# m:N Operations
# High Complexity Simulation

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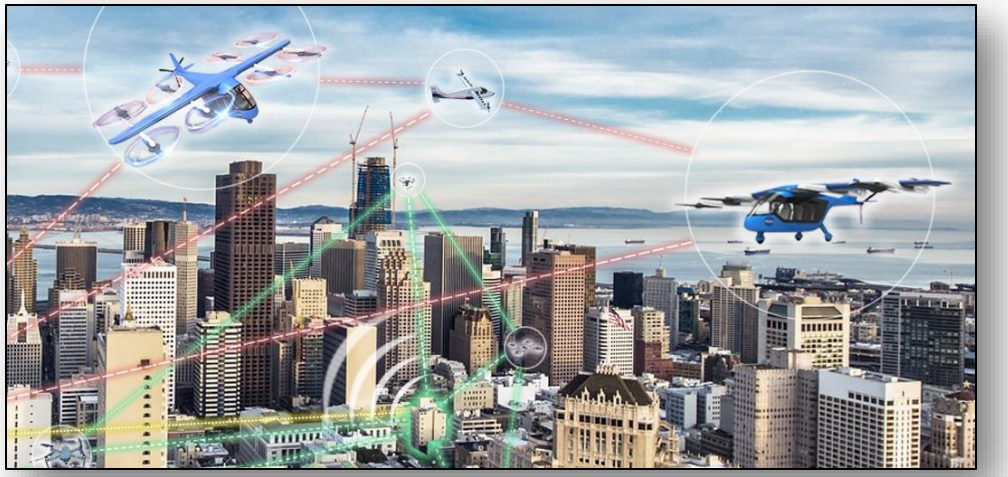
# Transformational Tools and Technologies

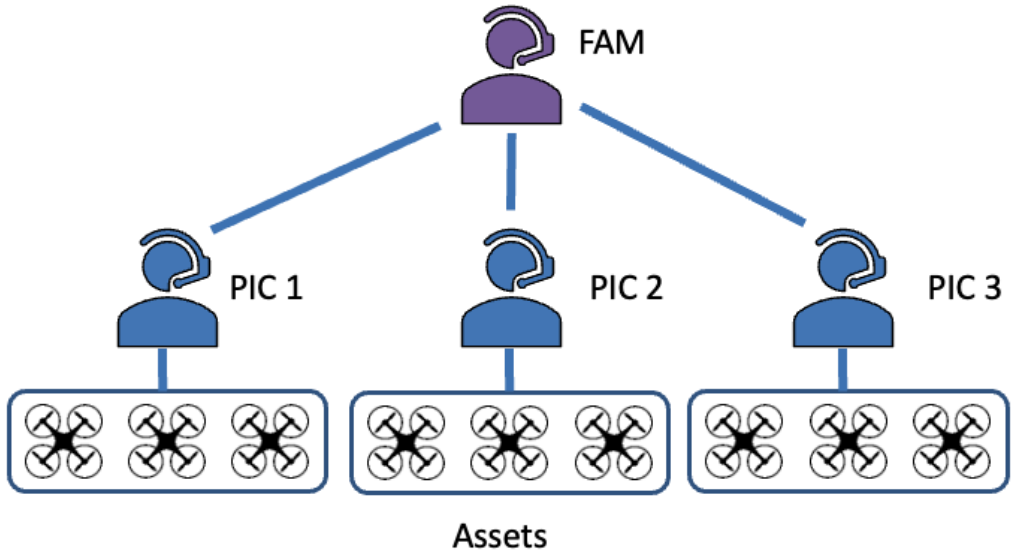
## NASA's T³ Project

- This work is conducted as part of the Revolutionary Aviation Mobility (RAM) subproject of NASA's ***Transformation Tools and Technologies*** **(T³)** project



## m:N Human-Autonomy Teaming (HAT) Activity

- Conducts ***human-in-the-loop (HITL) simulation research*** for NASA Ames
- Focus on how ***human performance can be augmented*** by increasingly autonomous systems
- Create a relationship between human and system that ***is inspired by a teammate relationship***
- ***Goal:*** test and enhance the safety and efficiency for novel, proposed operations in the National Airspace System



# High Complexity Sim Objective

**Objective:** Investigate the effects of **system-level operational disruptions** on **multi-Operator (i.e., UAM company) m:N vehicle management** and the resulting **impact(s) on system resilience**.

**Scope/Approach:** HITL simulation of **multiple UAM Operators**, each with multiple Ground Control Station Operators (GCSOs), in a hypothetical **vertiport network in Denver, CO**. Operational disruptions will at one or more vertiports will be introduced mid-scenario. Local and system-wide **capacity** (throughput), **efficiency** (delays, filed-vs-flown flight time), and **resilience** (recovery time) will be measured.

**Impact/Goal:** Characterization of the effects of system-level capacity disruptions on m:N UAM operations. Results of the experiment will provide insight into potential cascading effects of disruptions, system recovery times, emergent behaviors, and impacts to human performance.

