Federal Aviation Administration

Advanced Air Mobility Initial Services Assessment of eVTOL Aircraft Operations Los Angeles International Airport (LAX)

FINAL REPORT

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Acronyms

Acronym	Definition
AAM	Advanced Air Mobility
ATC	Air Traffic Control
ATCT	Airport Traffic Control Tower
CONRAC	Consolidated Rent-A-Car Facility
CTA3	Central Terminal Area 3
CTA7	Central Terminal Area 7
eVTOL	Electric Vertical Takeoff and Land
FAA	Federal Aviation Administration
FPA	Flight Path Angle
GPS	Global Positioning System
HC	Helicopter Control/Class B Control Position
HITL	Human-in-the-Loop
KHHR	Hawthorne Municipal Airport
KLAX	Los Angeles International Airport
LC1	Local Control 1 Position
LC2	Local Control 2 Position
LOA	Letter of Agreement
M&S	Modeling & Simulation
MMAC	Mike Monroney Aeromedical Center
MSL	Mean Sea Level
NAS	National Airspace System
NASA	National Aeronautics and Space Administration
NIEC	NAS Integration and Emerging Capabilities
OEM	Original Equipment Manufacturer
RA	Resolution Advisory
RTDW	Remote Tower Display Workstation
RVLT	Revolutionary Vertical Lift Technology
SCT	Southern California TRACON
SGNTR	Signature Fixed Based Operator
STARS	Standard Terminal Automation Replacement System
TA	Traffic Alert

TCAS	Traffic Collision and Avoidance System
TGF	Target Generation Facility
TLOF	Touchdown and Liftoff
TRACON	Terminal Radar Approach Control
VFR	Visual Flight Rules
VMC	Visual Meteorological Conditions
WJHTC	William J. Hugest Technical Center for Advanced Aerospace

Executive summary

This report presents observations and insights related to an Advanced Air Mobility (AAM) operational evaluation focused on airspace integration and vertiport viability for Los Angeles International Airport (KLAX). The research team aligned its efforts with the Federal Aviation Administration's (FAA) AAM integration initiative and conducted a series of Human-In-The-Loop (HITL) simulations at the FAA William J. Hughes Technical Center for Advanced Aerospace (WJHTC) on October 15–17, 2024, and April 1–3, 2025. The purpose of this research was to mature the AAM concepts of use at KLAX. The study applied an iterative process that combined fast-time modeling and high-fidelity HITL simulations to evaluate initial operational and safety concerns. The methodology consisted of two consecutive operational research blocks, with findings from Block 1 directly informing the research requirements for Block 2.

The simulations provided valuable insights from Air Traffic Control (ATC) experts and other stakeholders regarding the development of air traffic scenarios for KLAX. The primary objective involved evaluating potential vertiport locations to support electric Vertical Take-Off and Landing (eVTOL) aircraft operations. The research team incorporated currently certified Air Traffic Control Specialists (ATCS) assigned to the KLAX Airport Traffic Control Tower (ATCT) to ensure operational realism and accuracy.

The simulations identified several operational concerns, including ATCS and eVTOL pilot workload, procedure development needs, communication requirements, aircraft and wake separation standards, and a clearer understanding of capacity and throughput for eVTOL visual flight rules (VFR) operations at KLAX. The findings from this series of HITLs indicated that the two vertiport locations situated at the fixed-base operators (FBOs) on the south side of the airfield represent options for vertiport placement, provided that robust procedures are developed and coordination with the Hawthorne Municipal Airport (KHHR) ATCT occurs before implementation.

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1 Introduction

Advanced Air Mobility (AAM) is a transportation system that moves people and property between two points using aircraft equipped with advanced technologies, including electric aircraft and electric vertical takeoff and landing (eVTOL) aircraft, in both controlled and uncontrolled airspace. The Federal Aviation Administration (FAA) works with government and industry stakeholders to develop an AAM ecosystem that supports the safe and efficient integration of AAM into the National Airspace System (NAS). The work presented here focuses on near-term implementations that involve piloted operations.

Individual certified AAM operator initial entry-into-service (EIS) activities serve as foundational building blocks. The near future is expected to include multiple certified operators conducting complete EIS operations, with the potential for one or more key AAM sites supporting several operators simultaneously. The mature state of AAM is anticipated to include a mix of piloted, remotely piloted, and fully autonomous operations.

The FAA William J. Hughes Technical Center for Advanced Aerospace (WJHTC) conducted two Human-in-the-Loop (HITL) simulations during October 2024 and April 2025 in support of AAM initial entry-into-service (EIS) activities. The simulations used an ATCT suite that included an out-the-window visual display, surveillance systems, and communication capabilities. The primary goal involved obtaining feedback from air traffic control (ATC) subject matter experts (SMEs) on the operational feasibility of eVTOL operations at Los Angeles International Airport (KLAX). Certified Air Traffic Control Specialists (ATCSs) assigned to the KLAX ATCT evaluated multiple scenarios to assess different vertiport locations, eVTOL routes, and operational concepts. They examined the feasibility of proposed procedures and their impacts on the safety and tempo of legacy operations. Simulation pilots flew all legacy aircraft, and some eVTOL flights.

The FAA conducted a series of fast-time simulations before the HITL events to assess airspace integration, basic operational flows, airport transfer use cases, and interaction between eVTOL operations and existing traffic. Follow-on fast-time simulations were refined to focus on eVTOL performance characteristics, fleet operations, and vertiport configurations. FAA researchers ultimately examined more than 70 scenarios that included multiple potential vertiport locations and arrival and departure routes. The results informed the development of nominal and off-nominal scenarios for the high-fidelity HITL simulations, allowing researchers to evaluate overall operational performance and safety considerations.

The first HITL consisted of two multi-day dry runs and a formal simulation that examined 21 scenarios. The results provided initial insight into vertiport locations and air traffic operational challenges. Researchers eliminated one potential vertiport site because of wake turbulence concerns, proximity alerts involving legacy aircraft, limited ATCT line of sight, increased communication workload, and overall difficulty integrating eVTOL operations at that location. The first simulation also enabled refinement of air traffic scenarios and development of new eVTOL routes that aligned more effectively with existing operations.

The second HITL, conducted at the WJHTC from April 1–3, 2025, expanded on the initial effort. The primary goal focused on obtaining additional feedback from ATC SMEs on the updated air traffic scenarios created for KLAX. The scenarios again assessed the operational feasibility of eVTOL aircraft using various vertiport locations. Certified ATCSs assigned to the KLAX ATCT participated and evaluated potential impacts on the safety and tempo of legacy operations.

This report documents the results of the second KLAX HITL simulation (KLAX HITL 2). The report summarizes the scenarios evaluated, aircraft types used, and key assumptions applied throughout the simulations. KLAX HITL 2 further refined and assessed eVTOL operational concepts at KLAX. The first HITL identified the Consolidated Rent-A-Car Facility (CONRAC) vertiport location as infeasible and several eVTOL routes as impractical. KLAX HITL 2 eliminated the CONRAC location and incorporated updated eVTOL routes designed to reduce impacts on air traffic operations as well as controller communications and workload.

2 Technical Approach

The research team used the NAS Integration and Emerging Capabilities (NIEC) laboratory together with laboratories at the National Aeronautics and Space Administration (NASA) and the FAA Mike Monroney Aeronautical Center (MMAC). The NIEC ATCT simulator provided ATCS with a simulated 270-degree out-the-window view of KLAX and supported three operational positions: Local Control 1 (LC1) managed the south runway complex (Runways 7/25), Local Control 2 (LC2) managed the north runway complex (Runways 6/24), and Helicopter Control/Class B (HC) managed all helicopter and eVTOL traffic. The ATCT simulator also provided each control position with a Standard Terminal Automation Replacement System (STARS) Remote Tower Display Workstation (RTDW), ground surveillance, and communication capabilities. Figure 1 presents a schematic of the laboratory configuration.

