eVTOL Vehicle-Agnostic Instrument Flight Procedures Test Plan

Test Abstract

NASA Advanced Air Mobility National Campaign is researching the utility of electric vertical takeoff and land (eVTOL) advanced air mobility (AAM) instrument flight procedures. The result will be dynamic and tailored procedures that align to the following modus operandi: maximize *safety*, optimize *efficiency*, support *passenger comfort* and minimize *acoustic*s. This is achieved through dynamic airspace procedure design, which is a modular approach to create an airspace construct that customizes procedures to vehicle design and configuration, operation and environmental conditions. The test plan supports different eVTOL platforms and envisioned operations for flight test or simulation and may be leveraged by AAM aircraft manufacturers and operators for any given aircraft, location and operation.

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Revision History

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1	07 JUL 2023	All	Initial feedback and edits	David Zahn
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1.0 Introduction

1.1 Background

All aircraft in the National Airspace System (NAS) must currently fly under one of two sets of defined flight rules: Visual Flight Rules (VFR) or Instrument Flight Rules (IFR). VFR flight is not possible in instrument meteorological conditions (IMC). The IFR construct has additional benefits of safety and scalability compared to VFR. Generally, unless otherwise authorized, IFR aircraft must operate within Air Traffic Service (ATS) routes along airways or on routes along direct courses between navigational aids (NAVAIDS) or fixes. Instrument Flight Procedures (IFPs) are predetermined sets of maneuvers with specified protection from obstacles for safe operations and orderly traffic flow. IFPs offer benefits of standardization, obstacle clearance, noise abatement, and traffic separation. Different IFPs exist for different aircraft performance categories. Terminal IFPs are designed exclusively in accordance with very detailed standardized methods and Terminal Instrument Procedures (TERPS) criteria such as airport airspace, infrastructure, navigation facilities, obstacles, weather information and communications. Terminal IFPs are tailored to different airports with considerations for prevailing winds, geography, terrain, noise, obstacles and traffic flow. Neither IFPs nor IFP design/evaluation criteria currently exist for emerging electric Vertical Takeoff and Lift (eVTOL) aircraft, advanced air mobility (AAM), urban air mobility (UAM) operations or vertiports. The goal of this work is to support development of design criteria for UAM/AAM/eVTOL IFR-like procedures, similar to those found within the Federal Aviation Administration (FAA) 8260 series orders.

Unmanned/remotely piloted aircraft cannot currently fully comply with all requirements of VFR nor IFR. Some expression of specialized regulatory relief is typically necessary. New flight rule constructs for unmanned aircraft system (UAS) and AAM are being researched under automated flight rules (AFR). The future regulatory landscape is unknown. However, the hypothesis that underpins this research activity is that numerous potential benefits will be realized if IFR-like structured constructs and standardized IFPs are applied to future AAM and eVTOL aircraft operations. IFR-like structures for AAM will not only enable flight in IMC but also provide better standardization, predictability, consistency, and levels of safety not guaranteed by VFR-like operations. IFR-like structures will enable greater capacity for higher volumes of aircraft operations. Currently, the FAA 8260 series orders prescribe specific standardized methods for designing and evaluating IFPs for fixed wing and helicopter aircraft; the goal for this research is to contribute toward development of equivalent IFP design and evaluation criteria for eVTOL aircraft conducting AAM operations. Additional intent is to help resolve open unknowns about how standardized IFPs for AAM/eVTOL aircraft operations should be designed for the emerging needs of AAM.

Many thousands of IFPs exist for legacy aircraft and typical operations. Current IFPs are inadequate for future AAM operations for several reasons. Instrument departures and arrivals to/from the ground do not exist for rotorcraft. Fixed wing IFPs require large volumes of airspace which would be incompatible with envisioned urban operations and airspace constraints. IFPs are currently very expensive to develop due to a high degree of manual evaluation required in the design process, and the current design process is not upwardly scalable for the anticipated number of vertiports.

1.2 Dynamic Airspace Procedure Design

Overview

The research will assess tailored procedures created through Dynamic Airspace Procedure Design (DAPD). Each category of performance (*safety*, *efficiency*, *passenger comfort* and *acoustics)* is applied to each IFP variation for each phase of flight (*departure, enroute, final approach*, *missed approach*) commensurate with *vehicle design*, *configuration, operation type* and *environmental conditions* (Figure 1).

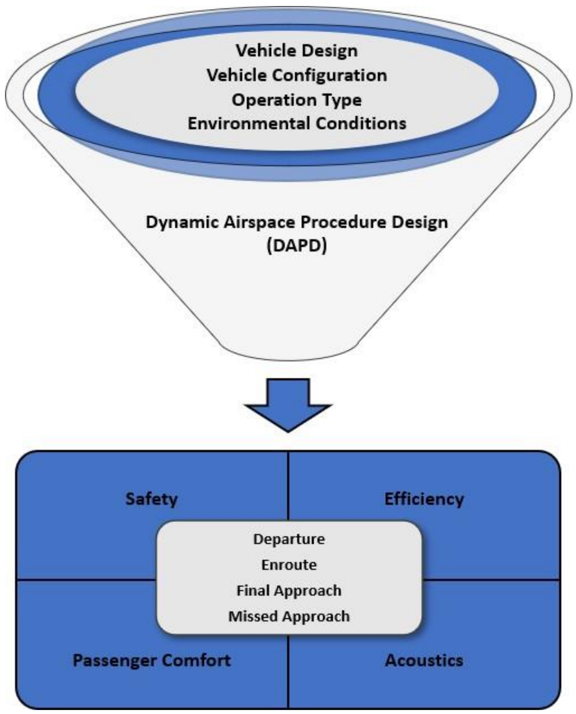

Figure 1. Dynamic Airspace Procedure Design filters and parameters

Purpose

The purpose of the flight test plan is to evaluate and accommodate new and novel vehicle design and configurations with respect to precision departure and approach procedures. The emerging state space includes new lift mechanisms and propulsion systems for various flight configurations (Figure 2). The test plan supports different eVTOL platforms and envisioned operations for flight test or simulation and may be leveraged by AAM aircraft manufacturers and operators for any given aircraft, location and operation.

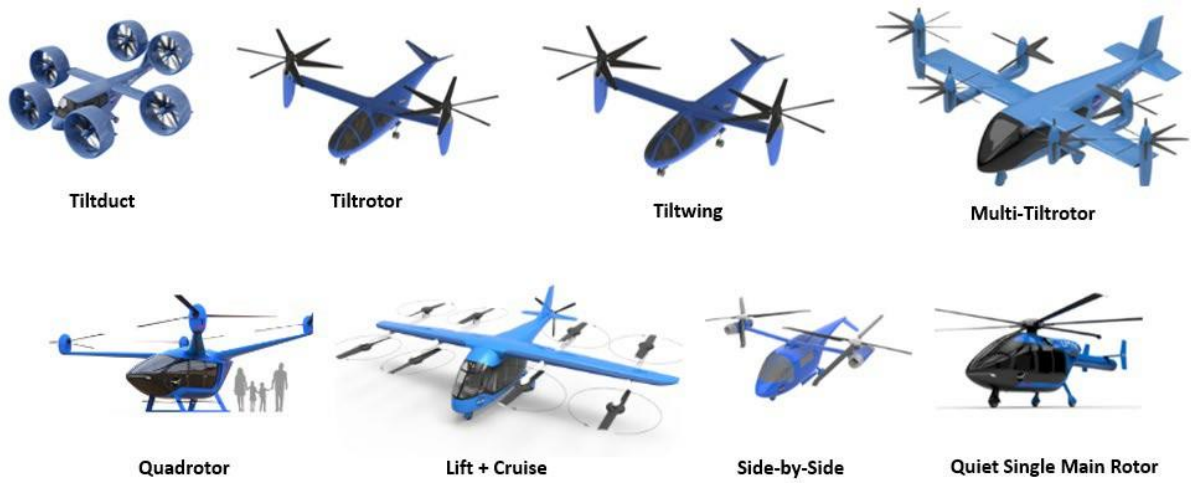

Figure 2. NASA AAM reference vehicles
credit: NASA Revolutionary Vertical Lift Technology (RVLT)

Vehicle Design & Configuration

The procedures account for vehicle design variants from tilt rotors, ducted fans, wings, lift plus cruise or single-, double-, quad- or multi-rotors. Additionally, the vehicle configuration may be on-wing, thrust-borne, or semi-thrust-borne.

Operation Type

Operation type drives the optimization applied to the procedures for the use case. A compensation-for-hire air taxi operation requires a ride quality filter applied to the terminal maneuvers. In contrast, a cargo or military operation necessitates the most efficient application based upon time and/or energy expended, respectively.

