

# DEVELOPMENT OF A PROTOTYPE VERTIPORT HUMAN AUTOMATION TEAMING TOOLBOX FOR URBAN AIR MOBILITY

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The future airspace system is envisioned to include urban air mobility enabled by new types of electric vertical takeoff and landing aircraft for transporting passengers and cargo quickly and safely. Success will depend, in part, on the design and operation of vertiports, that like airports and heliports, will enable these aircraft to transfer passengers and cargo, land, recharge and takeoff. Human factors need to be considered in these designs with humans in the role of vertiport operators. Requirements for arrival, surface, and departure traffic and the interaction of the human operators with increasingly autonomous aircraft and decision support systems have to be determined. A proof-of-concept simulation with a prototype workstation called the Vertiport-Human Automation Teaming Toolbox, employing arrival scheduling automation, highlights human-system interaction considerations. Needs for further research are identified for improving the understanding of human teaming with machine agents for integrated arrival, surface, and departure management.

The Federal Aviation Administration (FAA) in its Concept of Operations (ConOps) for an information-centric NAS (ICN) presents a vision for the National Airspace System (NAS) circa 2035 that includes Urban Air Mobility (UAM) based on a foundation of operations, supporting infrastructure, and integrated safety management (FAA, 2022a). The National Aeronautics and Space Administration (NASA) in its Sky-for-All vision of the NAS circa 2045 foresees highly automated aircraft operating in dense, complex urban airspace (NASA, 2022, 2023). Success of UAM will depend, in part, on the design and operation of vertiports for enabling quick and safe transport of passengers and cargo.

## **Purpose**

The thesis of this paper is that vertiport operations will rely on the human Vertiport Operator (VO) interacting with human-centered automation for acquiring the traffic data, processing the data for decision support, and displaying the information for enabling safe and efficient operations. Depending on their complexity, high density vertiports may share similarities in the design and operation of today's high tempo heliports and airports with multiple takeoff and landing areas and taxiways for surface movements. This paradigm shift drives the need to understand the information requirements of the VO and the interactions between the VO and vertiport automation to manage high volumes of traffic.

The prototype Vertiport-Human Automation Teaming Toolbox (V-HATT) was developed to assess VO information and performance requirements for vertiport design and operations, test

assumptions, and evaluate off-nominal scenarios (Crown, 2023). V-HATT has been used to study terminal airspace management (Chen et al., 2023).

Vertiports are seen as the bottleneck in future UAM transportation networks, limiting traffic flow throughput and therefore impacting business outcomes. Past studies include addressing route network design, vertiport operational capacity, and vertiport surface topology (e.g., Zelinski, 2020).

### Vertiport Design

A conceptual vertiport automation system from the Northeast Unmanned Aircraft System (UAS) Airspace Integration Research Alliance is shown in Figure 1 (NUAIR, 2021). This figure shows the layout of a vertiport with arrivals on the left (shown in green) with final approach and takeoff (FATO) airspace flowing to touchdown and liftoff areas (TLOFs). On the right is a departure FATO and a missed approach (shown in red). Other vertiport features include parking stands and passenger movement areas.