# BACKGROUND

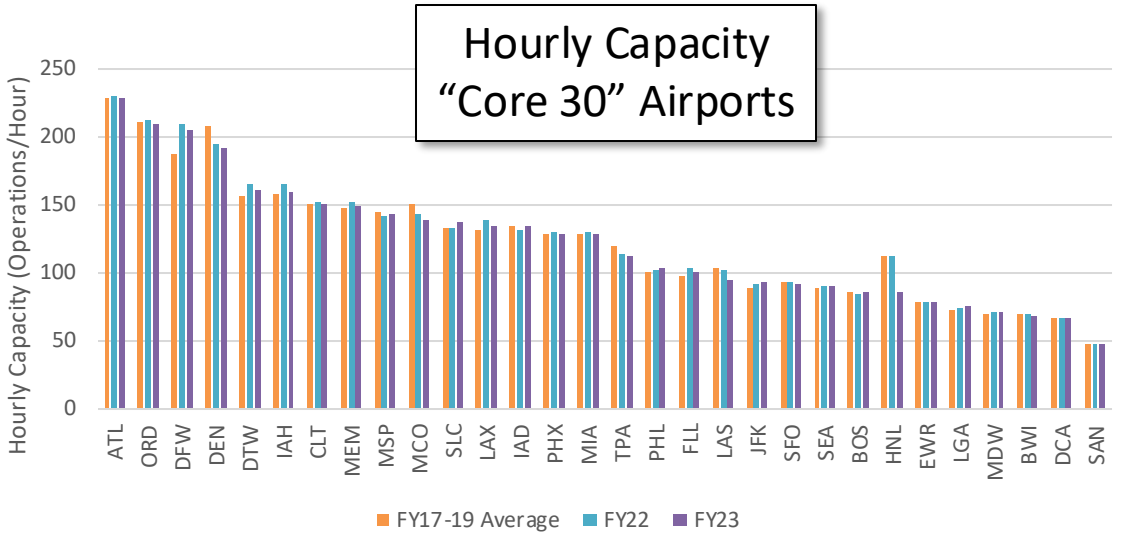
# Background: Capacity

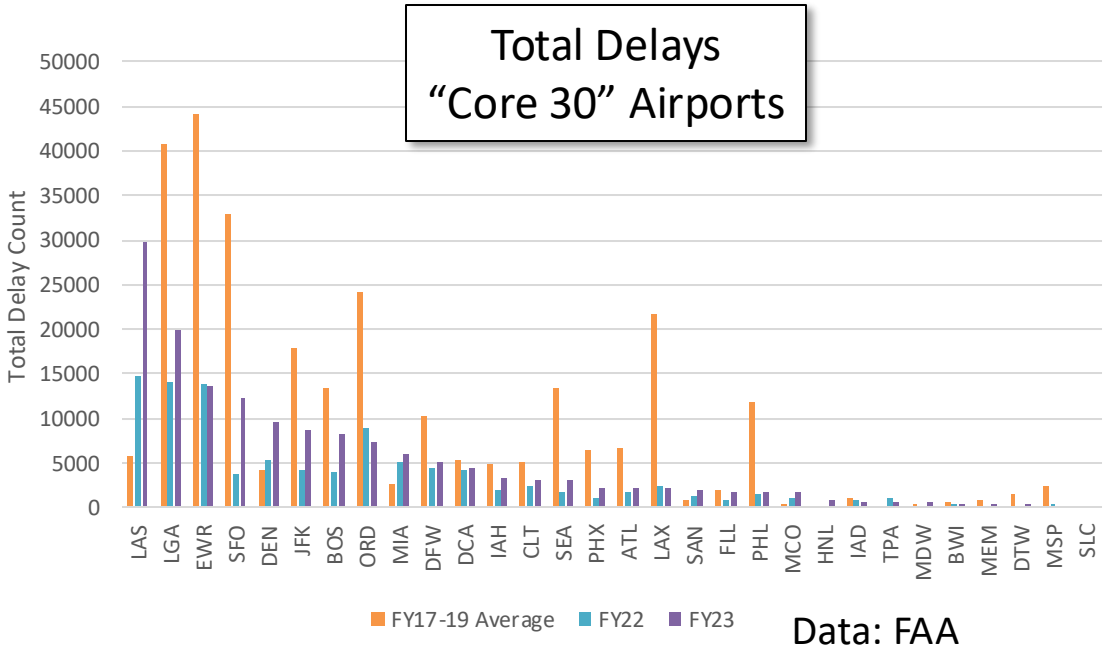
## Defining System Capacity

- **Throughput model** of capacity
  - *Maximum number of aircraft operations which can be accommodated at the airfield per unit time*
- AC 150/5060-5: Airport Capacity and Delay
  - Provides methods for calculating **hourly capacity** and **annual service volume**
- ACRP Report 79: Evaluating Airfield Capacity
  - Provides methods for calculating **maximum sustainable throughput** and **practical service volume**

## Systemwide Operational Metrics

- FAA Modernization and Reform Act of 2012, Section 214 "harmonized" measurement of the US aviation system in terms of:
  - Safety
  - *Efficiency*
  - *Capacity*
  - Environment
  - *Cost Effectiveness*




Data: FAA

# Background: Complexity

- Scalability and complexity: **how many aircraft can a person manage**?
  - Human cognitive limitations - at most direct control of 4 vehicles (Cummings, 2008)
  - Air Traffic Control: Performance degrades beyond 12 (Endsley & Rogers, 1996; Galsteret al., 2001)

- Complex **decision making**
  - Humans tend to consider **complex tradeoffs** sequentially (Hastie, 2010)
  - Multiple end goals and paths to achieve them
  - Consideration of branches of a decision tree one at a time

- Critical factor for m:N: **Situational Awareness**
  - Frequent attention switching
  - **Slower and more error-prone** after **task switching** (Monsell, 2003; Rubinstein et al., 2001)

- Subjective **workload sensitive to increasing N**
  - Higher N, higher workload ratings (Cummings et al., 2014; Galster et al., 2001)
  - **Excessive workload** leads to substantial **degradation in performance** (Sadler et al., 2023)