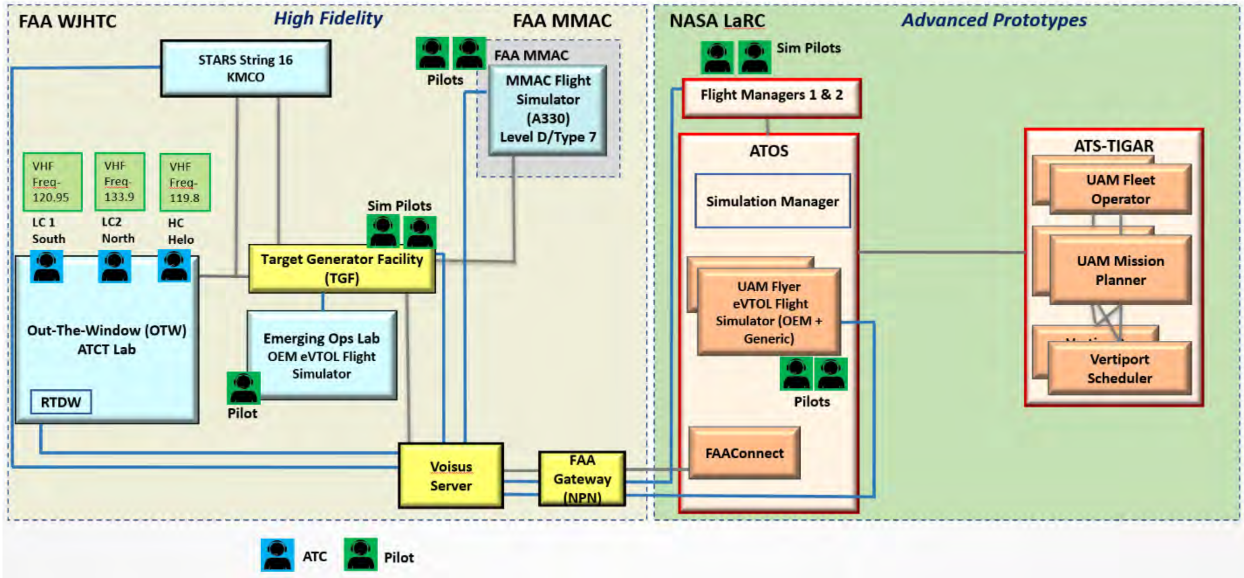

Figure 1. WJHTC AAM Integrated Laboratory Test Environment

The HITL simulation used three vertiport locations at KLAX: Central Terminal Area 3 (CTA3), Central Terminal Area 7 (CTA7), and the Signature Fixed Base Operator (SGNTR) vertiport. The Atlantic vertiport was not included because its proximity to SGNTR would result in similar operational characteristics. Each vertiport contained two Touchdown and Liftoff (TLOF) areas. CTA3 and CTA7 provided three aircraft parking spaces each, and SGNTR provided five. Each vertiport also featured a dedicated arrival and departure TLOF. For this effort, specific elements such as Instrument Flight Rules, land use, noise abatement, airport planning were out of scope and may require investigation prior to operational implementation. Figure 2 presents an overview of KLAX and the vertiport locations.

Figure 2. KLAX with vertiport locations. Note: CONRAC and ATLANTIC were not used

2.1 Flight Simulators

NASA pilots operated four remotely connected flight simulators to fly eVTOL aircraft using an out-the-window view, primary flight avionics, and flight controls. An FAA pilot operated an eVTOL flight simulator in the NIEC that also featured an out-the-window view, primary flight controls, and avionics. The NASA and FAA simulators did not replicate production eVTOL aircraft but provided realistic performance characteristics based on models supplied by the original equipment manufacturers (OEMs). The simulation included the MMAC high-fidelity, Level D aircraft simulator configured as an Airbus A330 (A330) equipped with a Traffic Collision Avoidance System (TCAS). Two pilots operated the A330. All flight simulator pilots shared a common operating environment and had the ability to observe other air traffic through their virtual windows.

2.2 eVTOL Aircraft Models

The simulation incorporated three eVTOL aircraft performance models. Simulated eVTOL aircraft were based on prototypes developed by the NASA Revolutionary Vertical Lift Technology (RVLT) Project (Generic eVTOL) and by two OEMs. Pseudo pilots controlled some eVTOL aircraft using keyboard inputs and conducted all required communications with ATC. Other eVTOL aircraft were flown by pilots operating flight simulators. Key performance characteristics for each eVTOL model included assumptions related to passenger capacity, rotor configuration, climb and descent rates, and cruise speeds.

2.3 HITL and Scenario Design Assumptions

Researchers established the following key assumptions which guided scenario development and enabled the simulation.

- The operating environment is based on existing infrastructure to support AAM operations and meet federal vertiport design standards
- AAM aircraft operate in daytime Visual Flight Rules (VFR) conditions
- Visual Meteorological Conditions (VMC) weather conditions prevail
- AAM aircraft are piloted with a pilot onboard
- AAM aircraft are type-certified – Power Lift, special class rotorcraft, may not perform like traditional helicopters (Note: performance may differ from production AAM aircraft)
- AAM aircraft are capable of advanced navigation (i.e., Global Positioning System, GPS)
- AAM operations are scheduled, not on-demand
- KLAX Instrument Flight Rules legacy operations are not delayed (AAM will need to be accommodated while minimizing impact to current KLAX operations)
- Current air traffic control separation standards apply
- Minimum Safe Altitude in accordance with part 91.113 and 194.302, regarding powered-lift operations.
- KLAX is on a west flow operation - It is estimated the airport operates in this direction most of the time due to prevailing wind and a waiver (FAA 8400.9) that permits runway selection with up to a 10-knot tailwind component
- Legacy arrival traffic uses outboard runways (RWY 25L and RWY 24R)
- Legacy departure traffic uses inboard runways (RWY 25R and RWY 24L)
- eVTOL aircraft operate under VFR
- A simulated Letter of Agreement (LOA) defines eVTOL operations at KLAX and within the Southern California Terminal Radar Approach Control (TRACON) (SCT) airspace
- Wake turbulence separation was applied based on aircraft classification and established FAA standards, in accordance with FAA Order 7110.126B - Consolidated Wake Turbulence, and JO 7110.65 - Air Traffic Control
- KLAX Ground Control operations are scripted (Unstaffed)
- SCT TRACON operations are scripted (Unstaffed)

The transit routes developed for three locations (Downtown Los Angeles, Van Nuys airport, and Long Beach airport) consider airspace class rules, existing helicopter routes, community impact, obstacles, and terrain, but are not formally certified routes.

2.4 Scenario Development

The research team developed eleven 45-minute scenarios for evaluation during the dry-run phase. Each scenario listed below was executed multiple times in laboratory dry runs, which allowed refinement of the scenarios and verification that the ATCT simulation platform, eVTOL flight simulators, and all supporting components operated correctly. Each scenario included approximately twelve eVTOL operations per hour with a balanced mix of arrivals and departures. Scenarios involving a single vertiport included approximately six arrivals and six departures during each 45-minute period. Scenarios involving multiple vertiports included eight to ten arrivals and eight to ten departures during the same period.