Environmental Conditions

It is critical to evaluate the performance planning characteristics associated with the environmental conditions for the time and location factors of the operation. These variables include field elevation, temperature, wind azimuth and velocity with respect to the gross weight of the vehicle.

Scalability Criteria

The candidate solutions under test need to be scalable for the commercial or military use case that envisions widespread high-density VTOL traffic. To scale adequately, the airspace architecture defined by the *departure, enroute, final approach* and *missed approach* flight segments are evaluated via four pillars: *safety, efficiency, passenger comfort* and *acoustics* (Table 1).

Table 1. Scalability criteria

SCALABILITY CRITERIA	METRICS
Safety	Clearance from terrain and vertical obstructions Vehicle operating limitations Procedure flyability

	Flight path conformance
Efficiency	Time required Airspace volume required Energy required Battery thermal performance
Passenger Comfort	Linear accelerations Rotational accelerations Jerk Rate Subjective pilot/passenger responses
Acoustics	Noise impact characterization against ground populations (commercial/residential/agricultural zoning or military implications)

The measures of performance will help inform future AAM criteria, policy, and regulations to standardize airspace evaluation and procedure development and may help avoid overtaxing FAA resources. The research aims to lay out methods to evaluate novel IFP designs for precision approaches suited for eVTOL characteristics. Eventually, tests like these may contribute to validation of candidate instrument flight procedures, which integrate a precision approach with a descent and deceleration profile to a point in space on the ground, in contrast to current helicopter approaches which end at a visual descent point which still requires a visual or VFR transition to the ground. In the future, this research could be extended to explore a conservation of airspace model and coding construct that includes departure, enroute and approach coding with waypoint restrictions covering speed, altitude, navigation and battery requirements. This research recommends a balanced approach to weigh flight path profile tradeoffs between passenger comfort, efficiency, noise and urban airspace constraints to maximize public acceptance for a scalable AAM airspace architecture (Figure 3).

Vehicle Configuration	Tiltduct	Tiltwing	Lift-plus-Cruise		Quadrotor		Side-by-Side		SMR
Propulsion System	DD TE	DD TE	DD TE	DD E	CS TS	CS E	CS TS	CS E	TS
Design gross weight (lb)	7089	6750	8190	8210	3740	6480	3470	4900	3740
(Prop)rotor diameter (ft)	7.08	7.33	10	10	18.4	26.2	21	29.8	34.5
Hover disk loading, T/A_R	30	20	13.1	13.1	3.5	3	5	3.5	4
Aircraft hover figure of merit	0.76	0.7	0.63	0.74	0.69	0.7	0.69	0.68	0.62
Cruise airspeed, V_{br} (kt)	151	148	128	112	122	98	116	98	102
Block speed (kt)	115	117	101	91.7	105	87.1	97	82.6	77.4
$L/D_e = WV_{br}/P$	9.1	8.7	7.9	8.5	4.9	5.8	5.9	7.2	5.4
Cruise wing area (ft^2)	229	128	256	275	N/A	N/A	21.3	42.9	N/A
Energy burn (MJ)	3170	3280	4260	1110	2670	1070	2210	686	2550
Weight/lift power (lb/hp)	7.32	6.03	6.65	7.4	12.8	14	10.7	12.6	10.5
Weight/cruise power (lb/hp)	19.6	20.3	22.5	24.9	13.1	18.4	16.9	24.4	16.9

Figure 3. NASA AAM reference vehicles design parameters
credit: NASA Revolutionary Vertical Lift Technology (RVLT)

1.3 Test Objectives Overview

The objectives and measures of the IFP test plan are partitioned into a structure of general test objectives (GTOs), specific test objectives (STOs) and measures of performance (MOPs) (Tables 3). These GTOs, STOs and MOPs have direct traceability to the former overarching subproject-level NC Objective #2 and can be summarized by the overall test activity objective (Table 2).

Table 2. High-level objectives

RESEARCH HIGH-LEVEL OBJECTIVES	
Overarching NC-1 Objective	**NC #2 - Develop Flight Procedure Guidelines** Develop preliminary guidelines for flight procedures and related airspace design criteria.
Overall Test Activity Objective	Assess the scalability of candidate Instrument Flight Procedures (IFPs) for AAM eVTOL aircraft to contribute to standardized methods for designing and evaluating AAM eVTOL IFPs akin to FAA Order 8260 series for fixed wing and helicopter aircraft.

Table 3. Test objectives

RESEARCH TEST OBJECTIVES							
GTO 1	**‘Dynamic procedure design’ Instrument flight procedures design criteria** Evaluate suitability and operational safety of candidate AAM/eVTOL IFP ‘dynamic procedure design’ design criteria, across different climb gradients including fast acceleration, optimized climb, and precision climb; different final and missed approach segments at steeper 5°, 8° and 12° glide paths both manually flown and with increased automation modes.						
STO 1.1	**Terminal Infrastructure** Validate potential/proposed requirements for obstacle clearance surfaces and vertiport landing area dimensions for eVTOL IFR operations.						
OBJECTIVES		Prior to Test	Departure	Enroute	Final Approach	Missed Approach	After Test
MOP 1.01	Experimental ‘dynamic procedure design’ IFP development in TARGETS and OEA execution for area that corresponds to dynamic procedure design radii for 5°, 8° & 12° glidepath angles.	X					
MOP 1.02	Characterize landing area scatter to partially validate potential TLOF, FATO & SA dimensions				X		
STO 1.2	**IFP Coding & Instrument Approach Plates** Validate usability and simplicity of candidate ‘dynamic procedure design’ IFP coding (ARINC 424) and instrument approach plate for AAM eVTOL use case.						
OBJECTIVES		Prior to Test	Departure	Enroute	Final Approach	Missed Approach	After Test
MOP 1.2.01	AAM candidate IFP code creation and ground validation via FIAPA	X					
MOP 1.2.02	eVTOL flight management system data ingestion	X					
MOP 1.2.03	Correct display of nav guidance on PFD and route on MFD	X					
MOP 1.2.04	IFP execution by pilot per primary flight display guidance (not coupled)		X	X	X	X	
MOP 1.2.05	Flight guidance execution through vehicle control system (fully coupled)		X	X	X	X	
MOP 1.2.06	Manual instrument flight procedure execution using paper instrument approach plate		X	X	X	X	

MOP 1.2.07	Assess code complexity (number of legs) for dynamic procedure design versus standard IFPs (sum total of MA, departure, arrival), normalized for number of departure & arrival azimuths		X					
MOP 1.2.08	Assess ability to easily duplicate dynamic procedure design code at disparate locations/vertiports, versus conventional IFP development							X
STO 1.3	**<u>Instrument Flight Procedures</u>** **Departure** - Validate and qualitatively assess candidate departure procedures including departure from hover taxi, departure from rolling taxi, and vertical takeoff using both pilot- and autopilot-flown departures. **Enroute -** Validate candidate enroute procedures using both pilot- and autopilot-flown routes across different altitude, airspeed, transition, and intercept designs. **Final Approach** - Validate and qualitatively assess candidate final approach procedures using both pilot- and autopilot-flown approaches across different altitudes, airspeeds, descent gradients, decelerations, transition rates, intercept angles and glide path angles (5°, 8°, 12°). Aircraft or simulator tests will include assessment at maximum speeds, worst -case winds and temperature limits. **Missed Approach** - Validate and qualitatively assess different candidate missed approach procedures for terminal area operations. Aircraft or simulator tests will include assessment at max speeds, worst-case winds and temperature limits.								
OBJECTIVES			Prior to Test	Departure	Enroute	Final Approach	Missed Approach	After Test
MOP 1.3.01	Safety	Navigation data verification for desired path		X	X	X	X	
MOP 1.3.02	Safety	Aircraft climb/descend path		X		X	X	
MOP 1.3.03	Safety	Qualitative pilot assessment of procedure flyability, safety and design		X	X	X	X	
MOP 1.3.04	Safety	Vertical flight technical error (FTE_V)		X	X	X	X	
MOP 1.3.05	Safety	Lateral flight technical error (FTE_L)		X	X	X	X	
MOP 1.3.06	Safety	Total System Error (TSE)		X	X	X	X	
MOP 1.3.07	Safety	4D Trajectory conformance (Predicted vs. Actual)		X	X	X	X	
MOP 1.3.08	Safety	Along-track (ATT) tolerance			X			
MOP 1.3.09	Safety	Cross-track (XTT) tolerance			X			
MOP 1.3.10	Safety	Vertical-track (VTT) tolerance			X			
MOP 1.3.11	Safety	Flight plan conformance timing			X			
MOP 1.3.12	Safety	Flight plan conformance required bank angles			X			
MOP 1.3.13	Safety	Predicted NIC-NAC-SIL-SDA message reporting			X			
MOP 1.3.14	Safety	Predicted NIC-NAC-SIL-SDA message latencies			X			
MOP 1.3.15	Safety	Distance of Reaction and Roll (D_{RR})					X	
MOP 1.3.16	Safety	Flat Surface Length (FSL)					X	