# HAT Lab m:N Research To-Date


- Part-Task Simulations
- Mostly 1:N
- Single Operator (i.e., Single Company)
  - Occasionally with background traffic
- Focus on one feature (e.g., handoffs, comms, plays) at a time

## What happens when you start combining/increasing these pieces? What works well together and what doesn't?


- Part-Task Simulations
- Mostly 1:N
- Single Operator (i.e., Single Company)
  - Occasionally with background traffic
- Focus on one feature (e.g., handoffs, comms, plays) at a time

# Community-Informed HITL Approach

- HITLs are designed **in collaboration with industry partners**
  - Partners: Wisk, Joby (emeritus), Zipline (emeritus)
  - Partner approach provides external validity and greater realism to simulations
  - Results shared with “the community” and made publicly available

- HAT m:N Activity engages closely with the **Multi-Vehicle m:N Working Group**
  - Take in research needs from the community
  - Brief progress and results of experiments

Partnerships

Working Group

# HIGH COMPLEXITY SIM EXPERIMENT DESIGN

# Objectives and Research Questions

## Objectives

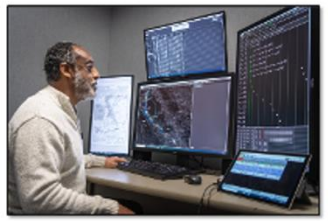
- To characterize vertiport and operational resilience with multiple operators experiencing disruptions of varying scale
- Discover emergent behaviors from simulating two UAM Operators
- Feedback on utility of UIs and tools

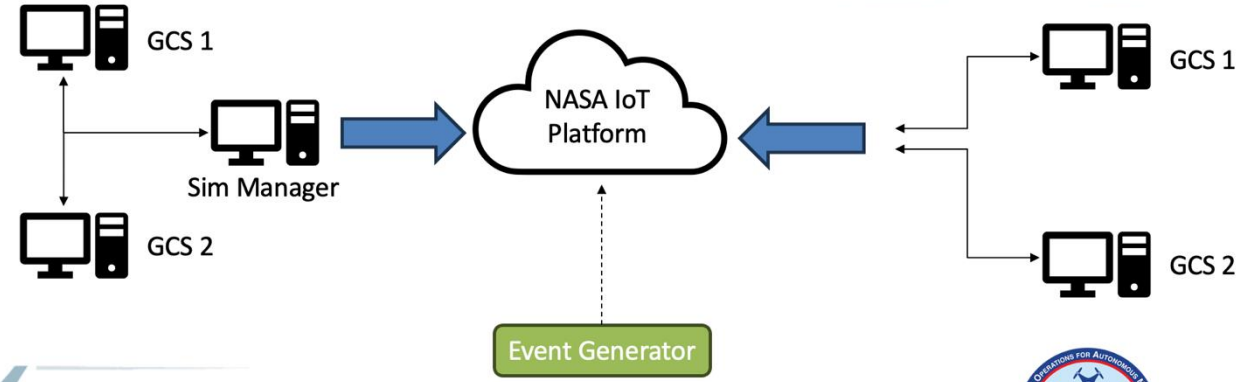
## Research Questions

- What are the systems-level impacts of disruptions to UAM operations?
  - What effect does UAM operator response to the disruption have on the system?
    - How is coordination between Operators affected?
    - Are different UAM operators affected evenly or differentially?
  - Does a corridor assumption affect the magnitude of the impact?
  - How long is the recovery period to return operations at the nominal rate?
- What are the effects of disruptions on human performance operating m:N?
  - Situation Awareness
  - Workload
  - Stress
  - Response Times

# Experimental Design

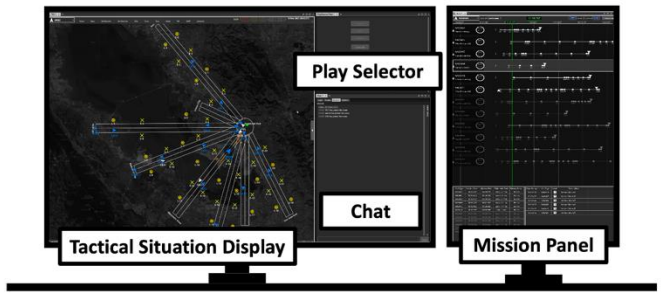
- Independent Variables (3 x 2 x 2 mixed subjects)
  - System Disruption – 3 levels, within-subjects
    - Low: 1 vertiports affected
    - Med: 2 vertiports affected*
    - High: 3+ vertiports affected
  - m:N Ratio – 2 levels, within-subjects
    - 2:6
    - 2:12
  - Corridor Assumption – 2 levels, between-subjects
    - With UAM corridors
    - Without UAM corridors
- Blocked by m:N Ratio
- Subjects
  - Part 135 & Part 107 rated
  - 10 total (2 pre-test + 8 data collection)
- 45-Minute Scenario Duration