Signature Vertiport Operations (6 arrivals 6 departures/45 minutes)
Scenario #1 – Hawthorne arrivals from south, Imperial departures east (1 operator FAA)
Scenario #2 – Hawthorne arrivals from north & south, Imperial departures east (3 operators)

CTA3 Vertiport Operations
Scenario #3 - Sheraton arrivals / Marina departures (1 operator FAA) to/from north
Scenario #4 - Hawthorne arrivals / Dockweiller departures (1 operator FAA) to/from south
Scenario #5 - Sheraton arrivals / Lincoln departures (1 operator FAA) to/from north

CTA7 Vertiport Operations
Scenario #6 - Sheraton arrivals / Marina departures (1 operator NASA) north
Scenario #7 - Hawthorne arrivals / Dockweiller departures (1 operator NASA) south
Scenario #8 - Sheraton arrivals / Lincoln departures (1 operator NASA) north

Multiple Vertiport Operations (8-10 arrivals 8-10 departures/45 minutes)
Scenario #9 - Sheraton arrivals / Marina departures - Vertiports: CTA3 & CTA7 (2 operators)
Scenario #10 - Hawthorne arrivals / Dockweiller departures - Vertiports: CTA3 & CTA7 (2 operators)
Scenario #11 - Arrivals north & south, departures west - Vertiports: Signature, CTA3 & CTA7 (3 operators)

The HITL simulation evaluated only a subset of the planned scenarios. The Air Traffic Control Specialist (ATCS) participants and the research team agreed not to run scenarios that included the Dockweiler or Marina routes because of their altitude profiles and proximity to the shoreline. The marine weather layer, including fog, often prevents VFR operations during portions of the day. These factors rendered several scenarios no longer viable, and they were excluded from this HITL. Figure 3 presents the scenario run schedule as executed during the simulation.

Tuesday 04/01/25	Wednesday 04/02/25	Thursday 04/03/25
01:00-02:00 Kickoff Meeting 02:00-02:45 LAX Scenario #1 02:45-03:15 Debrief 03:30-04:15 LAX Scenario #2 04:15-04:45 Debrief	09:00-09:45 Review & adjust 09:45-10:30 LAX Scenario #5 10:30-11:00 Debrief 11:00-11:15 Break 11:15-12:00 LAX Scenario #2 Repeated 12:00-12:30 Debrief 12:30-01:30 Lunch 01:30-02:15 LAX Scenario #9 02:15-02:45 Debrief 02:45-03:00 Break 03:00-03:45 OEM simulator demo/ Hawthorne mini tower	09:00-09:45 Review 09:45-10:30 LAX Scenario #11 10:30-11:00 Debrief 11:00-11:15 Break 11:15-12:00 LAX Scenario #12 Repeated 12:00-12:30 Debrief 12:30-01:30 Lunch 01:30-04:00 HITL Out Brief

Figure 3. KLAX HITL 2 Schedule of Runs

3 Simulation Runs and Scenarios - Descriptions and Metrics

This section provides a description of each scenario evaluated during the simulation, along with associated simulation, voice communication, and wake turbulence metrics. The simulation metrics present the duration of each run and the corresponding air traffic operations count. The communication metrics present the number and duration of air-to-ground radio transmissions made and received at each simulated position. The research team analyzed the aircraft tracks from each run and applied the wake separation criteria as defined in FAA Order JO 7110.65BB (FAA, 2025), section 5-5-4, Separation Minima, paragraph f., Wake Turbulence Application; section 3-9-7, Wake Turbulence Separation for Intersection Departures; Table 5-5-1, Wake Turbulence Separation for Directly Behind; and Table 5-5-2, Wake Turbulence Separation for On Approach. The research team used the Target Generation Facility (TGF) data reduction and analysis tools to identify potential wake separation violation events. ATC SMEs reviewed each event to validate the data and determine if a wake separation violation occurred. Only one event met the criteria to be considered a wake separation violation and is discussed in Section 3.6. The following sections provide a narrative summary of the data.

3.1 Run 1, Scenario #1 - Vertiport Location: Signature FBO

Scenario #1 implemented an eVTOL arrival route, designated HAWTHORNE, to the Signature FBO at 2,000 feet mean sea level (MSL). The arrival approached from the southeast, turned north, then turned west over Hawthorne Municipal Airport (KHHR), and descended to the vertiport. The departure route, designated IMPERIAL, required eVTOL aircraft to depart to the south to avoid descending arrivals, then turn east and climb to 500 feet MSL above Imperial Highway. Figure 4 depicts the eVTOL routes. Only the FAA eVTOL aircraft model flew in this scenario.

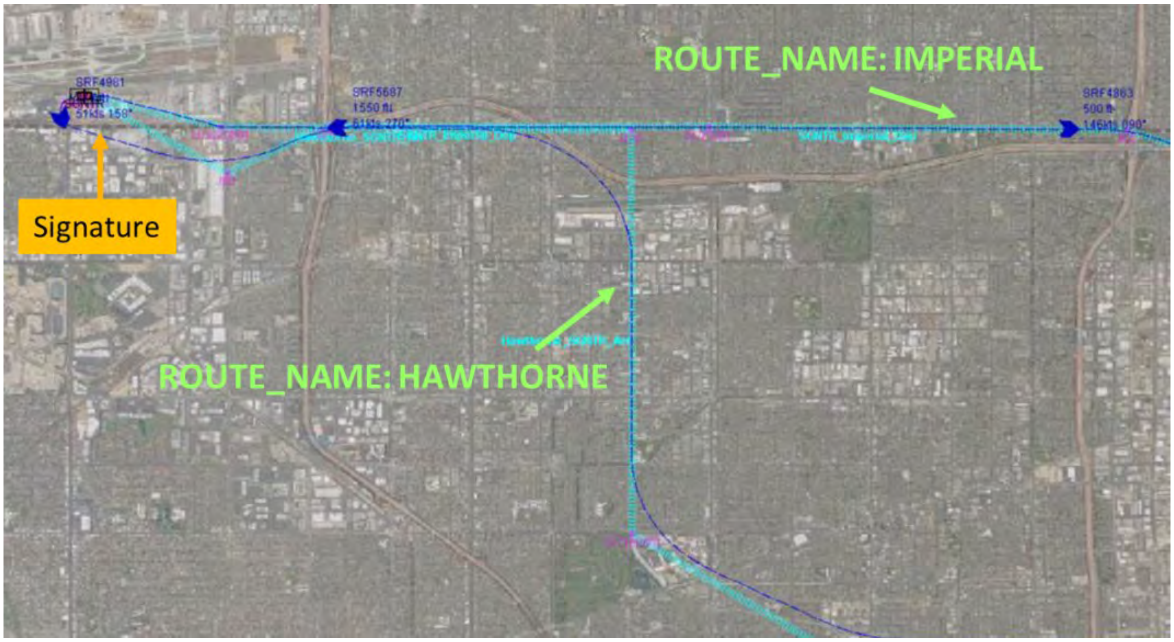

Figure 4. Scenario #1 – Signature FBO

The simulation metrics indicate that background air traffic was relatively busy. The scenario included ten eVTOL arrivals and eleven eVTOL departures to the Signature FBO. A total of 851 voice radio transmissions occurred, with most transmissions made from the LC1 position, which managed the south runway complex (RWY 25L/25R), followed by LC2, which managed the north complex (RWY 24L/24R). The ATCS at the HC position made 82 transmissions (one transmission every 36.5 seconds, 4.2 seconds per transmission) and received 96 transmissions from eVTOL pilots (one transmission every 31.2 seconds, 4.4 seconds per transmission). Table 1 and Table 2 present the simulation and communications data for Run 1, Scenario #1.