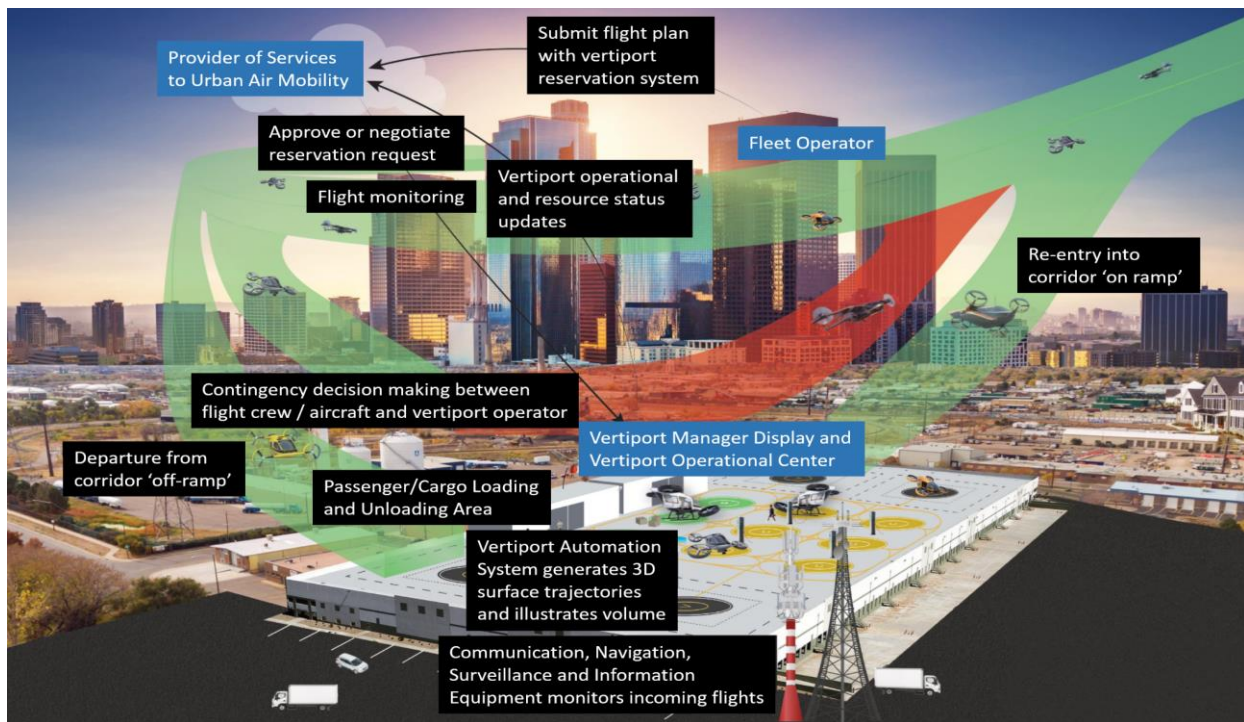


Figure 1. Vertiport and airside operations (NUAIR 2021).

The FAA provides specifications and guidance for vertiport design such as for TLOF and FATO design, VFR approach, and charging/electronic infrastructure (2022b). In addition, industry input on vertiport design included operational integration and safety considerations (Mendonca et al., 2022).

### Technical Approach

The technical approach consisted of a series of steps necessary to understand the envelope of VO responsibilities, information requirements, and human-machine interface (HMI) capabilities.

#### Human-Autonomy Teaming Knowledge Elicitation

Human-Autonomy Teaming (HAT) knowledge elicitation involved identifying operational needs with stakeholders including heliport and airport operators. The operational needs were categorized to

provide context and support insights that were leveraged in subsequent steps to derive user stories and functional capability requirements for V-HATT. Key points included that general understanding, expectations, and assumptions about vertiport throughput exceed the limits posed by practical concerns associated with off-nominal scenarios, and the airspace navigation services expected to be provided by Providers of Services to UAM (PSU) may not be sufficient for complexities such as helicopters and electric vertical takeoff and landing (eVTOL) aircraft arriving unannounced, requesting landing and parking without significant advance pre-coordination.

## **Vertiport Operator User Interface Requirements Development**

The operational needs were used to develop a set of user stories. A user story was in the form of “As a [ ], I would like to [ ] so that [ ]” with mission phase assigned to each use story. For example, “As a Vertiport Operator, I would like to specify and configure the type of schedule (scheduled, on-demand, hybrid) of operations so that I may simulate a specific type of vertiport schedule approach.” The user stories were construed to be an acceptable starting point for further analysis.

The user stories were used to develop a set of V-HATT functional capabilities broken into Pre-Mission, Mission, and Post-Mission phases. Some user stories were based on a single functional capability and other stories on multiple capabilities. Some stories uncovered additional capabilities. The analysis brought forth assumptions about these capabilities including that there are no locations in the terminal airspace where hovering will be required due to energy management concerns, air traffic control or other air navigation manager may provide en route handoff to the VO, and taxiing capabilities involve use of powered ground taxi and hover taxi but not use of tugs.

The Pre-Mission Phase involved the Surface Resource Management Design with surface objects such as the TLOF, FATO, taxiway, and parking stand. V-HATT capabilities include creating different areas on the vertiport surface, adjusting object position and spacing, and assigning aircraft performance attributes. The Arrival and Departure Airspace Design concerned approach and departure fixes, obstructions, approach decision point, and holding pattern. V-HATT capabilities included visualizing the local airspace, ground environment, and weather data. The Operational Parameter Configuration involved settings such as for weather, types and probabilities of off-nominal situations, and the type of vertiport operating model (scheduled, on-demand, or hybrid approach). Pre-Mission is the simulation design.