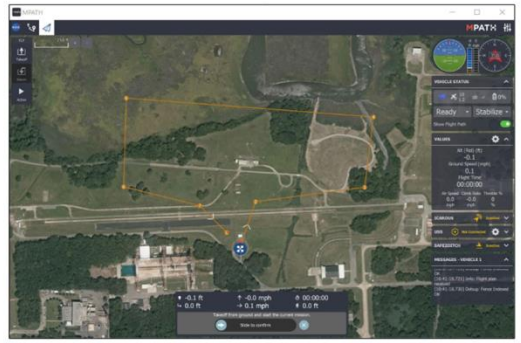



HAT Lab – Ames Research Center

ROAM Lab – Langley Research Center




Vigilant Spirit Control Station



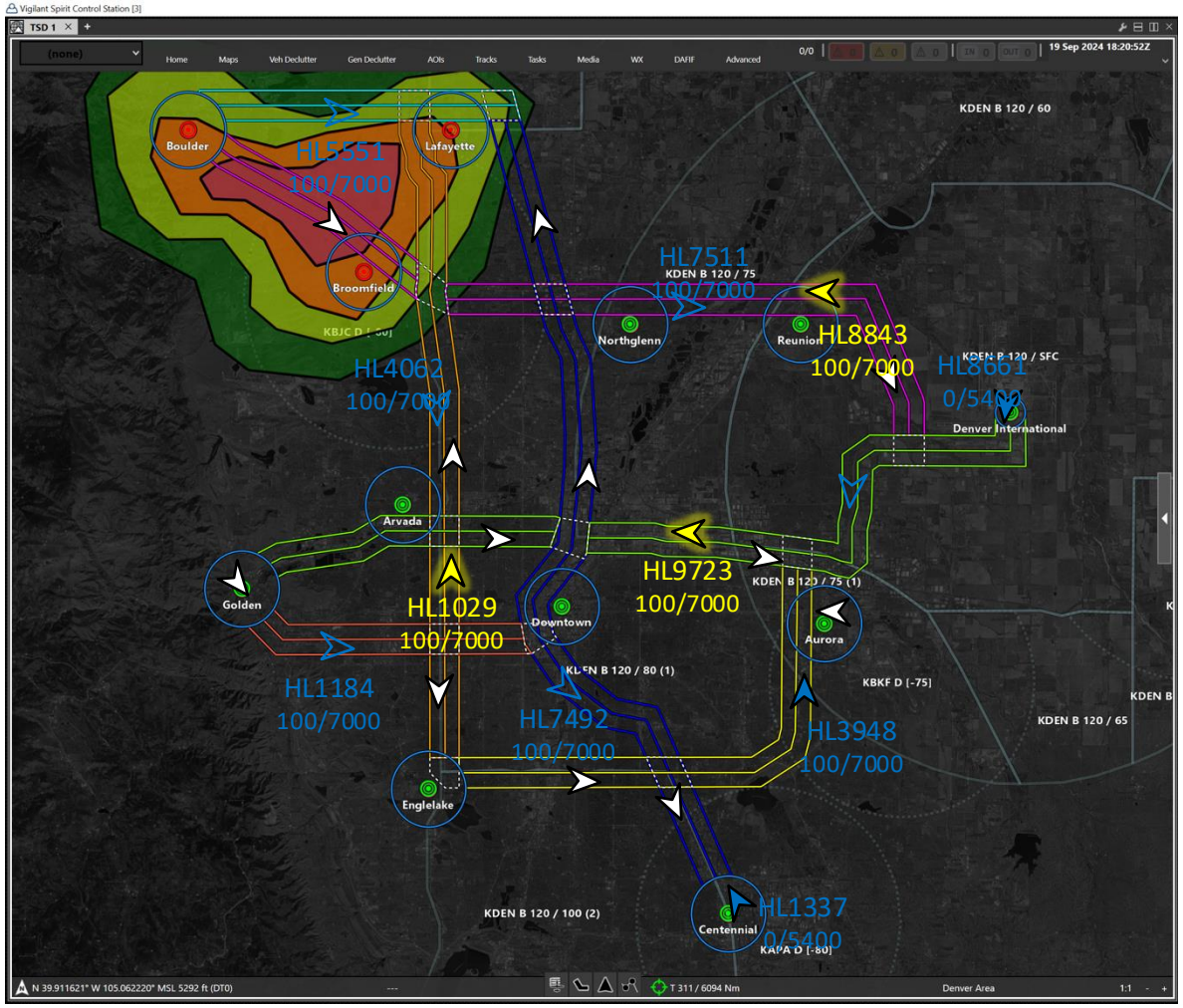
MPATH

* subject to change

# Potential Vertiport Disruptions

Scenario Source Document: [High Density Automated Vertiport Concept of Operations]