Table 1. Simulation Metrics for Run 1, Scenario #1 – Signature FBO

Date	4/1/2025
Duration (H:MM:SS)	0:49:53
Fixed wing aircraft count	158
Helicopter count	12
eVTOL count	21
Departure Count South Complex	22
Departure Count North Complex	24
Arrival Count South Complex	27
Arrival Count North Complex	26

Table 2. Voice Communication Metrics for Run 1, Scenario #1 – Signature FBO

Comm Position	Duration (seconds)	Transmission Count
Class B	**760.29**	**178**
AAM Pilot	267.31	71
TGF Helicopter Pilot	150.59	25
Helicopter Control	342.39	82
North	**848.58**	**301**
TGF Pilot 04	204.77	70
TGF Pilot 05	278.63	93
Local Control 2	365.18	138
South	**1518.67**	**372**
MMAC Pilot	18.02	5
TGF Pilot 02	329.74	95
TGF Pilot 03	259.52	96
Local Control 1	911.39	176
Grand Total	**3127.54**	**851**

Run 1, Scenario 1 – Vertiport Location: Signature FBO - HITL Observations

The MMAC pilots operating the A330 flight simulator flew one pass during the scenario and experienced a brief TCAS Traffic Alert (TA). The ATCS issued a traffic callout, and the pilots reported that they were able to visually identify the aircraft involved. The TA resolved quickly, did not escalate to a Resolution Advisory (RA), and never transitioned to an amber alert indicating the need for potential action.

The NASA pilots reported no significant issues during the scenario. They described the radio call to request Class B clearance as straightforward and expressed some concern that the steep descent flight path angle (FPA) and bank angle might be uncomfortable for passengers.

The ATCSs reported that eVTOL departures climbing to 500 feet MSL on the IMPERIAL route offered limited margin for deviation and discussed modifying the route to extend further west before rejoining IMPERIAL. They agreed that the steep descents worked well and recommended establishing a reporting point at Alondra Park, where Torrance and Hawthorne airspace intersect. The ATCSs also noted that the departures skirted Class B airspace and suggested creating a GPS route farther from the final approach course to reduce risk. They added that departing helicopters are typically handed off to the KHHR ATCT and recommended that eVTOL departures from the Signature FBO continue westbound before turning east onto IMPERIAL to make the procedure less demanding for pilots. The ATCSs also reported concerns regarding aircraft separation and potential wake turbulence effects on eVTOL aircraft during go-arounds on Runway 25L. Finally, they discussed the feasibility of sequencing eVTOL departures between arriving legacy aircraft on Runway 25L.

3.2 Run 2, Scenario #2 - Vertiport Location: Signature FBO

Scenario #2 expanded on Scenario #1 by adding an eVTOL arrival route from the north, designated SEPULVEDA, and by incorporating additional eVTOL aircraft models. As in Scenario #1, eVTOL aircraft flew to the Signature FBO at 2,000 feet mean sea level (MSL) from the southeast, turned north via the HAWTHORNE arrival route, and then turned west toward the vertiport. Arrivals from the north maintained 2,500 feet MSL on the SEPULVEDA route as they passed over KLAX, turned east, and then turned north to merge with traffic on the HAWTHORNE route. As in Scenario #1, eVTOL departures from the Signature FBO flew west along the IMPERIAL route, climbed to 500 feet MSL, and then joined the ALAMEDA route to continue north or south. All three eVTOL aircraft models participated in this scenario, with the FAA eVTOL arriving from the north and the NASA OEM aircraft arriving from the south. Figure 5 depicts the eVTOL routes.

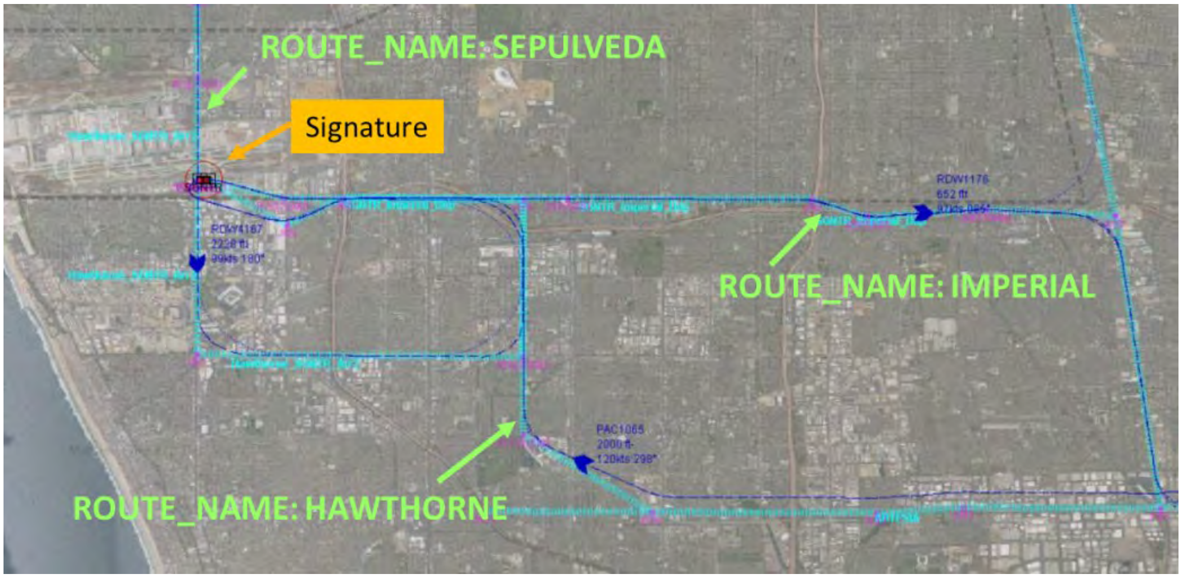

Figure 5. Scenario #2 - Signature FBO

The run time for Scenario #2 was just over 37 minutes, resulting in fewer overall operations, although air traffic remained busy based on the simulation metrics. The scenario included seven eVTOL arrivals and seven eVTOL departures to the Signature FBO. A total of 586 voice transmissions occurred, with the LC1 and LC2 positions making and receiving the same number of transmissions. The ATCS managing eVTOL traffic at the HC position made 49 transmissions (one transmission every 45.4 seconds, 4.8 seconds per transmission) and received 57 transmissions from eVTOL pilots (one transmission every 39 seconds, 4.5 seconds per transmission). Table 3 and Table 4 present the simulation and communication metrics for Run 2, Scenario #2.

Table 3. Simulation Metrics for Run 2, Scenario #2 – Signature FBO

Date	4/1/2025
Duration (H:MM:SS)	0:37:03
Fixed wing aircraft count	131
Helicopter count	11
eVTOL count	14
Departure Count South Complex	14
Departure Count North Complex	17
Arrival Count South Complex	19
Arrival Count North Complex	19

Table 4. Voice Communication Metrics for Run 2, Scenario #2 – Signature FBO

Comm Position	Duration (seconds)	Transmission Count
Class B	**496.32**	**106**
AAM Pilot	135.54	38
TGF Helicopter Pilot	123.65	19
Helicopter Control	237.13	49
North	**928.91**	**237**
TGF Pilot 04	185.28	61
TGF Pilot 05	230.68	66
Local Control 2	512.95	110
South	**862.71**	**243**
MMAC Pilot	19	7
TGF Pilot 02	220.16	64
TGF Pilot 03	159.58	62
Local Control 1	463.97	110
Grand Total	**2287.94**	**586**

3.3 Run 3, Scenario #2 - Vertiport Location: Signature FBO

Run 3 repeated Scenario #2 to create additional opportunities for the TCAS-equipped MMAC A330 flight simulator to fly approaches to Runway 24L. The scenario generated 653 total transmissions, with the LC1 and LC2 positions making and receiving approximately the same number of transmissions. The ATCS managing eVTOL traffic at the HC position made 101 transmissions (one transmission every 24 seconds, 5.2 seconds per transmission) and received 85 transmissions from eVTOL pilots (one transmission every 28.5 seconds, 4.7 seconds per transmission). Overall transmission activity remained similar between Runs 2 and 3. The increased number of transmissions from the HC position resulted primarily from additional communication with the MMAC flight simulator pilots as they conducted multiple approaches. Table 5 and Table 6 present the simulation and communication metrics for Run 3, Scenario #2 (repeated).