MOP 1.3.17	Safety	Distance of Height Loss (2σ)					X	
MOP 1.3.18	Safety	Approach Angle Divergence					X	
MOP 1.3.19	Safety	Height of Missed Approach Surface (HMAS)					X	
MOP 1.3.20	Safety	Departure Intercept Point (DIP)					X	
MOP 1.3.21	Efficiency	Energy required		X	X	X	X	
MOP 1.3.22	Efficiency	Battery temperature increase		X	X	X	X	
MOP 1.3.23	Efficiency	Minimization of airspace volume		X	X	X	X	
MOP 1.3.24	Efficiency	Minimization of time duration		X	X	X	X	
MOP 1.3.25	Pax Comfort	Linear acceleration (x,y,z)		X	X	X	X	
MOP 1.3.26	Pax Comfort	Rotational acceleration (pitch, roll and yaw)		X	X	X	X	
MOP 1.3.27	Acoustics	Acoustic signature (Peak dB / Average dB)		X	X	X	X	

2.0 Test and Evaluation

2.1 Test Approach

Test data should be collected across the available spectrum of aircraft automation, including operating the aircraft in both manually piloted and "autopilot" modes to the maximum extent possible. Testing should collect data from multiple pilots to characterize the Total System Error (TSE)/Flight Technical Error (FTE) scatter, skew and deviations with the best statistical strength possible. Candidate ARINC 424 coding should be uploaded into the eVTOL Flight Monitoring System (FMS) to include lateral and vertical guidance and waypoint restrictions. An in-depth knowledge of the vehicle operating limitations and flight envelope will be required to test tailored procedures to a specific aircraft design.

2.2 Test Objectives

GTO 1.0 Flight Profile Design Criteria

The primary test GTO (Table 4) is decomposed into three STOs. All STOs together will evaluate and inform the viability of the candidate AAM/eVTOL 'dynamic procedure design' IFP construct.

Table 4. GTO 1.0 objectives

GENERAL TEST OBJECTIVE	
GTO 1.0	**‘Dynamic procedure design’ Instrument flight procedures design criteria** Evaluate suitability and operational safety of candidate AAM/eVTOL IFP design criteria, across different climb gradients including fast acceleration, optimized climb, and precision climb; different final and missed approach segments at steeper 5°, 8° and 12° glide paths; and both manually flown and “autopilot” (increased automation) modes.
SPECIFIC TEST OBJECTIVES	
STO 1.1	Validate potential/proposed requirements for **obstacle clearance surfaces** and **vertiport landing area dimensions** for eVTOL IFR operations.
STO 1.2	Validate usability of candidate “dynamic procedure design” **IFP coding** (ARINC 424) and **instrument approach plate** for AAM eVTOL use case.
STO 1.3	**Instrument Flight Procedures** Validate procedures across each test phase of flight. **Departure** - Validate and qualitatively assess candidate departure procedures including departure from hover taxi, departure from rolling taxi, and vertical takeoff using both pilot- and autopilot-flown departures. **Enroute -** Validate candidate enroute procedures using both pilot- and autopilot-flown routes across different altitude, airspeed, transition, and intercept designs. **Final Approach** - Validate and qualitatively assess candidate final approach procedures using both pilot- and autopilot-flown approaches across different altitudes, airspeeds, descent gradients, decelerations, transition rates, intercept angles and glide path angles (5°, 8°, 12°). Aircraft or simulator tests will include assessment at maximum speeds, worst -case winds and temperature limits. **Missed Approach** - Validate and qualitatively assess different candidate missed approach procedures for terminal area operations. Aircraft or simulator tests will include assessment at max speeds, worst-case winds and temperature limits.

Dynamic procedure design Overview

The candidate terminal airspace construct, termed ‘dynamic procedure design,’ can be easily adjusted, flexed, or retracted at time of design for a specific vertiport location and aircraft configuration to account for airspeed, obstacles and winds enabling on-demand departure and approach procedures. The departure and approach radius are defined by vehicle performance and the altitude will account for any controlling obstacle(s) as seen in Figure 4. The usable portion of the ‘dynamic procedure design’ upside-down cone may be easily limited to certain sectors (pie slices) of the cone, or certain sectors (pie slices) could be easily removed based on outcomes of a streamlined obstacle evaluation and airspace analysis process when the ‘dynamic procedure design’ is first designed for a given vertiport location.

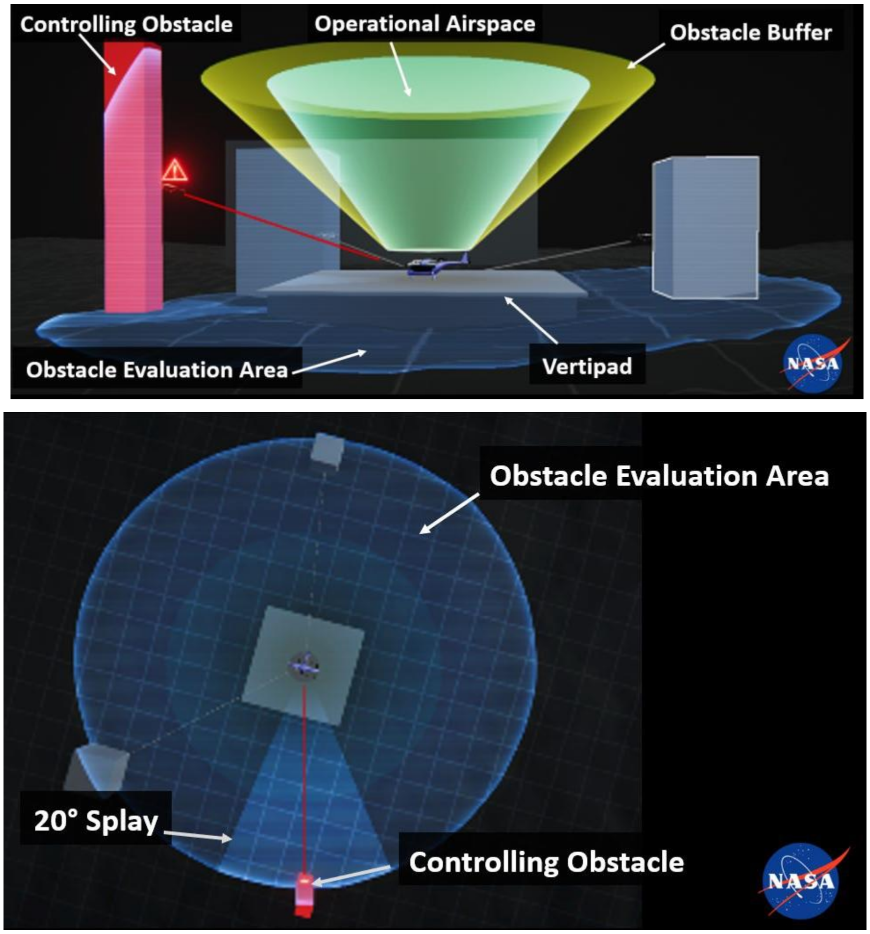

Figure 4. Candidate 'dynamic procedure design' terminal airspace construct profile (top) and overhead (bottom)

STO 1.1 Vertiport Landing Area Dimensions and Obstacle Clearance Surfaces

This STO covers development of the novel dynamic procedure design IFP in Terminal Area Route Generation Evaluation and Traffic Simulation (TARGETS) with an appropriately tailored OE/AAA and data collection to help inform landing area dimension requirements to constitute two supporting MOPs (Table 5).

Table 5. STO 1.1 objectives

SPECIFIC TEST OBJECTIVES	
STO 1.1	Validate potential/proposed requirements for **obstacle clearance surfaces** and **vertiport landing area dimensions** for eVTOL IFR operations.
MEASURES OF PERFORMANCE	
MOP 1.1.01	Experimental 'dynamic procedure design' IFP development in TARGETS and OEA execution for area corresponding to 5°, 8° & 12° glidepath angle 'dynamic procedure design'.
MOP 1.1.02	Characterize landing area scatter to partially validate TLOF, FATO & SA dimensions

Background on TARGETS

The NAS consists of an inventory of approximately 20,000 approach, arrival, departure, and enroute IFPs. This inventory of conventional and Performance-based Navigation (PBN) procedures must be continuously evaluated as IFPs are added or canceled, navigational aids are implemented or discontinued, new obstacles are identified, airspace is redesigned, and regulations evolve. The TARGETS system is the FAA's enterprise solution for that mission. The TARGETS tool was developed by MITRE and sponsored by the FAA. It has capabilities for design, analysis, and operational assessment of air traffic procedures and airspace. TARGETS incorporates data visualization with design elements to enable procedure designers to run simulations. The data output is formatted to support operational, certification, and charting needs.