The Mission Phase involved actions taken by automation or the human VO. Surface Resource Management capabilities included providing clearance to taxi, introducing delay, designating a resource as unavailable, and assigning aircraft to an arrival TLOF or parking stand. Arrival and Departure Management capabilities included actions for scheduling and sequencing, resolving schedule conflicts, and providing situational awareness such as aircraft position on a terminal airspace map and displaying the density of traffic along a current fix or holding pattern. Mission is the simulation execution.

The Post-Mission Phase consisted of a human-in-the-loop simulation for the proof-of-concept with human factors analysis. V-HATT was designed to collect all HMI interactions, data exchanges, and data from the simulation. Measures included instantaneous subjective workload every two to three minutes using a 5-point rating scale, post-scenario measures using NASA Task Load Index for average and peak workload, and activity measures including counts of data inputs using the keyboard or mouse. Post-Mission is the simulation performance and human factors analysis.

## **VO-Automation Workflow**

The V-HATT prototype demonstrated actions and interactions of the VO and vertiport automation, as shown in Figure 2. Automated scheduling algorithms were developed to calculate a

schedule of operations that sufficiently meets the throughput operations as well as pre-specified separation criteria. If there is a conflict in the vertiport, the VO uses the vertiport scheduling service to change the throughput. Throughput is then propagated to the automated arrival scheduling algorithms, which then recalculates a new set of required time of arrivals (RTAs) for all aircraft. The algorithms will then maneuver the aircraft (e.g., speed up, slow down, enter holding pattern) to meet the new set of RTAs.

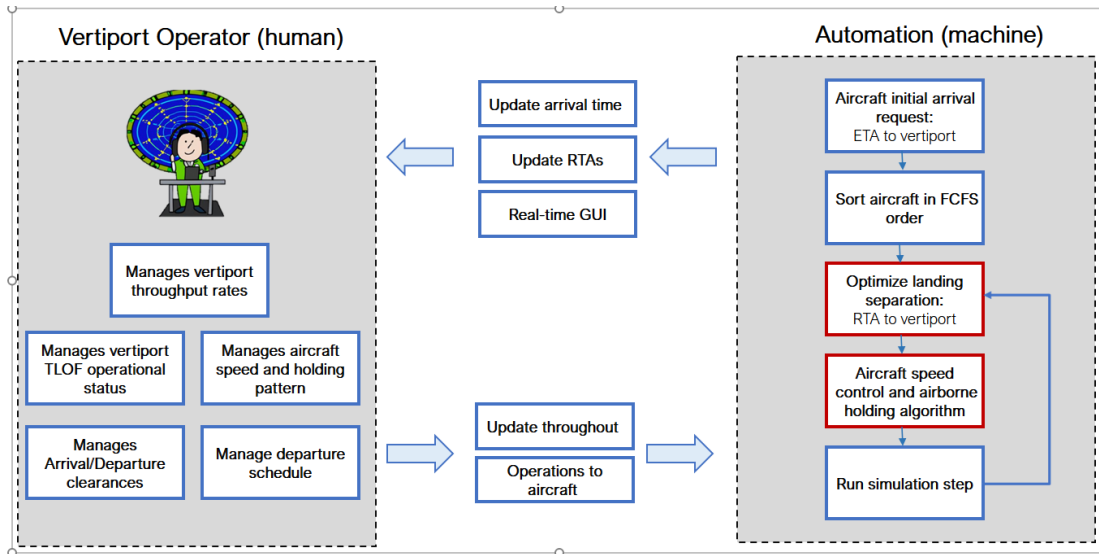


Figure 2. Vertiport VO display design.