Table 5. Simulation Metrics for Run 3, Scenario #2 (repeated) – Signature FBO

Date	4/2/2025
Duration (H:MM:SS)	0:40:25
Fixed wing aircraft count	140
Helicopter count	12
eVTOL count	14
Departure Count South Complex	12
Departure Count North Complex	16
Arrival Count South Complex	17
Arrival Count North Complex	17

Table 6. Voice Communication Metrics for Run 3, Scenario #2 (repeated) – Signature FBO

Comm Position	Duration (seconds)	Transmission Count
Class B	**927.06**	**186**
AAM Pilot	258.85	60
TGF Helicopter Pilot	138.85	25
Helicopter Control	529.36	101
North	**665.38**	**234**
MMAC Pilot	49.71	17
TGF Pilot 04	137.92	49
TGF Pilot 05	172.21	61
Local Control 2	305.54	107
South	**804.28**	**233**
TGF Pilot 02	167.55	52
TGF Pilot 03	223.7	77
Local Control 1	413.03	104
Grand Total	**2396.72**	**653**

Run 2 and Run 3, Scenario #2 – Vertiport Location: Signature FBO - HITL Observations

The MMAC pilots operating the A330 flight simulator flew one approach during Run 2 and experienced a brief TCAS TA. During Run 3, they encountered no TCAS alerts on the first approach, observed a TA at 1,500 feet AGL on the second approach, experienced a TA/RA on the third approach that may have resulted from the aircraft spawn location, and received an amber TA for departing traffic climbing off Runway 25R on the fourth approach.

The NASA pilots did not report any significant issues during these runs. They suggested that transitions out of Class B airspace could be smoother and recommended using Los Angeles–based pilots who are familiar with the region's airspace in future simulations. They stated that the procedures worked but found the shallow descent profile for the Generic OEM aircraft model undesirable. The pilots began making earlier radio calls at Foxhill to the HC position to initiate descent sooner, and this adjustment worked effectively.

The ATCSs reported that the eVTOL routes were well designed. They identified an issue with a police helicopter in the scenario that should have been flying at 900 feet AGL instead of 500 feet AGL, which caused a conflict with one of the NASA-operated eVTOLs; this was corrected in later runs. The ATCSs also noted that the Generic eVTOL model lacked sufficient performance to manage the arrival route and had to fly too low over KHHR. Based on recommendations from Run 1, eVTOL pilots made initial contact with KLAX at Alondra Park before entering Class B airspace, and the ATCSs stated that this procedure worked well. The ATCSs highlighted that they control the triangle-shaped Class D airspace north and south of KLAX, which allowed them to better accommodate eVTOL arrivals from the north and departures to the south. During the runs, the ATCSs requested that the MMAC flight simulator pilots fly multiple approaches to gather additional TCAS data. Although the MMAC pilots received several TCAS alerts, none of those alerts were triggered by eVTOL aircraft.

3.4 Run 4, Scenario #5 - Vertiport Location: CTA3

Scenario #5 focused on eVTOL operations at the CTA3 vertiport. Arrivals approached from the north on the SHERATON route at 1,500 feet AGL, descended, and turned west to land at CTA3. Departures made a relatively quick turn to the north and overflew the active runways before joining the LINCOLN route. Only the FAA eVTOL aircraft model flew in this scenario. Figure 6 depicts the eVTOL routes.

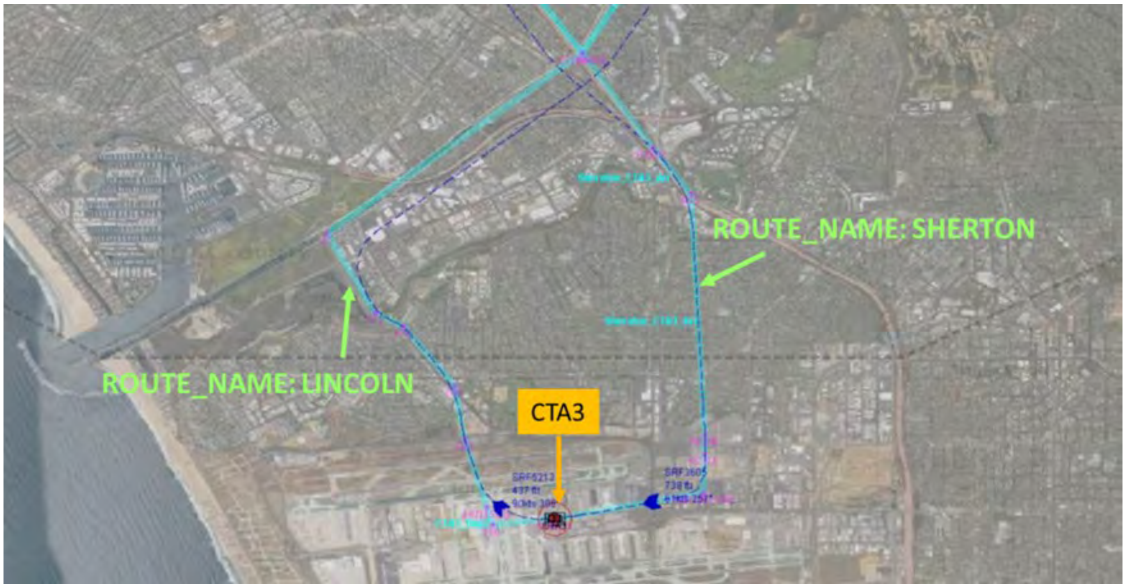

Figure 6. Scenario #5 - CTA3

A steady flow of eVTOL arrivals and departures operated at the CTA3 vertiport during this run. Run 4, Scenario #5 included 556 total voice transmissions. LC1 made 92 transmissions and received 112, and LC2 made 104 transmissions and received 114. The ATCS managing eVTOL traffic at the HC position made 65 transmissions (one transmission every 31.2 seconds, 4.6 seconds per transmission) and received 69 transmissions from eVTOL pilots (one transmission every 29.4 seconds, 4.3 seconds per transmission). Table 7 and Table 8 present the simulation and communication metrics for Run 4, Scenario #5.

Table 7. Simulation Metrics for Run 4, Scenario #5 – CTA3

Date	4/2/2025
Duration (H:MM:SS)	0:33:50
Fixed wing aircraft count	123
Helicopter count	11
eVTOL count	17
Departure Count South Complex	12
Departure Count North Complex	16
Arrival Count South Complex	17
Arrival Count North Complex	17

Table 8. Voice Communication Metrics for Run 4, Scenario #5 – CTA3

Comm Position	Duration (seconds)	Transmission Count
Class B	**595.74**	**134**
AAM Pilot	197.17	54
TGF Helicopter Pilot	99.09	15
Helicopter Control	299.48	65
North	**798.95**	**218**
TGF Pilot 04	165.99	56
TGF Pilot 05	191.87	58
Local Control 2	441.09	104
South	**784.62**	**204**
MMAC Pilot	48.89	18
TGF Pilot 02	132.71	40
TGF Pilot 03	149.62	54
Local Control 1	453.4	92
Grand Total	**2179.31**	**556**

Run 4, Scenario #5 – Vertiport Location: CTA3 - HITL Observations

The FAA pilot who flew the eVTOL flight simulator did not report any issues during this run. The MMAC pilots flew two approaches and received a TCAS TA at 1,100 feet MSL caused by an amber target below them representing departing legacy traffic. During the second pass, they observed a brief TA for aircraft departing the parallel runways. The NASA pilots reported that the timing of callouts required tactical adjustments before entering Class B airspace and noted that a 360-degree holding turn worked well.