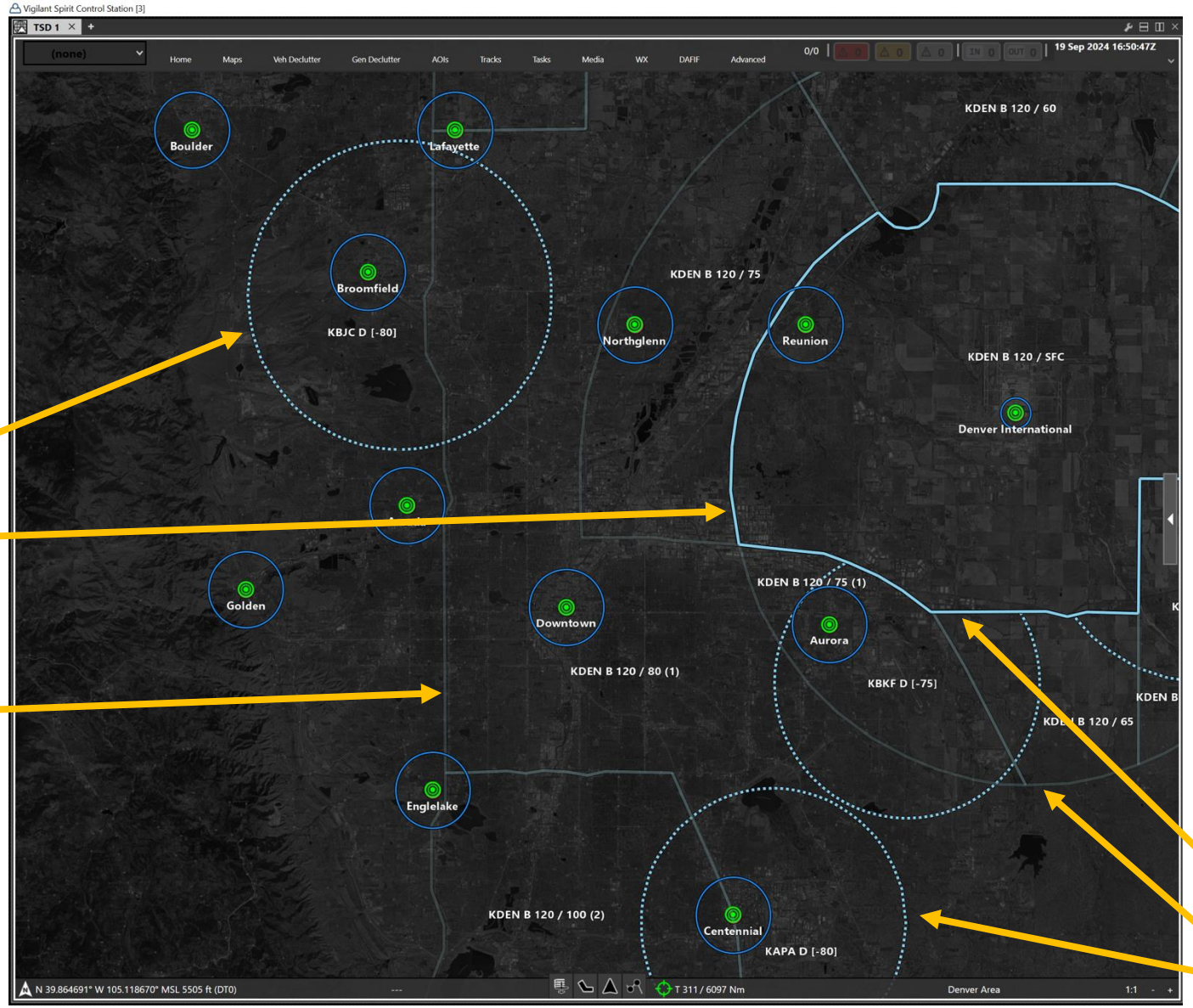
- Low System Disruption (1 vertiport)
  - Partial Vertiport Closure (Scenario 5.2.1.5)
    - Landing pad unavailable due to disabled aircraft affecting single vertiport
- Medium System Disruption (2 vertiports)*
  - Vertiport Infrastructure Failure (Scenario 5.2.1.3)
    - Degraded GPS environment affecting multiple vertiports
- High System Disruption (3+ vertiports)
  - Worsening Weather (Scenario 5.2.1.1)
    - Thunderstorm causes temporary closure if multiple vertiports




* subject to change

# Simplified Airspace – Non-Corridors

| Legend | |
|---|---|
| | Class B airspace |
| | Class D airspace |
| | Vertiport Operations Area |
| | Vertiport |




| Vertiports |
|---|
| Arvada |
| Aurora |
| Boulder |
| Broomfield |
| Centennial |
| Denver Int’l |
| Downtown |
| Englelake |
| Lafayette |
| Northglenn |
| Reunion |