On the human operator's side, a set of vertiport display management interfaces was designed for vertiport operators to monitor and direct the aircraft. For example, the VO can change the current vertiport throughput rate, or directly issue maneuvers to the in-air aircraft for safety separation or emergency situations, like leave space for medical helicopter. On the automation side, the centralized system would firstly collect the landing requests from all aircraft, then sort the aircraft in first-come-first-serve order. Then, an optimization method is used to compute the required time of arrival (RTA) to the vertiport, which is based on the current traffic density and vertiport required throughput. After getting the RTA, an aircraft speed control and airborne holding algorithm is used to compute the desired speed and holding time for each aircraft. During the operation, the automation system will keep listening to the vertiport. If the throughput changes, the system could reschedule and issue the new RTAs to aircraft. On the other hand, automation will also keep posting messages like aircraft RTA and actual arrival time to the vertiport, to help human operators make the decision.

### Design of HMI Configurable Interfaces

The display design for the vertiport operator is shown in Figure 3. The top-left area is a Surface Situational Awareness Display showing the locations of TLOFs, parking stands, and real-time locations of aircraft. The top-right area is an airside traffic situational awareness display showing arrivals starting, for purposes of this simulation, three miles out from the vertiport. Traffic was shown against a background of geo-located rings marking operational flow areas. Along the bottom area several arrival and departure flow ribbon displays showed the sequencing and spacing of traffic based on scheduler automation. It was assumed the VO would issue the RTA to the pilot and automation would handle holding and reroutes. The display design was evaluated through a walkthrough of an off-nominal scenario involving closure of an arrival TLOF to assess how the VO would interact with the arrival scheduler automation to re-assign arrivals to another TLOF.

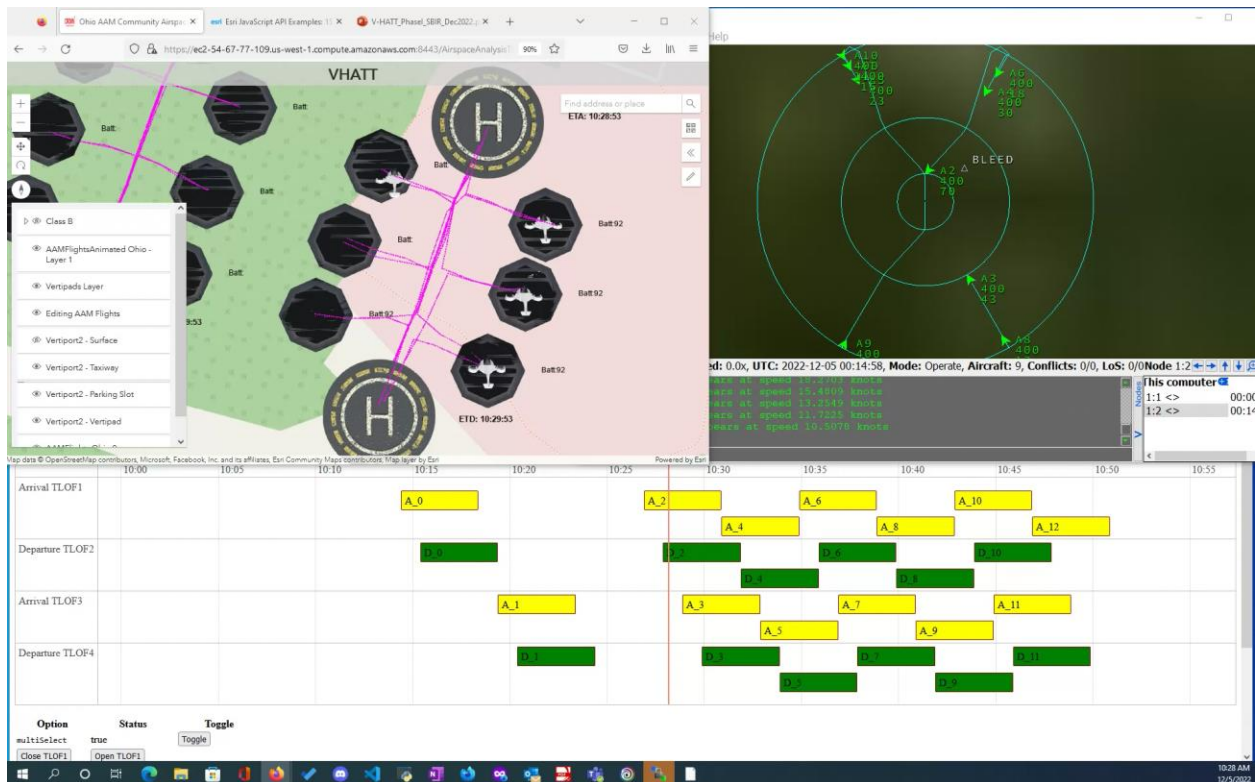


Figure 3. Vertiport VO display design.