Construction in TARGETS

TARGETS is expected to be capable of creating the novel dynamic procedure design IFP, but several abnormal workarounds are expected to be required. TARGETS has been developed to enable procedure designers to create IFPs that meet current TERPS requirements for legacy aircraft and navigation methods. TARGETS essentially enables and enforces IFP design to adhere to current IFP design criteria, with which the novel candidate dynamic procedure design construct is not compatible. The procedures will be developed in FAA TARGETS Computer-aided Design (CAD) software for MOP 1.1.01. There are three coding ‘dynamic procedure design’ rings: Initial approach fix (IAF) | holding ring (outer circle), transition ring for coding purposes and alignment (middle circle) and precision final approach fix (PFAF) | final approach ring (inner circle) (Figure 5). Construction for dynamic procedure design rings is derived from the horizontal distance of the vertipoint to PFAF which is consequent from the desired glidepath angle at a given speed and a resultant PFAF altitude. Dynamic procedure design rings maintain an equivalent level of safety for emerging eVTOL aircraft. Operation on the dynamic procedure design ring requires on airspeed by the holding ring. Additionally, the vehicle is ‘at airspeed’ by the holding ring and ‘at altitude’,’ at airspeed’ and ‘at wings level’ by the final approach ring.

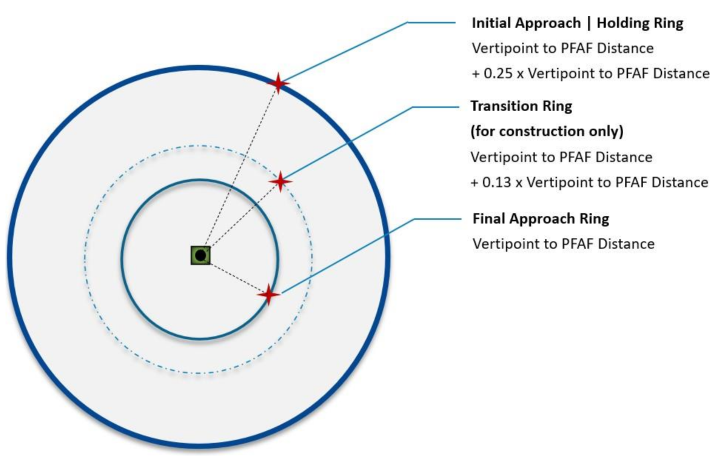

Figure 5. TARGETS ‘dynamic procedure design’ construction

MOP 1.1.01: TARGETS and OE/AAA execution

MOP 1.1.01 is a precursor before coding the procedure in ARINC 424. MOP 1.1.01 describes development of the dynamic procedure design IFP in the FAA's TARGETS application in conjunction with execution of an Obstruction Evaluation/ Airport Airspace Analysis (OE/AAA), which are the typical first steps required for any terminal IFP (Table 6). This MOP does not involve or require any aircraft original equipment manufacturer (OEM) simulator or flight testing. The FAA's AJV group will execute this MOP, with exit criteria for successful creation of the dynamic procedure design IFPs in TARGETS, with the IFPs properly designed/limited considering any obstacles and airspace limitations, all associated TARGETS process outputs, and a record of all TARGETS abnormal workflows/criteria violations.

Background on OE/AAA

After a new IFP is created in TARGETS, the system also enables an OE/AAA. Detailed obstacle clearance surface requirements exist for legacy aircraft and terminal IFPs but not for UAM/eVTOL. An Obstacle Evaluation Assessment Area (OEAA) is established from any landing surface outbound towards an approach path. This assessment area is used to evaluate terrain, vertical obstructions and airspace penetrations. Once the outer dimensions of the assessment area are established and vertical obstructions are populated within the evaluation plane, the vertical component will be evaluated against the minimum climb gradient required for a departure or against a rise over run obstacle clearance slope from the landing surface. Executing this process for the candidate dynamic procedure design IFP will enable an omni-directional evaluation, which would provide scalability and increased operational flexibility for UAM. Due to the inherent simplicity, repeatability, and versatile nature of the candidate dynamic procedure design IFP, vertiport evaluations and procedure development will be greatly streamlined in contrast to current fixed wing terminal IFPs, which are highly complex and highly variable/unique from one to another. The 'dynamic procedure design' provides standardization and a streamlined UAM IFP architecture versatility for any location. An eVTOL dynamic procedure design IFP would provide precision for instrument departures and arrivals to and from the ground, which does not currently exist for rotorcraft. Currently, instrument procedures are uniquely customized for each airport runway and individually tailored to the runway centerline using manually intensive evaluation criteria.

Table 6. TARGETS and OE/AAA test details

COMPONENT	TARGETS and OE/AAA TEST DETAILS
MOP 1.1.01	Experimental 'dynamic procedure design' IFP development in TARGETS and OEA execution for area corresponding to 5°, 8° & 12° glidepath angle.
Evaluation Criteria	Ensure criteria meets or exceeds safety ratios or surface slopes set for heliport and vertiport surface evaluation in concurrence with IFR operations.
Test Methodology	Within TARGETS software system (but must currently be done manually): 1. AJV- Define outer boundaries of SA 2. AJV- Measure distance from TLOF center point to PFAF 3. AJV- Draw RNP values left and right of centerline 4. AJV- Connect SA boundaries with outermost RNP boundaries at PFAF 5. AJV-A- Reduce wheel ring segments (20° splay of vertiport reference point to obstacle) to protect all airspace constraints against the departure criteria (worst case rate of climb – manual hover 300 ft/nautical mile (NM) (worst case split between fixed wing and rotorcraft)) (76% OCS for terrain/obstacles departure evaluation criteria)

<table>
<tr><td>Success Criteria</td><td colspan="2">MOP is complete when OEA has been applied to all planned vertiport locations for each worst-case departure climb with nominal winds.</td></tr>
<tr><td>Data Requirements</td><td>AJV</td><td>1. TARGETS procedure file
2. TARGETS IFP criteria violations/flags and workaround steps (and/or any process steps that were atypical or non-obvious)
3. TARGETS sequential steps to manually build procedures</td></tr>
<tr><td>Asset Requirements</td><td colspan="2">1. TARGETS file & output
No EVTOL simulator or flight test required.</td></tr>
<tr><td>Data Analysis</td><td colspan="2">1. N/A</td></tr>
<tr><td>Final Data Product</td><td colspan="2">1. Summary of steps to manually apply procedures in TARGETS
2. TARGETS program outputs, after completed OE/AAA, to feed ARINC coding and charting</td></tr>
<tr><td rowspan="3">Test Points</td><td colspan="2">1.1.001 Evaluation at Vertiport #1</td></tr>
<tr><td colspan="2">1.1.002 Evaluation at Vertiport #2</td></tr>
<tr><td colspan="2">1.1.003 Evaluation at Vertiport #3</td></tr>
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Background on related FAA guidance

In 2022 the FAA released Engineering Brief No. 105 “Vertiport Design,” which was only scoped for VFR operations with a pilot on board and did not address IFR, "autonomy" or unmanned operations. The draft vertiport design engineering brief did provide related guidance for VFR vertiport approach, departure and transitional surfaces, which must be clear of penetrations unless an FAA aeronautical study determines the penetrations not to be hazards. These VFR surfaces are not valid for IFR operations. If these VFR surfaces were inappropriately applied to IFR, they would equate to RNP 0.04 (if the 95% TSE requirement was set to 250’, with only 500’ full left to right for approach and departure surfaces and 4000’ horizontally from the FATO), which is not currently obtainable. For IFP testing, apply RNP 0.1 (95% TSE = 607.6’) with 1215’ for the full left to right final approach segment (FAS) entry surface width. RNP Authorization Required (AR) approaches support the lowest RNP value in initial, intermediate, final and missed approach segments. However, design criteria for RNP AR only supports RNP values down to 0.1. The intent of this research is to design and test a built-in descent and deceleration using the lowest possible current RNP criteria.

