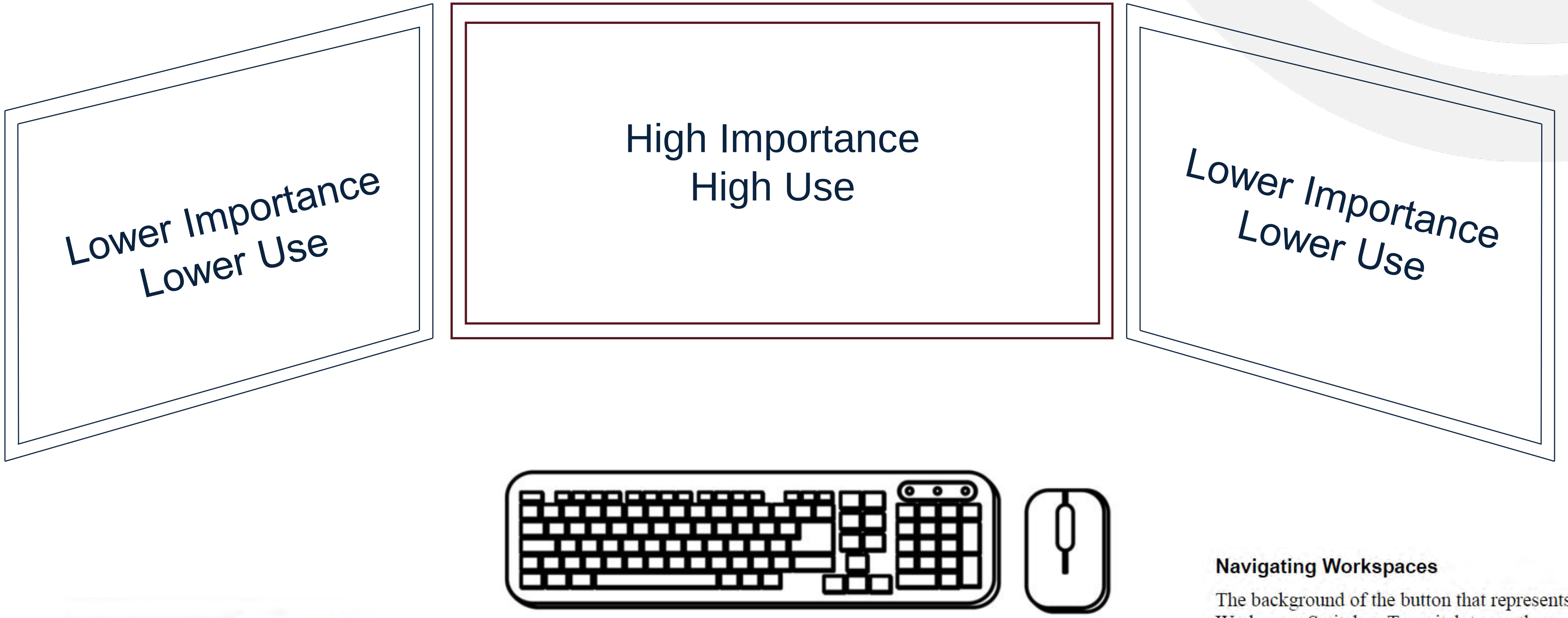
Future Concepts

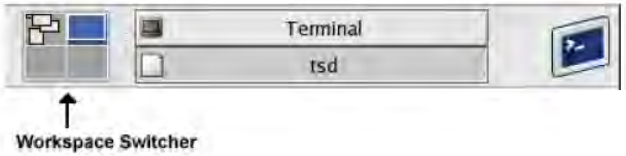
- High levels of automation will be required to reach the proposed UML-4 traffic density
  - Transitions the normal use case from a human-in-the-loop perspective to human-on-the-loop
  - Focus becomes more strategic than tactical

#	Display Name	Description
1	Business Intelligence (BI)	• Business intelligence software to provide insight and analytics into business and operation performance • Aircraft throughput for day, week, month, quarter • Costs and revenue for day, week, month, quarter • Hazard trends (e.g., conformance metrics) • Punctuality trends (on-time departure, on-time arrivals)
2	Adaptive Automation/Graceful Degradation	• The VAS should adapt automation and the role of the user according to available capabilities and extent environmental and system-wide conditions. The automation should keep the user informed of any evolution of capabilities and functions to increase the user's trust in the system. The user should always know why or be able to figure out why the system is behaving as it does.

VERTIPORT AUTOMATION SYSTEM
Workstation Layout

- Layout will likely consist of a suite of monitors, perhaps in a horizontal wrapround configuration with the most important and frequently used components in the center





Navigating Workspaces

The background of the button that represents the current workspace is highlighted in the Workspace Switcher. To switch to another workspace, click on the button that represents the workspace. To return to your original workspace, click on the button that represents that workspace in the workspace switcher.