The Air Traffic Control Specialists (ATCSs) reported that extensive coordination and numerous callouts were required between the HC position and LC2 because of the LINCOLN departure route. eVTOL aircraft departing CTA3 flew west to "get on the wing" before turning north on LINCOLN, but the short westbound segment made it difficult for controllers to move eVTOLs through gaps in arriving traffic. ATCSs indicated that they would likely wait for larger gaps in real-world operations and questioned whether eVTOLs could depart directly to the north rather than first tracking west. Given the workload and challenge of sequencing eVTOLs between arrivals, the ATCSs concluded that departure speed was more critical than achieving a specific altitude in this scenario. They also highlighted the effects of crosswinds on an eVTOL's ability to depart northbound and raised concerns about the frequent marine layer that can create low fog and IMC conditions west of CTA3. The pilots and ATCSs agreed that earlier “pass behinds” on the SHERATON arrival route were desirable because they reduced the need to keep all aircraft at 1,500 feet MSL and allowed eVTOLs to begin their descent sooner.

3.5 Run 5, Scenario #9 - Vertiport Location: CTA3 and CTA7

Like the previous run, eVTOL arrivals approached from the north on the SHERATON route at 1,500 feet MSL before turning west to land at CTA3 or CTA7. The LINCOLN departure route was modified so that aircraft departed on a heading of 330 degrees, climbed to 1,000 feet MSL, and then continued climbing to 1,500 feet MSL after passing beneath the SHERATON arrivals. Both OEM aircraft models participated in this scenario. Figure 7 depicts the eVTOL routes.

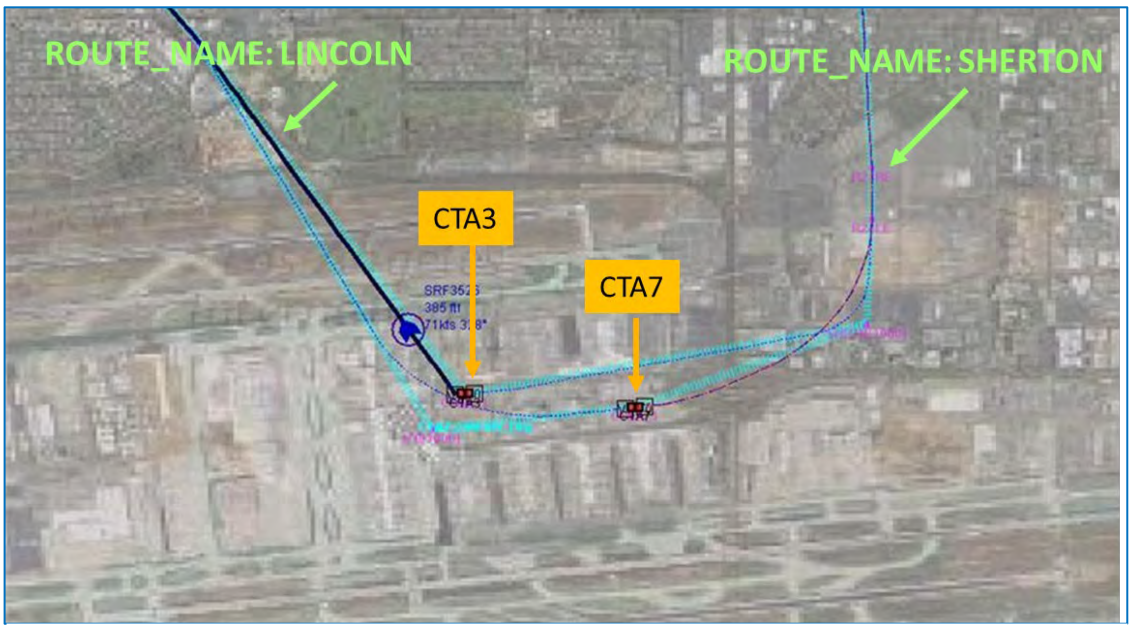

Figure 7. Scenario #9 - CTA3 and CTA7

The scenario included busy background legacy traffic, and ATCSs managed six eVTOL arrivals and six eVTOL departures at each vertiport. Run 5, Scenario #9 generated 666 total voice transmissions. LC1 made 117 transmissions and received 152, and LC2 made 112 transmissions and received 131. The ATCS managing eVTOL traffic at the HC position made 77 transmissions (one transmission every 32.6 seconds, 4.3 seconds per transmission) and received 77 transmissions from eVTOL pilots. Table 9 and Table 10 present the simulation and communication metrics for Run 5, Scenario #9.

Table 9. Simulation Metrics for Run 5, Scenario #9 – CTA3 and CTA7

Date	4/2/2025
Duration (H:MM:SS)	0:41:51
Fixed wing aircraft count	141
Helicopter count	12
eVTOL count	24
Departure Count South Complex	16
Departure Count North Complex	15
Arrival Count South Complex	22
Arrival Count North Complex	22

Table 10. Voice Communication Metrics for Run 5, Scenario #9 – CTA3 and CTA7

Comm Position	Duration (seconds)	Transmission Count
Class B	**658.24**	**154**
AAM Pilot	225.38	60
TGF Helicopter Pilot	103.8	17
Helicopter Control	329.06	77
North	**777.65**	**243**
TGF Pilot 04	258.64	81
TGF Pilot 05	152.14	50
Local Control 2	366.87	112
South	**800.59**	**269**
MMAC Pilot	35.18	11
TGF Pilot 02	261.03	81
TGF Pilot 03	148.69	60
Local Control 1	355.69	117
Grand Total	**2236.48**	**666**

Run 5, Scenario #9 – Vertiport Locations: CTA3 and CTA7 - HITL Observations

The FAA pilot flying the eVTOL flight simulator reported that departing on a direct heading from the CTA3 vertiport to the LINCOLN departure route was easy. Departing directly to the north also worked well, and the pilot stated that the direct route reduced workload. During the run, the ATCSs diverted one of the FAA eVTOL flights from CTA3 to CTA7, and the pilot noted that maintaining altitude while switching pads in real-world operations could be challenging. The pilot suggested implementing a holding point on the LINCOLN departure route for eVTOLs departing CTA7 and recommended a teardrop departure pattern to gain altitude before crossing the runways, stating that this pattern would be easier to control within limited maneuvering airspace. The FAA-piloted eVTOL experienced a STARS conflict alert (CA) with a legacy aircraft during approach, although the HC controller monitored the situation, and no loss of separation or wake turbulence issue occurred.

The NASA pilots flying the eVTOL simulators expressed concern that the designated point for contacting KLAX to request Class B clearance may be too late when the frequency is congested or when maneuvering is required. They also observed that the train station created a visual obstruction when departing CTA7 until the aircraft turned north to establish visual contact with traffic. The pilots added that unfamiliarity with the eVTOL performance characteristics created uncertainty about whether certain maneuvers demonstrated in simulations (e.g., hover taxiing between pads, taxiing on landing gear) would be feasible in real operations. The MMAC pilots flew three approaches in the A330 simulator; the first approach generated one TA at 750 feet AGL involving legacy traffic, and the subsequent two approaches were uneventful.

The ATCSs reported experimenting with various instructions during this run to observe potential outcomes, including directing an eVTOL to reposition or land on a different vertipad. They concluded that eVTOL departures from the CTAs required forward speed over altitude to effectively merge into gaps in legacy arrival flows and transition safely over the runways. The controllers also noted the STARS CA involving an eVTOL and a legacy aircraft arriving on RWY 25L. The ATCSs agreed with NASA pilots that eVTOL pilots may need to request Class B clearance earlier, particularly when the radio frequency is congested.