## Proof-of-Concept Simulation

The proof-of-concept simulation demonstrated the importance of the teaming of human operator actions with arrival traffic. This teaming would extend to actions with a fully capable prototype that includes surface and departure management. A simulation provides valuable understanding and insight into HMI design based on VO performance and workload data. A post-simulation questionnaire provides information about VO concerns about HMI ease of use and areas for improvement.

## Discussion

Further Vertiport-Human Automation Teaming Toolbox development will explore the relationship of the VO managing vertiport operations by collaborating with automation acting as a machine teaming agent. The human-machine teaming component of proposed toolbox and the simulation capability will be designed to employ various teaming strategies with differing degrees of automation to examine the performance of the teaming relationship. This entails configuring the vertiport to a specific set of circumstances that impact vertiport throughput in a specific manner. For example, a vertiport operator may need to designate a touchdown and liftoff area for helicopter traffic at certain times so all eVTOLs could be redirected to other touchdown and liftoff areas. The operator could load a 'playbook' operation for this that would automatically reconfigure the vertiport for this operation signaling the scheduling services for a different throughput from normal operations (NASA, 2023). Also, the VO or automation could provide the RTA, holding, or reroutes to the pilot or aircraft.

Additional human factors considerations include that the HMI design should follow the FAA Human Factors Design Standard, HF-STD-001B (2016). VO information requirements related to real-time vertiport surface and airside operations could be supported through use of remote cameras including during low visibility conditions. The complexity of HMI parallels changes in the balance between humans



and automation. The design of algorithms and the processes for their use provide a context for potential issues with automation involving "use, misuse, disuse, and abuse" (Parasuraman & Riley, 1997). Issues shaping the use of automation include trust, over-reliance on automation to detect problems, reduced attentiveness to deal with false alarms, and degradation of skills (Smith & Baumann, 2019).

In conclusion, vertiports have a critical role in future visions of UAM. The V-HATT prototype provides a significant tool for designing the HMI for vertiports of different sizes and operational complexity. Further development will integrate arrival, surface, and departure capabilities.

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### **References**

- Chen, S., Wei, P., Krois, P., Block, J., Cobb, P., Chatterji, G., & Kurian, C. (2023). Arrival Management for High-density Vertiport and Terminal Airspace Operations. Air Traffic Control Association Technical Symposium.
- Crown Consulting. (2023). Vertiport Human Automation Teaming Toolbox (V-HATT) Phase I Final Report. Alexandria, VA.
- Northeast UAS Airspace Integration Research Alliance, Inc. (2021). High-Density Automated Vertiport Concept of Operations. Rome, NY.
- Federal Aviation Administration. (2016). Human Factors Design Standard HF-STD-001B. Washington, DC: FAA.
- Federal Aviation Administration (2022a). Charting Aviation's Future: Operations in an Info-Centric National Airspace System. Washington, DC: FAA.
- Federal Aviation Administration. (2022b). Engineering Brief No 105, Vertiport Design. Washington, DC.
- Mendonca, N., Murphy, J., Patterson, J., Alexander, R., Juarez, G., & Harper, C. (2022). Advanced Air Mobility Vertiport Considerations: A List and Overview. AIAA Aviation Forum.
- National Aeronautics and Space Administration. (2022). Sky for All Portal. <https://nari.arc.nasa.gov/skyforall/>
- National Aeronautics and Space Administration. (2023). NASA is Creating an Advanced Air Mobility Playbook. <https://www.nasa.gov/feature/nasa-is-creating-an-advanced-air-mobility-playbook>
- Parasuraman, R., & Riley, V. (1997). Humans and automation: Use, misuse, disuse, abuse. *Human Factors*, 39, 230-253.
- Smith, P.J. & Baumann, E. (2020). Human-automation teaming: Unintended consequences of automation on user performance. Proceedings of the 2020 Digital Avionics Systems Conference (DASC).
- Zelinski, S. (2020). Operational Analysis of Vertiport Surface Topology. Proceedings of the 2020 Digital Avionics Systems Conference (DASC).