MOP 1.1.01 will measure if the dynamic procedure design can be successfully modeled in TARGETS in conjunction with an OE/AAA. The usable dynamic procedure design sectors and IFP obstacle clearance surfaces that result will be whatever they are, based on real world obstacles and airspace constraints for the vertiport locations where the dynamic procedure design is created. Analysis of the MOPs for TSE and Flight Technical Error (FTE) for departure, approach and missed approach will permit evaluating if the obstacle surfaces designed as part of this MOP were appropriate. Candidate anticipated obstacle clearance surfaces are envisioned to accommodate various glide paths for the aircraft or simulator eVTOL aircraft. A top-down view for one approach heading is shown in Figure 6.

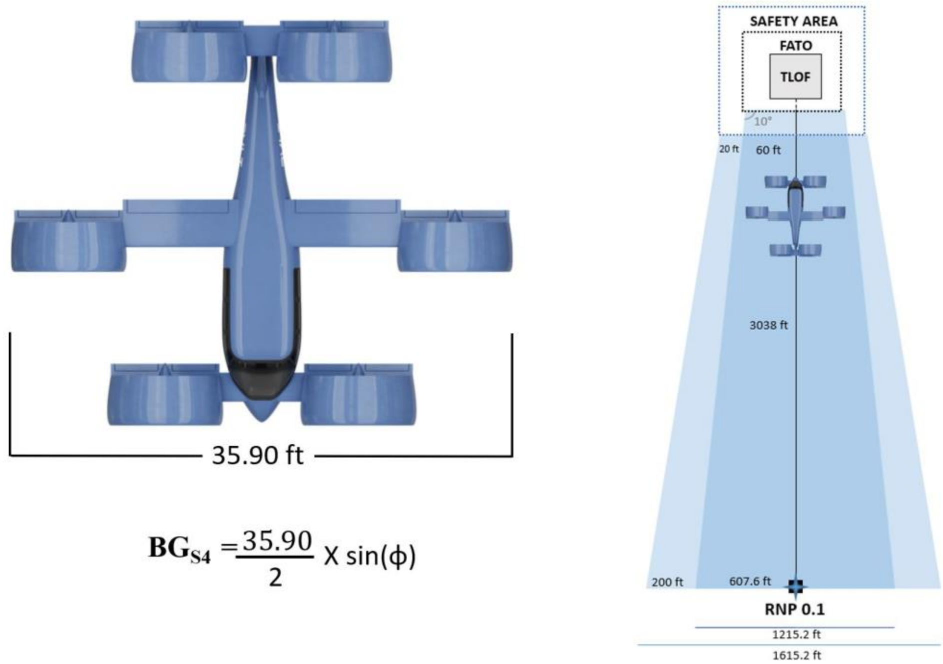


Figure 6. Candidate NASA UAM representative vehicle (left) candidate RNP 0.1 landing surfaces diagram (right)

(Note –candidate image not drawn to scale)

MOP 1.1.02 Characterize landing area scatter to partially validate TLOF, FATO & SA dimensions

The landing area should be assessed via eVTOL simulator or flight test. Both manual with flight-directed guidance and autopilot augmentation (maximizing automation available or fully coupled) with flight-directed guidance should be tested in MOP 1.1.02 (Table 7). Statistical analysis will be run against the landing area lateral scatter data to contribute toward potential appropriate TLOF, FATO and safety area dimensions for candidate AAM operations.

Table 7. Landing scatter test details

COMPONENT	LANDING SCATTER TEST DETAILS
MOP 1.1.02	Characterize landing area lateral scatter to partially validate candidate TLOF, FATO & SA dimensions
Evaluation Criteria	Collect scatter data to determine if TLOF, FATO & SA dimensions in the FAA *Engineering Brief No. 105, Vertiport Design* appear adequate for IFR operations.
Test Methodology	1. This MOP reflects identical test points to STO 1.5 Final Approach and will be evaluated through STO 1.5 landings. 2. Determine center point lat/lon of TLOF (vertipoint) 3. Test conductor calls out when aircraft first crosses FATO boundary

	4. Pilot or aircraft automation executes vertical landing targeting center of the landing pad
Success Criteria	MOP is complete when all final approaches (no MA) are complete through landing.
Data Requirements	1. Record final touchdown lat/lon for each approach 2. Record lateral deviations from vertipoint
Asset Requirements	1. Vertipoint lat/lon 2. eVTOL simulator or flight test
Data Analysis	1. Assess statistical deviance from TLOF center point (vertipoint)
Final Data Product	1. Statistical summary for flight path landing deviations
Definitions	Manual: No use of automation Autopilot: Maximum use of automation
Test Points	Use 1.5 Final approach test points 1.5.001-1.5.017

STO 1.2 – Coding & Instrument Approach Plate

The STO 1.2 is a precursor to simulator or flight test to assure that the novel candidate 'dynamic procedure design' instrument flight procedure (IFP) ARINC 424 coding is feasible for ingestion, readable, and potentially useful and efficient for the UAM use case. The 'dynamic procedure design' synthesizes all individual legs or a condensed short-haul flight into one lengthened ARINC 424 code sequence inclusive of all waypoints (Table 8). In the future, additional waypoint requirements that could relate to speed or energy reserve may be explored via STO 2.2 in this flight test plan.

Table 8. STO 1.2 objectives

SPECIFIC TEST OBJECTIVE	
STO 1.2	Validate usability and efficiency of candidate 'dynamic procedure design' **IFP coding** (ARINC 424) and **instrument approach plate** for UAM eVTOL use case.
MEASURES OF PERFORMANCE	
MOP 1.2.01	UAM candidate IFP code creation and ground validation via FIAPA
MOP 1.2.02	eVTOL flight management system data ingestion
MOP 1.2.03	Correct display of navigation guidance on PFD and route on MFD
MOP 1.2.04	IFP execution by pilot per primary flight display guidance (not coupled)
MOP 1.2.05	Flight guidance execution through vehicle control system (fully coupled)
MOP 1.2.06	Manual instrument flight procedure execution using paper instrument approach plate
MOP 1.2.07	Assess code complexity (number of legs) for dynamic procedure design versus standard IFPs (sum of MA, departure, arrival), normalized for number of departure & arrival azimuths
MOP 1.2.08	Assess ability to easily duplicate dynamic procedure design code at disparate locations/vertiports, versus conventional IFP development

Coding Overview

The activity is testing high-precision point in space operations with RNP 0.1 (1215.2 ft length) final approach segment to the vertipad safety area of 120 ft (RNP 0.019). The obstacle evaluation area (OEA) scaling is represented in Figure 5. Modern PBN navigation specifications rely on aircraft automation and flight guidance to maintain the flight path. New coding guidance within DO-236 may be required to govern advanced RNP targets needed for the safe and scalable future of AAM operations. The FAA is developing a candidate code that can be standardized and validated through existing FAA Flight Check mechanisms.

Coding Background

Every segment of every IFR departure, enroute segment, arrival and approach is a specific type of leg. Each leg is coded using a two-letter identifier that is entered as code (ARINC 424 legs) in the navigation database, and IFPs are sequences of those legs. There are 23 ARINC 424 leg types that have been created to be digested and used by the FMS. The legs are also known as "path terminators" because they describe the path or action to be taken on that leg and show where that path will end so the next leg can begin. Flight plans are entered in the FMS by chaining procedures from the navigation database together.

RNP procedures require the repeatability and predictability of a specified ground track. The dynamic procedure design wheel will be built using a combination of legs. A Radius-to-Fix (RF) leg is defined as a constant radius circular path around a defined turn center that terminates at a fix. A Track-to- Fix (TF) leg is intercepted and acquired as the flight track to the following waypoint. TF legs are sometimes called 'point-to-point' legs for this reason. The procedures should be constructed using only DO-236 preferred leg types (TF, RF) because they are fixed and not subject to different executions.

Coding Assumptions

Tailored ARINC 424 coding with TF leg types on Final Approach and RF leg types for the intermediate and final approach alignment. The eVTOL vehicle FMS should be capable to ingest candidate UAM ARINC 424 coding (Figure 7) and display flight guidance on a pilot display with the same level of precision with the departure, route, and approach coding. Ingesting experimental coding can be challenging for some eVTOL OEMs, and opportunities to involve the navigation database vendor should be explored.