3.6 Run 6, Scenario #11 - Vertiport Locations: CTA3, CTA7 and Signature FBO

Researchers designed Scenario #11 to assess the operational feasibility of simultaneous eVTOL operations at all three vertiport locations. eVTOLs landing at CTA3 arrived via the SHERATON route at 1500 feet AGL, descended, and turned west to land. CTA3 departures made a quick turn to the north on a heading of 330 and flew over the active runways to follow the LINCOLN route. CTA7 and Signature FBO arrivals approached from the southeast and flew at 2000 feet MSL before turning north via the HAWTHORNE arrival route and then west towards the vertiport. eVTOLs departing CTA7 turned south and followed the modified LINCOLN route which replaced DOCKWEILER. eVTOL departures from the Signature FBO followed the IMPERIAL route to the west before turning south to their destination. All three OEM aircraft models flew during this scenario. Researchers conducted the FAA eVTOL flights at CTA3, the NASA OEM flights at CTA7, and Generic OEM flights at Signature FBO. The eVTOL routes are depicted in Figure 8.

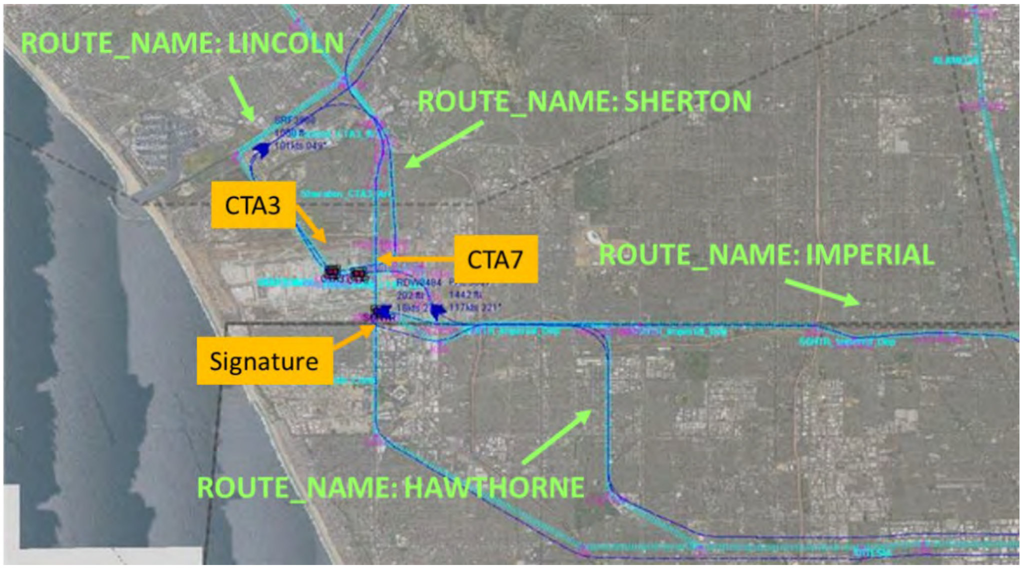

Figure 8. Scenario #11 – CTA3, CTA7 and Signature FBO

During this busy scenario, ATCSs managed a total of 34 eVTOL operations with about six arrivals and departures at each vertiport. There were 921 total transmissions during Run 6, Scenario #11. LC1 made 152 and received 190 transmissions during the run. LC2 made 138 transmissions and received 171 transmissions. The ATCS managing eVTOL traffic at the HC position made 137 transmissions during the run (1 transmission/21.1 seconds, 3.7 seconds/transmission) and received 127 transmissions (1 transmission/22.8 seconds, 4.3 seconds/transmission) from eVTOL pilots.

Scenario #11 was arguably the most complicated scenario because it presented simultaneous operations to all three vertiport locations with eVTOL aircraft that had a range of performance characteristics. One wake turbulence violation occurred during this scenario. The wake turbulence violation involved a heavy Airbus A332 (callsign HAL21) and an eVTOL (callsign PAC7768) at 22 minutes and 15 seconds into the scenario and had a duration of 39 seconds. HAL21 departed RWY 24L and PAC7768 was departing from the CTA. HAL21 rotated for takeoff at about midfield and then PAC7768 departed from the CTA, turned north and crossed the north runway complex flying through the wake of HAL21. At the beginning of the wake encounter, both aircraft were at approximately 200 feet AGL and were horizontally separated by 3,984 feet. The wake encounter violated the 7110.65BB rule 5-5-4.f.1.c.2 because the flight path of PAC7768 was less than 1,000’ below HAL21 and trailing by less than 5 nautical miles (0.66 nautical miles). Table 11 and Table 12 present the simulation and communication metrics for Run 6, Scenario #11.

Table 11. Simulation Metrics for Run 6, Scenario #11 – CTA3, CTA7 and Signature FBO

Date	4/3/2025
Duration (H:MM:SS)	0:48:12
Fixed wing aircraft count	156
Helicopter count	12
eVTOL count	34
Departure Count South Complex	20
Departure Count North Complex	20
Arrival Count South Complex	27
Arrival Count North Complex	25

Table 12. Voice Communication Metrics for Run 6, Scenario #11 – CTA3, CTA7 and Signature FBO

Comm Position	Duration (seconds)	Transmission Count
Class B	**1049.66**	**270**
AAM Pilot	425.54	107
TGF Helicopter Pilot	116.27	20
Helicopter Control	500.25	137
North	**846.34**	**309**
TGF Pilot 04	211.44	82
TGF Pilot 05	273.87	89
Local Control 2	361.03	138
South	**1060.45**	**342**
MMAC Pilot	66.25	28
TGF Pilot 02	247.74	73
TGF Pilot 03	224.78	89
Local Control 1	521.68	152
Grand Total	**2956.45**	**921**

3.7 Run 7, Scenario #11 (modified) - Vertiport Locations: CTA3, CTA7, Signature FBO

For Run 7, the ATCS participants and research team decided to re-run Scenario #11 to explore different methods of integrating eVTOL arrivals with legacy traffic. They sought to determine how best to implement a “pass behind” procedure, in which an eVTOL would pass behind an arriving legacy aircraft before turning to descend to the vertiport. They also aimed to evaluate a contingency operation involving an undefined eVTOL go-around procedure.

ATCSs managed a total of 34 eVTOL operations with approximately six arrivals and six departures at each vertiport. The run included 836 total transmissions. LC1 made 143 transmissions and received 177, and LC2 made 118 transmissions and received 149. The ATCS managing eVTOL traffic at the HC position made 125 transmissions (one transmission every 22.4 seconds, 3.7 seconds per transmission) and received 124 transmissions (one transmission every 22.6 seconds, 4.0 seconds per transmission) from eVTOL pilots. Table 13 and Table 14 present the simulation and communication metrics for Run 7, Scenario #11 (modified).

Table 13. Simulation Metrics for Run 6, Scenario #11 (modified) – CTA3, CTA7 and Signature FBO

Date	4/3/2025
Duration (H:MM:SS)	0:46:42
Fixed wing aircraft count	152
Helicopter count	12
eVTOL count	34
Departure Count South Complex	19
Departure Count North Complex	22
Arrival Count South Complex	26
Arrival Count North Complex	24

Table 14. Voice Communication Metrics for Run 6, Scenario #11 (modified) – CTA3, CTA7 and Signature FBO

Comm Position	Duration (seconds)	Transmission Count
Class B	**962.98**	**249**
AAM Pilot	372.57	101
TGF Helicopter Pilot	125.11	23
Helicopter Control	465.3	125
North	**810.35**	**267**
TGF Pilot 04	222.56	77
TGF Pilot 05	216.11	72
Local Control 2	371.68	118
South	**1076.28**	**320**
MMAC Pilot	51.17	17
TGF Pilot 02	216.21	65
TGF Pilot 03	239.62	95
Local Control 1	569.28	143
Grand Total	**2849.61**	**836**

<u>Run 6 and Run 7, Scenario #11 – Vertiport Locations: CTA3, CTA7 & Signature FBO - HITL Observations</u>

The FAA pilot who flew the eVTOL flight simulator during the run reported that the first arrival followed a direct route with effective descent rates and speeds. The pilot fell behind on the second arrival and became concerned with aircraft speed, despite describing overall workload as low. The pilot also stated that departures flown opposite the direction of legacy arrivals were "scary and did not feel safe." The pilot attempted a climbing test pattern on departure to reach 2,500' feet AGL above the CTAs before turning north over the runways, but the pattern proved ineffective for ATC and created apparent wake turbulence issues from arriving legacy aircraft.