Bright Outline:
Common-Altitude Boundaries

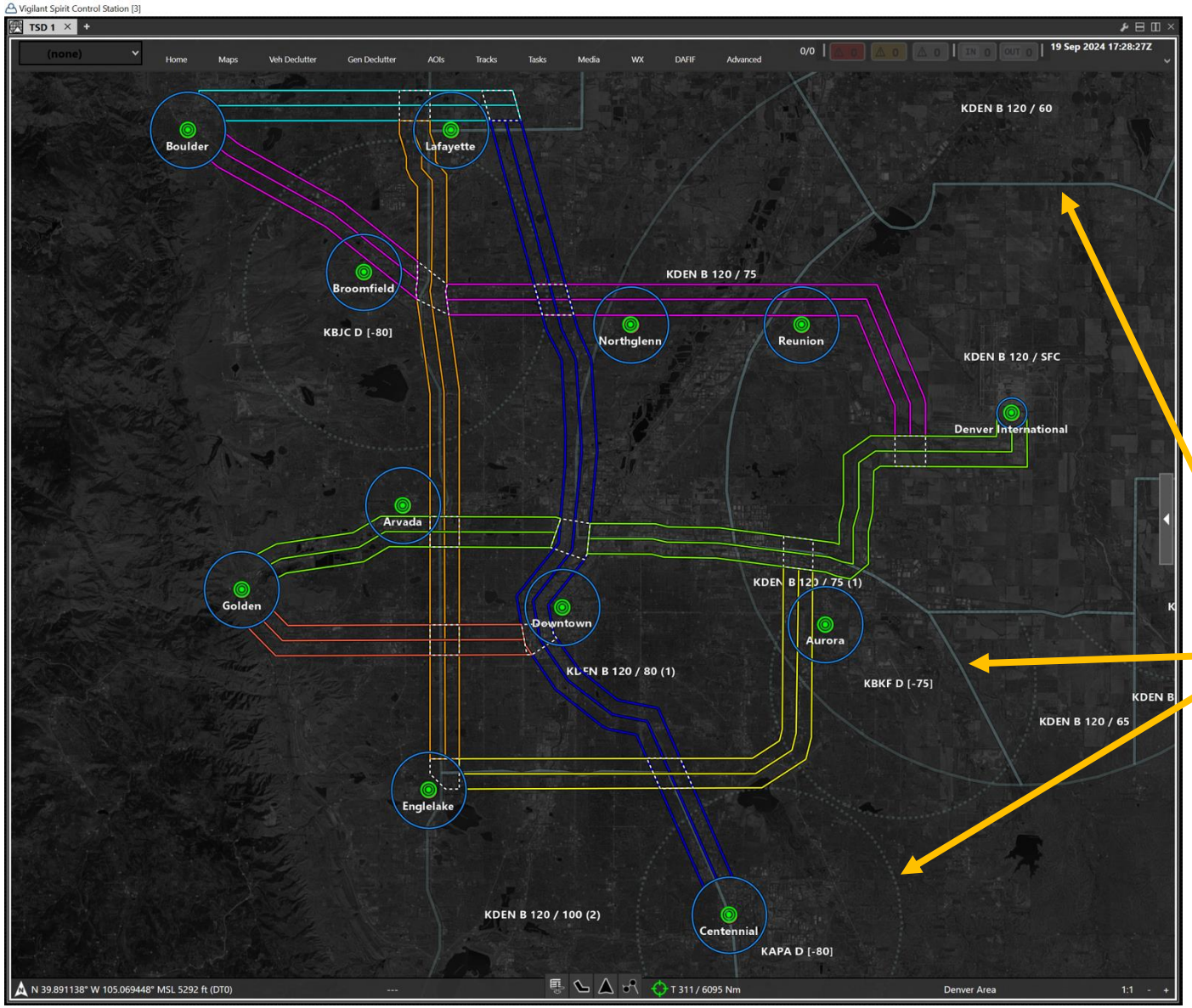
Dim Outline:
Above Operation Altitude

Airspace Boundaries

# Simplified Airspace – UAM Corridors

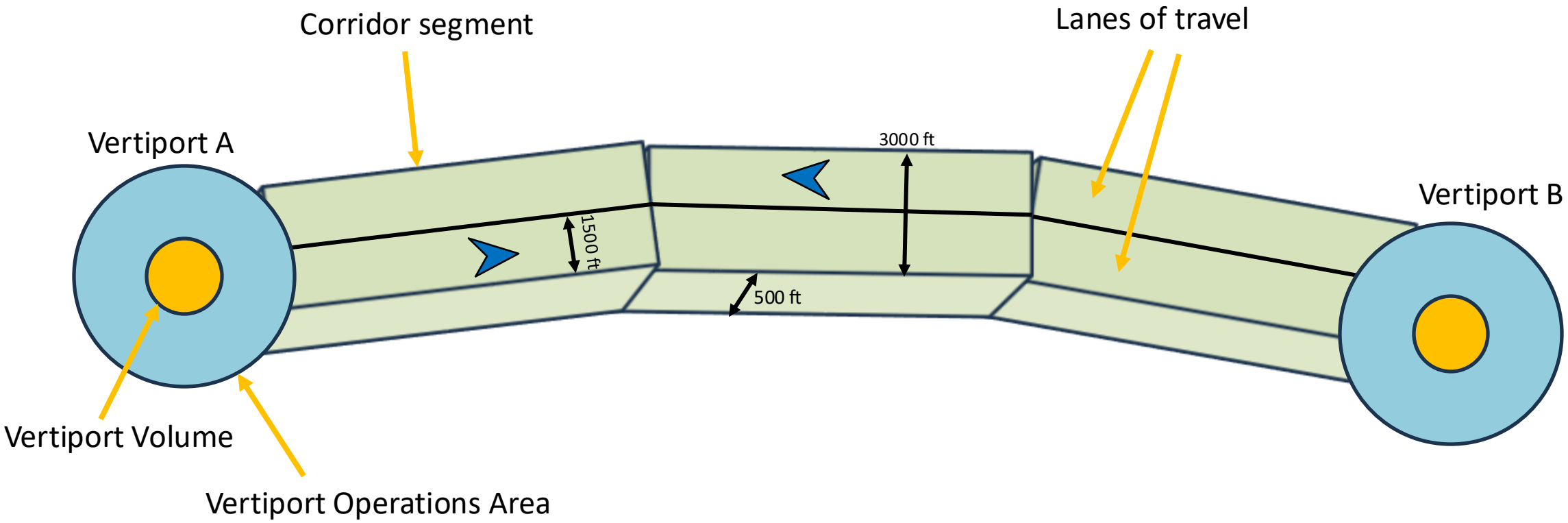
| Legend | |
|---|---|
| | Class B/D airspace |
| | UAM Corridor |
| | Corridor Intersection |
| | Vertiport Operations Area |
| | Vertiport |

| UAM Corridors |
|---|
| Arapahoe |
| Cheyenne |
| Lakeview |
| Red Rock |
| University |
| Valley |
| Voyager |




Airspace Boundaries (for reference/SA)

# Corridor Dimensions



# METRICS AND ANALYSIS

# Metrics

- Demographics
- System Performance
  - System efficiency
    - Sum of total arrivals and departures per time
  - Overall Mission Cost
    - Relative increase or decrease in cost of all operations
- Operator Performance
  - Operator efficiency
    - Sum of operator's arrivals and departures per time
  - Mission Cost
    - Relative increase or decrease in cost to individual operators
- Human Performance
  - Workload
  - Situation Awareness
  - Stress
  - Gaze Fixations
  - Service Times
  - Response Times
- Queuing Metrics
  - Task waiting times
  - Number of tasks waiting for completion
- Post-Simulation Debriefing Interview