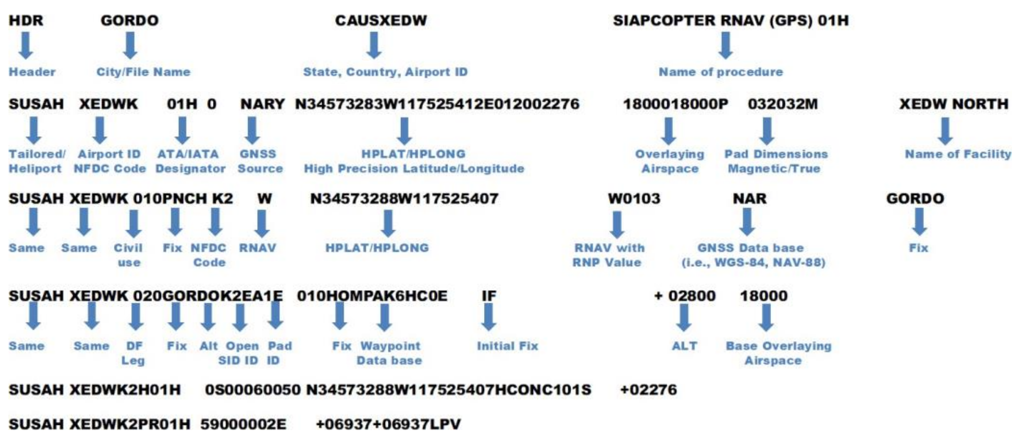


Figure 7. FAS Data ARINC 424 coding

Code Validation

The code and airspace constructs created in TARGETS by FAA AJV-A for STO 1.1 should be validated by FAA Flight Operations Flight Check using the Flight Inspection Airborne Processing Application (FIAPA) software desktop simulation by FAA AJF (Table 9). The initial files of the dynamic procedure design IFP procedures are intended to be compatible with initial envisioned eVTOL performance and operations.

Table 9. Coding design test details

COMPONENT	CODING DESIGN TEST DETAILS
MOP 1.2.01	UAM Candidate IFP Code creation and Ground Validation via FIAPA

Evaluation Criteria	ARINC 424 format confirmed capable of enabling dynamic procedure design procedure with no errors	
Test Methodology	1. Develop ARINC 424 code for UAM IFPs (AJV-A) 2. FAA execute flight check ground run for FIAPA code validation (AJF) via desktop simulator 3. Ensure packaging, spatial data validation, and investigate for any errors	
Success Criteria	MOP is complete when FIAPA code validation process completed.	
Data Requirements	FAA AJV	1. Provide NC documented results/outputs from code validation process
Asset Requirements	1. TARGETS 2. Dynamic procedure design ARINC 424 code 3. FAA AJF FIAPA desktop software for IFP code validation eVTOL simulator and/or flight test not required.	
Data Analysis	N/A	
Final Data Product	1. Loadable & correct IFP database code 2. AJF validation findings	
Test Points	1.2.001 Create code combining UAM departure, enroute and approach ARINC 424 coding in “dynamic procedure design” model to include Radius-to-Fix alignment to Track-to-Fix Final with Altitude and speed restrictions	
	1.2.002 AJF Flight check ground run coding validation through FIAPA simulator desktop	

Coding Ingestion

The validated code will then be ingested into the eVTOL FMS for test in simulator or flight test and verified via MOP 1.2.02 - MOP 1.2.06 (Table 10):

Table 10. Coding ingestion test details

COMPONENT	CODING INGESTION TEST DETAILS
MOP 1.2.02	eVTOL Flight Management System Data Ingestion
Evaluation Criteria	Successful eVTOL FMS ingestion of candidate procedures (ARINC 424 to binary to FMS/C) in aircraft avionics, and limits/tailoring for Collins/Universal packing tool are not violated
MOP 1.2.03	Correct display of navigation guidance on PFD and route on MFD
Evaluation Criteria	Candidate procedure code results in correctly displayed flight guidance on PFD and correctly displayed route info on Multi-Function Display
MOP 1.2.04	IFP execution by pilot per primary flight display (not coupled)
Evaluation Criteria	PFD flight guidance able to be executed/followed by pilot in loop (not coupled), allowing for successful IFP execution by pilot
MOP 1.2.05	Flight guidance execution by vehicle control system (fully coupled/ maximum use of automation)
Evaluation Criteria	Flight guidance successfully executed by vehicle control system when fully coupled / ‘autopilot’ augmentation mode active/ using maximum vehicle automation
MOP 1.2.06	Manual instrument flight procedure execution using paper instrument approach plate
Evaluation Criteria	Pilot considers approach plate clear and useable for manual execution and the procedure executes without issues. Procedure portrays properly on charts and is easily interpreted. Evaluate the proposed charting for correctness, clarity, and ease of interpretation
Test Methodology	1. Provide input flight path coding to the eVTOL FMS 2. Pilot/FTE Verify flight path navigation guidance displayed properly on primary flight display 3. Pilot/FTE Verify flight route displayed properly on multi-function display 4. Pilot verify PFD flight guidance able to be executed with pilot in loop (not coupled)

	5. Pilot/FTE Verify flight guidance able to be executed by aircraft automation (fully coupled/ aircraft mode that provides maximum automation/ "autopilot" function active) 6. Pilot manually reviews and executes an approach using a paper instrument approach plate, provides comments if instrument approach plate is clear and useable 7. Code-related test points complete when ingestion of coding is successful, and display and flight guidance determined live & useable/executable. Instrument approach plate test point complete after review and cursory manual execution of approach plate.	
Success Criteria	MOP complete when all test method steps executed successfully once.	
Data Requirements	eVTOL OEM	1. Qualitative record that evaluation criteria has been met from pilot/FTE (no data logs required)
Asset Requirements	1. Validated dynamic procedure design IFP code 2. Printed Instrument Approach Plate for human consumption 3. eVTOL or eVTOL simulator	
Data Analysis	N/A	
Final Data Product	1. Record if evaluation criteria for all MOPs was satisfied	
Test Points	1.2.003 Determine coding ingestion process/capability in partner FMS	
	1.2.004 Authenticate correct display of navigation guidance on PFD and route on MFD from coding	
	1.2.005 Manual using PFD guidance	
	1.2.006 Autopilot (maximum automation)	
	1.2.007 Manual (no FMS, no PFD--just paper instrument approach plate)	
	1.2.008 Determine coding ingestion process/capability in partner FMS	
	1.2.009 Authenticate correct display of navigation guidance on PFD and route on MFD from coding	

Coding Feasibility

A comparison of the scalability for the new procedures vs. standard IFPs will be conducted for MOP 1.2.07 - MOP 1.2.08 (Table 11):

Table 11. Coding feasibility test details

COMPONENT	CODING FEASABILITY TEST DETAILS
MOP 1.2.07	Assess code complexity (number of legs) for dynamic procedure design versus standard IFPs (sum total of MA, departure, arrival), normalized for number of departure & arrival azimuths
Evaluation Criteria	Quantify number of 'dynamic procedure design' legs when normalized is less than standard fixed wing IFPs
MOP 1.2.08	Assess ability to easily duplicate dynamic procedure design code at disparate locations/vertiports, versus conventional IFP development
Evaluation Criteria	Qualify improved versatility to apply the 'dynamic procedure design' ARINC code to other vertiports
Test Methodology	1. FAA AJV-A/AFS 400 subject matter expert (SMEs) and NC TERPS/coding SMEs review code & compare it to standard IFPs for both fixed wing and helicopters as reference baselines.
Success Criteria	MOP completes when FAA & NC SMEs review code, make comparison and reach determinations.

Data Requirements	SME determinations will be written/documented.
Asset Requirements	1. Dynamic procedure design Code eVTOL OEM simulator/ flight test not required.
Data Analysis	N/A
Final Data Product	1. SME findings to include FAA to quantify legs and qualify ARINC 424 coding scalability
Test Points	1.2.10 Assess code complexity 1.2.11 Assess scalability of code to another vertiport

FAA TARGETS

The TARGETS system is an FAA tool to automate evaluation of fixed-wing procedures using existing criteria. TARGETS will not evaluate against rotorcraft procedures nor UAM/eVTOL procedures (criteria for which does not yet exist). The system connects to Instrument Flight Procedures Automation (IFPA): IFP fix, OE/AAA (40 NM range of obstructions), terrain manually loaded (Digital Terrain Elevation Data (DTED-1) (later will use DTED-2)), AIRNAV (NAVAIDS, airports), worst-case winds or historical 5-yr average. Next, aeronautical information specialists apply the procedure to standard instrument approach procedures (SIAP) database for approaches or apply the results from TARGETS work in a manual process. Finally, the prerequisites for ARINC 424 coding are compiled for the FAA coders. Evaluation areas can be manually bound within the CAD software tool to assess flat and sloped surfaces. For the UAM/eVTOL activity, the aeronautic information specialist manually created the procedure within TARGETS. In the future, TARGETS may be coded to automate this process once applicable criteria can be developed and approved.