NASA pilots reported significant radio congestion and considered requesting Class B clearance earlier on the arrival route. At least one eVTOL issued a late call because of the busy frequency. One NASA pilot flew a missed approach to the TLOF that worked well but emphasized the need for more missed-approach options and procedures, especially at the CTAs where maneuvering space is limited. The pilot also noted challenges when interacting with legacy arrival traffic, and ATCSs recommended remaining farther east of the airport. The NASA pilot operating primarily at Signature FBO reported no issues and stated that flying behind arriving legacy traffic was tight but achievable. Another NASA pilot conducted a deliberate missed approach and reported that the 360-degree turn procedure worked smoothly without tactical concerns.

MMAC pilots flew three approaches in the A330 flight simulator. During the first approach, they received a traffic call for a nearby eVTOL, visually acquired the aircraft, and maintained visual separation. During the second approach, they encountered an eVTOL on a two-mile final, visually identified the traffic, and received a TCAS TA. During the third approach, ATC instructed an eVTOL to pass behind the A330, and the pilots received two brief TCAS TAs at 1,100 feet AGL and 600 feet AGL. Both alerts corresponded to an eVTOL landing at the CTAs, although the pilots could not determine which aircraft triggered the alerts.

ATCSs continued discussions on eVTOL missed approaches and go-arounds. The observed eVTOL go-around surprised controllers and succeeded only because a gap existed in the arrival flow. Controllers expressed uncertainty about how to respond if no such gap was available and the eVTOL could not cross the runways. They recommended further development of contingency procedures and alternative landing options. ATCSs also stated that southbound arrivals to the CTAs on the SHERATON route were unsuitable due to wake turbulence and TCAS issues. They believed the route was shifted too far east, forcing eVTOL aircraft into longer, higher, and faster approach paths that made issuing a pass-behind instruction at the same altitude extremely difficult.

4 General HITL Observations

ATCS participants used a simulated LOA and pre-arranged coordination procedures to reduce coordination between operational control positions at KLAX. The procedures proved effective, yet controllers still required substantial coordination because of the proximity of eVTOL and legacy aircraft operations. Intrafacility coordination requires further discussion, clearer definition, and evaluation by the air traffic facility. The current KLAX ATCT Standard Operating Procedures (SOP) manual states, “Helicopters must not overfly another aircraft,” and ATCSs believe a safety risk analysis must be completed before implementing any specific eVTOL procedures.

ATCSs also noted numerous STARS CAs between arriving legacy aircraft and eVTOLs near the airport and expressed concerns about wake-turbulence risks created by heavy-jet missed approaches on RWY 25L. Legacy missed approaches can create unsafe encounters with eVTOL aircraft, depending on timing. One arrival route from the north requires eVTOL traffic to cross the RWY 24R final approach course at approximately 1,500 feet MSL before descending to the

CTAs. A missed approach on RWY 24R could create a conflict when both aircraft are in a critical phase of flight with limited maneuverability. Failure of the pilot to report the missed approach, or failure of the controller to detect it promptly, could worsen the encounter. A heavy-jet missed approach combined with an eVTOL missed approach could trap the eVTOL between runway complexes due to wake turbulence, and insufficient situation awareness at the HC position could further degrade safety.

All scenarios included staffing of the HC position. The KLAX SOP includes this position, although the facility rarely staffs it today because it is typically combined with LC2. ATCSs reported that the level of eVTOL traffic in the scenarios would require dedicated staffing of the HC position, and eVTOL operations to the CTAs would demand significant coordination between HC and the LC position, most affected by the routing. LC Assist positions, which are routinely staffed during moderate or higher traffic levels, could provide additional coordination support for the HC position.

Simulation pilots also provided several general observations. Pilots emphasized the need to fly routes with high precision due to the complexity of the airspace. Many arrival patterns were difficult to fly visually, and pilots found it challenging to identify ground reference points, particularly at higher altitudes. Pilots also expressed concern about bi-directional routes, describing them as problematic and unnerving. Two such routes initially tested were deemed unsuitable and were modified to remove the most difficult elements, including turns that limited pilots' ability to see oncoming aircraft. Arrivals via the SHERATON route at high speed required careful energy management; pilots stated that pass-behind instructions could be challenging and sometimes placed eVTOL aircraft nearly head-on with legacy arrivals. Earlier pass-behind instructions would help pilots manage trajectory and descent profiles more effectively. Reducing airspeed sometimes helped but required time, along with additional maneuvering.

5 Summary & Conclusions

ATCSs from KLAX controlled simulated legacy and AAM eVTOL traffic during seven high-density HITL scenarios. The controllers managed traffic from the LC1, LC2, and HC positions using a west-flow runway configuration. Each scenario evaluated the operational feasibility of integrating eVTOL operations at KLAX across various routes and vertiport locations.

Controller and pilot feedback indicated that most eVTOL routes were viable, although the SHERATON arrival route raised concerns. The route offered limited maneuvering room, which created aircraft separation and wake-turbulence challenges when legacy aircraft executed go-arounds on RWY 25L. Controllers also noted that the SHERATON route was too far east and made pass-behind maneuvers more difficult due to altitude constraints. Pilot-applied visual separation through pass-behind instructions proved effective because it enabled earlier descents and reduced altitude-maintenance requirements.

The Generic OEM eVTOL model lacked sufficient performance to meet all route and altitude requirements, which may have contributed to controller concerns about the SHERATON route. Controllers and pilots agreed that earlier radio calls for Class B clearance improved operations by reducing the need for maneuvering outside Class B airspace, especially when frequencies were congested.

Controllers reported that significant coordination between LC2 and HC was necessary to sequence eVTOL departures into gaps in the legacy arrival flow, particularly on the LINCOLN departure route. Flying a direct post-departure heading proved more effective than maintaining a specific airspeed, and this coordination requirement warrants further evaluation through a safety risk analysis before implementation.

Vertiports located within the CTA created substantial challenges because controllers had to “hit gaps” in legacy traffic, resulting in increased workload and extensive coordination demands. Wake turbulence was also a concern for eVTOLs landing between the runway complexes. The traffic volume simulated in the HITL demonstrated that the HC position must be staffed independently rather than combined with LC2. Vertiport locations at the FBOs (Atlantic and Signature) south of all runways were viewed as more operationally independent and capable of supporting a nominal flow of six arrivals and six departures, although the procedures would require robust coordination with KHHR ATCT prior to operational use.

Additional operational complexity arose from performance disparities between legacy and eVTOL aircraft, increased mandatory traffic advisories, and the application of wake-turbulence separation standards. Missed approaches, go-arounds, and other off-nominal events further intensified controller workload and created potential safety hazards.

Although the data analysis noted one wake turbulence separation violation, wake turbulence considerations became a factor with eVTOL operations near the airport, especially with the shoreline departure routes and heavy jet missed approaches. Vertiport locations in proximity to the runway environment (e.g. within 2,500 feet of runway centerline, under or near arrival/departure routes) will require a wake safety analysis when finalized procedures are evaluated and developed. eVTOL arrival and departure routes will require wake safety analysis as procedures are developed (e.g., charted visual approaches). Off-nominal operations such as missed approaches or go-arounds would require an extensive level of ATCS coordination to maintain an acceptable level of safety and wake avoidance and will need extensive evaluation prior to operational acceptance and approval.