# Data Analysis

- Descriptive Statistics
  - Overall
  - By Scenario/Condition
  - By Demographic
- Qualitative Analyses
  - Thematic Interview Analysis
  - Emergent Behaviors

# Timeline

- Experimental design: May 7, 2024
- Development (software, scenarios, study materials, admin): June 2024 – March 2025
- Data Collection: April – May 2025
- Results Dissemination: September 2025

- Deliverables
  - TTT Project Outbrief (September 2025)
  - m:N Working Group Brief (Fall 2025 F2F)
  - Conference Proceedings Paper (Fall 2025)

# Thank You

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# BACK UP

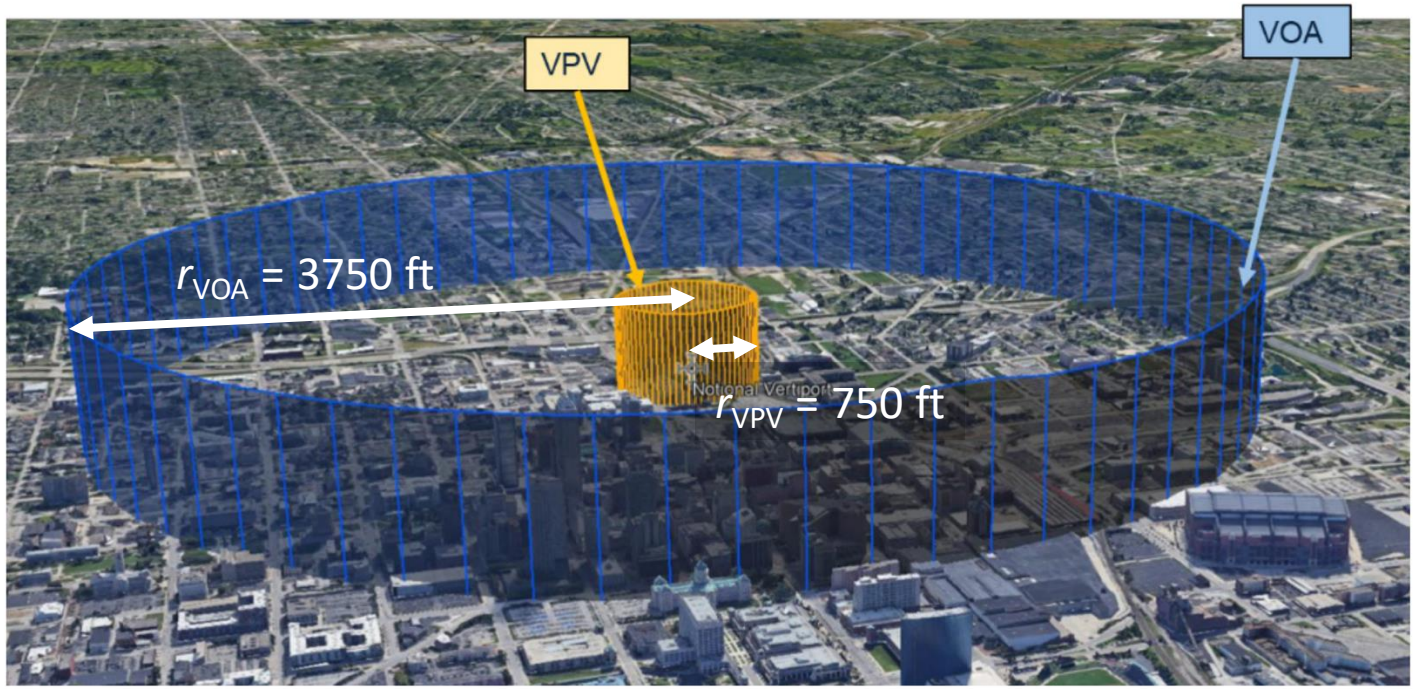
# Vertiport Design

## Vertiport Operations Area (VOA)

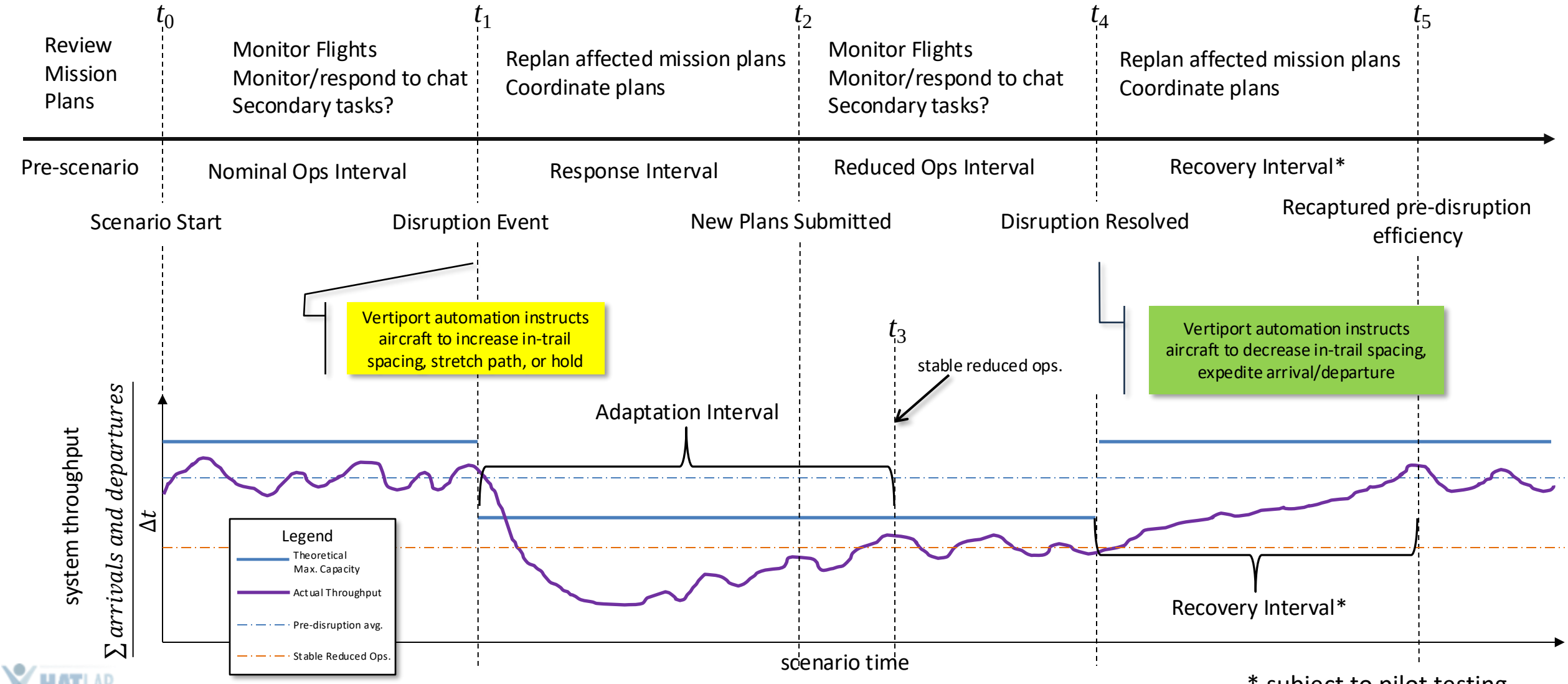
- The VOA is the outermost volume surrounding an individual vertiport or several vertiports in which flight operations much be coordinated with a PSU.

## Vertiport Volume (VPV)

- The VPV is the innermost volume surrounding an individual vertiport that is managed by that vertiport and within which fleet operators must coordinate with the vertiport operator.



## Notional scenario progression




* subject to pilot testing

# Tentative Training and Test Schedule

| Training Day | | | | Testing Day | | | |
|---|---|---|---|---|---|---|---|
| **Time PDT** | **Time EDT** | **Activity** | | **Time PDT** | **Time EDT** | **Activity** | |
| 0800 | 1100 | Arrival & Introductions | | 0700 | 1000 | Arrival | |
| 0805 | 1105 | Consent and Demographics | | 0705 | 1005 | Study & Task Review | |
| 0815 | 1115 | Study Overview | | 0730 | 1030 | Refamiliarization Practice | In Coordination With ROAM Lab |
| 0845 | 1145 | VSCS Training Presentation | | 0815 | 1115 | Data Collection Trial #1 | |