UAM/eVTOL IFP Differences

Several IFP components designated for the activity are novel to existing criteria and operations (Table 12):

Table 12. IFP guidance components

IFP COMPONENT	GUIDANCE COMPARISON
Glideslopes	Glideslopes currently programmed for fixed wing up to 7.5° (24% of value for the glideslope clearance; OCS is 76% against terrain) Candidate UAM eVTOL glideslopes are researched at 5°, 8° & 12°
Precision to Ground	UAM/eVTOL requires precision to surface while helicopter procedures consist of Point in Space (PinS) followed by VFR to ground

STO 1.3 – Instrument Flight Procedures

The purpose of this STO is to characterize the safety, efficiency, passenger comfort and noise signature of different candidate eVTOL/UAM instrument phase of flight profiles (Table 13). This STO will enable the identification of the relative strengths and weaknesses of the different candidate procedures, considering the four components of IFP scalability (safety, efficiency, passenger comfort and acoustics) (Table 14).

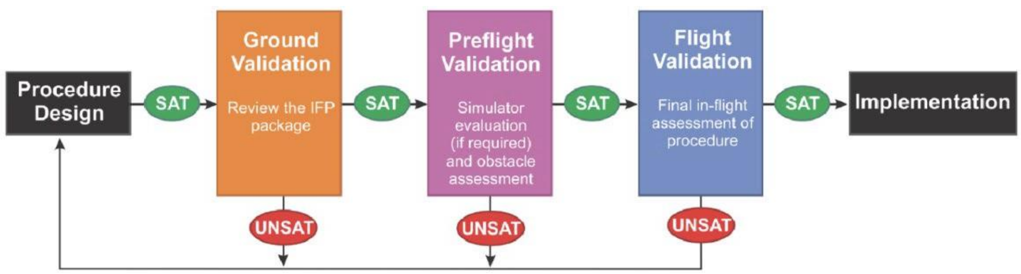
Table 13. STO 1.3 objectives

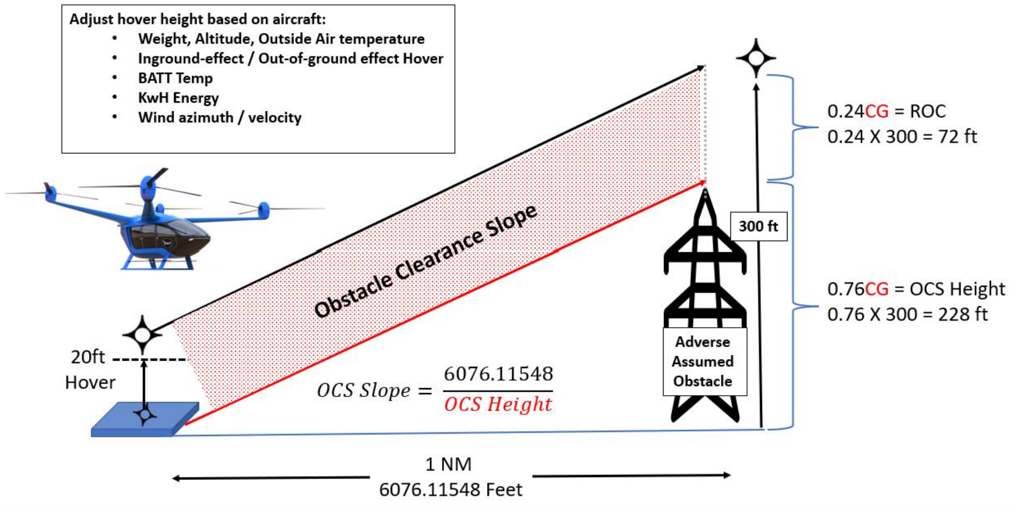
SPECIFIC TEST OBJECTIVE

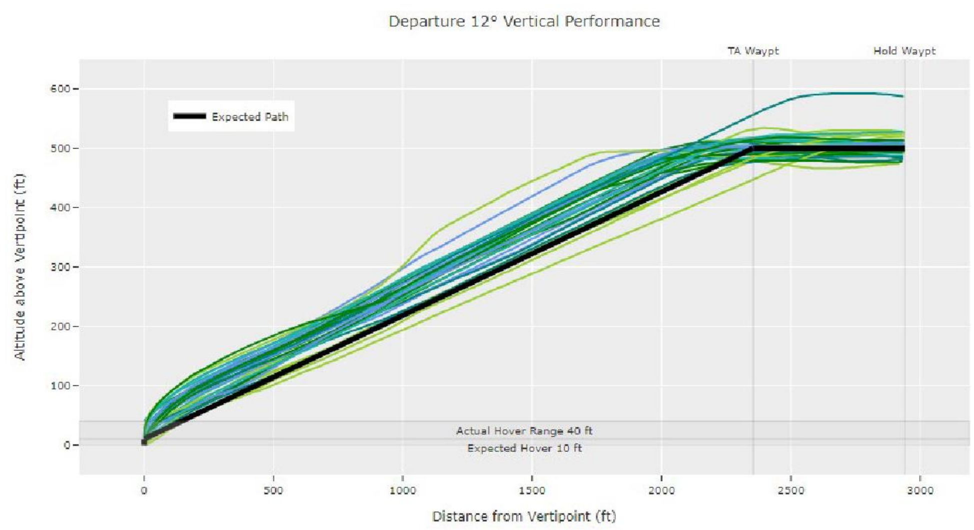
STO 1.3	**Instrument Flight Procedures** Validate procedures across each test phase of flight. **Departure** - Validate and qualitatively assess candidate departure procedures including departure from hover taxi, departure from rolling taxi, and vertical takeoff using both pilot- and autopilot-flown departures. **Enroute -** Validate candidate enroute procedures using both pilot- and autopilot-flown routes across different altitude, airspeed, transition, and intercept designs. **Final Approach** - Validate and qualitatively assess candidate final approach procedures using both pilot- and autopilot-flown approaches across different altitudes, airspeeds, descent gradients, decelerations, transition rates, intercept angles and glide path angles (5°, 8°, 12°). Aircraft or simulator tests will include assessment at maximum speeds, worst -case winds and temperature limits. **Missed Approach** - Validate and qualitatively assess different candidate missed approach procedures for terminal area operations. Aircraft or simulator tests will include assessment at max speeds, worst-case winds and temperature limits.							
OBJECTIVES			Prior to Test	Departure	Enroute	Final Approach	Missed Approach	After Test
MOP 1.3.01	Safety	Navigation data verification for desired path		X	X	X	X	
MOP 1.3.02	Safety	Aircraft climb/descend path		X		X	X	
MOP 1.3.03	Safety	Qualitative pilot assessment of procedure flyability, safety and design		X	X	X	X	
MOP 1.3.04	Safety	Vertical flight technical error (FTE_V)		X	X	X	X	
MOP 1.3.05	Safety	Lateral flight technical error (FTE_L)		X	X	X	X	
MOP 1.3.06	Safety	Total System Error (TSE)		X	X	X	X	
MOP 1.3.07	Safety	4D Trajectory conformance (Predicted vs. Actual)		X	X	X	X	
MOP 1.3.08	Safety	Along-track (ATT) tolerance			X			
MOP 1.3.09	Safety	Cross-track (XTT) tolerance			X			
MOP 1.3.10	Safety	Vertical-track (VTT) tolerance			X			
MOP 1.3.11	Safety	Flight plan conformance timing			X			
MOP 1.3.12	Safety	Flight plan conformance required bank angles			X			
MOP 1.3.13	Safety	Predicted NIC-NAC-SIL-SDA message reporting			X			
MOP 1.3.14	Safety	Predicted NIC-NAC-SIL-SDA message latencies			X			
MOP 1.3.15	Safety	Distance of Reaction and Roll (D_{RR})					X	
MOP 1.3.16	Safety	Flat Surface Length (FSL)					X	
MOP 1.3.17	Safety	Distance of Height Loss (2σ)					X	
MOP 1.3.18	Safety	Approach Angle Divergence					X	
MOP 1.3.19	Safety	Height of Missed Approach Surface (HMAS)					X	
MOP 1.3.20	Safety	Departure Intercept Point (DIP)					X	
MOP 1.3.21	Efficiency	Energy required		X	X	X	X	
MOP 1.3.22	Efficiency	Battery temperature increase		X	X	X	X	

MOP 1.3.23	Efficiency	Minimization of airspace volume		X	X	X	X	
MOP 1.3.24	Efficiency	Minimization of time duration		X	X	X	X	
MOP 1.3.25	Pax Comfort	Linear acceleration (x,y,z)		X	X	X	X	
MOP 1.3.26	Pax Comfort	Rotational acceleration (pitch, roll and yaw)		X	X	X	X	
MOP 1.3.27	Acoustics	Acoustic signature (Peak dB / Average dB)		X	X	X	X	