| 0915 | 1215 | VSCS Hands-On Training | | 0900 | 1200 | PT Questionnaires | |
| 0945 | 1245 | Task Overview | | 0915 | 1215 | Data Collection Trial #2 | |
| 1015 | 1315 | Hands-On Task Training | | 1000 | 1300 | PT Questionnaires | |
| 1100 | 1400 | LUNCH BREAK | | 1015 | 1315 | Data Collection Trial #3 | |
| 1200 | 1500 | Practice Scenario #1 | In Coordination With ROAM Lab | 1100 | 1400 | PT + PB Questionnaires | |
| 1245 | 1545 | Practice #1 Q&A | | 1115 | 1415 | LUNCH BREAK | |
| 1300 | 1600 | Practice Scenario #2 | | 1215 | 1515 | Data Collection Trial #4 | In Coordination With ROAM Lab |
| 1345 | 1645 | Practice #2 Q&A | | 1300 | 1600 | PT Questionnaires | |
| 1400 | 1700 | Equipment & Questionnaire Familiarization | | 1315 | 1615 | Data Collection Trial #5 | |
| 1500 | 1800 | Practice Scenario #3 (w/ physio) | | 1400 | 1700 | PT Questionnaires | |
| 1530 | 1830 | Training Debrief | | 1415 | 1715 | Data Collection Trial #6 | |
| 1600 | 1900 | END | | 1500 | 1800 | PT + PB + PS Questionnaires | |
| | | | | 1530 | 1835 | Experiment Debrief Interview | |

**Legend**
PT = Post-Trial
PB = Post-Block
PS = Post-Sim

# Tentative Test Schedule

## April 2025

| Sunday | Monday | Tuesday | Wednesday | Thursday | Friday | Saturday |
|---|---|---|---|---|---|---|
| | | 1 | 2 | 3 | 4 | 5 |
| 6 | 7 | 8 | 9 | 10 | 11 | 12 |
| 13 | 14 | 15 | 16 | 17 | 18 | 19 |
| 20 | 21 | 22 | 23 | 24 | 25 | 26 |
| 27 | 28 | 29 | 30 | | | |

## May 2025

| Sunday | Monday | Tuesday | Wednesday | Thursday | Friday | Saturday |
|---|---|---|---|---|---|---|
| | | | | 1 | 2 | 3 |
| 4 | 5 | 6 | 7 | 8 | 9 | 10 |
| 11 | 12 | 13 | 14 | 15 | 16 | 17 |
| 18 | 19 | 20 | 21 | 22 | 23 | 24 |
| 25 | 26 | 27 | 28 | 29 | 30 | 31 |

With Corridors | Pre-Test | Modifications | Test | Training Day