Table 14. IFP test details

COMPONENT	INSTRUMENT FLIGHT PROCEDURES TEST DETAILS
MOP 1.3.01	<u>**Navigation data verification**</u> for desired path
Safety Evaluation Criteria	Comprehensive/holistic verification that navigation data was correct and resulted in desired flight path: (1) Flight path maintained with no deviation (2) No data navigation errors 
MOP 1.3.02	<u>**Aircraft climb/descent path**</u> (which enables calculation of required climb gradient and descent gradient obstacle clearance surface for the given departure profile)
Safety Evaluation Criteria	Determine which takeoff/approach profile(s) have best or optimal climb paths for best obstacle clearance and potential easiest integration in an urban environment. (Outside of this single MOP, in consideration of all the other MOPs, climb path will be weighed against the other variables and conflicting goals of low energy expenditure, low noise, etc.) Assumptions: 200’/NM climb gradient (for fixed wing) 400’/NM for rotorcraft is considered a base requirement for low-end performance for eVTOL. Example:





MOP 1.3.03	**<u>Qualitative pilot assessment</u>** of procedure flyability, safety and design, see **Appendix A** for description and the assessment Procedure Rating Automation Matrix (PARM)
Safety Evaluation Criteria	Verify flyability is satisfactory. Pilot determination/evaluation that the procedure can be flown/ was flown safely; route produces a seamless path and is flyable in a consistent, smooth, predictable and repeatable manner. Aircraft maneuvering must be consistent with safe operating practices for the performance capability of the aircraft intending to use the procedure. Cockpit workload is acceptable. Turn anticipation is appropriate, acceptable relationship to standard rate turns and bank angle limits, suitable waypoint spacing and segment length for aircraft performance, IFP compatible with normal aircraft maneuvering, required climb gradients achievable, IFP not overly complex, IFP simple to the extent possible, consistent with proposed charting. (See FAA 8200.1D definition of “flyability”) Example:

	Conduct flyability and human factors assessment 1. Fly each segment of the IFP on-course and on-path. 2. Validate the intended use of IFPs as defined by stakeholders and described in the conceptual design. 3. Evaluate other operational factors, such as charting, required infrastructure, visibility, intended aircraft category. 4. Evaluate the aircraft maneuvering area for safe operations for each category of aircraft to use the IFP. 5. Evaluate the turn anticipation and rate of turns required. 6. Evaluate the IFP complexity, required cockpit workload, and any unique requirements. 7. Check that waypoint spacing and segment length are suited for aircraft performance. 8. Evaluate the aircraft position at the DA and/or MDA, and the ability to execute a normal landing. 9. Evaluate the proposed charting for correctness and clarity, and for ease of interpretation. Evaluate TAWS warnings (if applicable).

Synthesized Pilot Comments for Departures

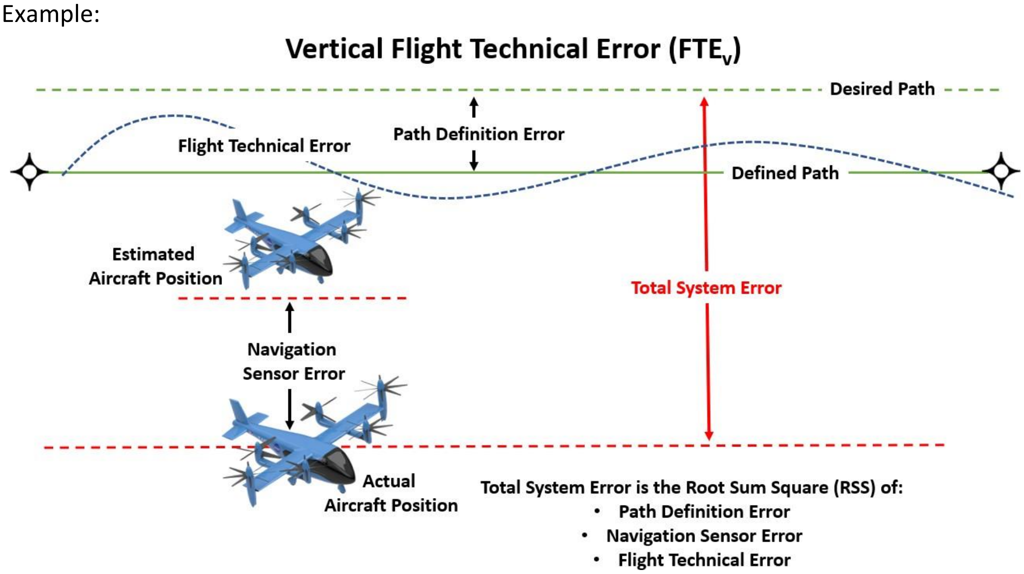
Test Point	Mean score	Synthesized comments
1.3.001 Manual Takeoff 5° at 45 kts	9.3	Conservative, easy to stay ahead of airplane, no task saturation.
1.3.002 Manual Takeoff 5° at 60 kts	9.3	Easy after just one practice
1.3.003 Manual Takeoff 5° at 80 kts	9.2	Easy, standard climb out, proficiency through training. Possible to overshoot altitude - no actual flight guidance.
1.3.004 Pilot-Assist Takeoff 5° at 45 kts	9.3	Easier to maintain flight path angle with airspeed automated. Lack of actual flight guidance problematic. Unable to precisely capture pattern altitude.
1.3.005 Pilot-Assist Takeoff 5° at 60 kts	8.9	Aircraft handles well at 60 kts. Flight guidance lacking. Tough to precisely capture altitude and time turn to join wheel. Recommend IFR rated pilot.
1.3.006 Pilot-Assist Takeoff 5° at 80 kts	8.9	Insufficient time - waypoints too tight for 80kts - can't make turn to join wheel. Doable but not without better guidance.
1.3.007 Manual Takeoff 8° at 45 kts	8.8	Easy when using flight path marker to maintain climb angle.
1.3.008 Manual Takeoff 8° at 60 kts	9.0	Comfortable speed. Lack of flight guidance problematic.
1.3.009 Manual Takeoff 8° at 80 kts	8.6	Too fast for the pattern. Blew well outside of waypoints. Pattern too tight/ not flyable at 80 kts.
1.3.010 Pilot-Assist Takeoff 8° at 45 kts	8.7	Accelerate to climb speed command quite helpful. IR pilot good to go. Pattern needs additional/more frequent waypoints for pilot anticipation.
1.3.011 Pilot-Assist Takeoff 8° at 60 kts	8.7	Aircraft happy at 60 kts but departure does happen faster. Good to go with training/ pilot anticipation required.
1.3.012 Pilot-Assist Takeoff 8° at 80 kts	8.0	Waypoints unusable/ way too tight for 80 kts. With training and revised correct waypoints would be doable.
1.3.013 Manual Takeoff 12° at 45 kts	8.6	Higher workload, task saturation possible. Training definitely required. Once off parameters, hard to reacquire/correct.
1.3.014 Manual Takeoff 12° at 60 kts	7.6	Happens too fast, overshooting waypoints, not enough cues to make turn, speeds faster than expected, turn came quickly, easy to overshoot airspeed.
1.3.015 Manual Takeoff 12° at 80 kts	6.2	Too fast, completely overshoot waypoints, blew through altitude, too complicated, unable to monitor all tasks, turn exceeds aircraft performance for speed & steepness
1.3.016 Pilot-Assist Takeoff 12° at 45 kts	8.5	Inadequate without flight guidance. Didn't perfectly maintain 12 deg thru transition. Slightly difficult to level off and execute tight turn at same time.
1.3.017 Pilot-Assist Takeoff 12° at 60 kts	7.5	High mental tasking, busy, too fast, blew by turn waypoints, too tight, overshoot altitude, too abrupt, complex, not enough time, not comfortable.

MOP 1.3.04	**Vertical flight technical error** (FTE_V) (the accuracy with which the aircraft is controlled). Vertical TSE characterizes vertical accuracy of navigation. Vertical FTE can provide rough indication of TSE. Will indicate what vertical path performance limits for vertical navigation may be met.
Safety Evaluation Criteria	Total System Error (TSE) = Navigational System Error (NSE) + Flight Technical Error (FTE). TSE expected to be dominated by FTE. Aircraft or simulator test unlikely/not expected to provide/account for NSE. FTE may serve as aircraft or simulator-based proxy of expected TSE ballpark. FTE: - the accuracy with which the aircraft is controlled - i.e., difference of estimated/indicated aircraft position from defined/commanded - i.e., difference between in-flight avionics estimated aircraft position and defined IFP path

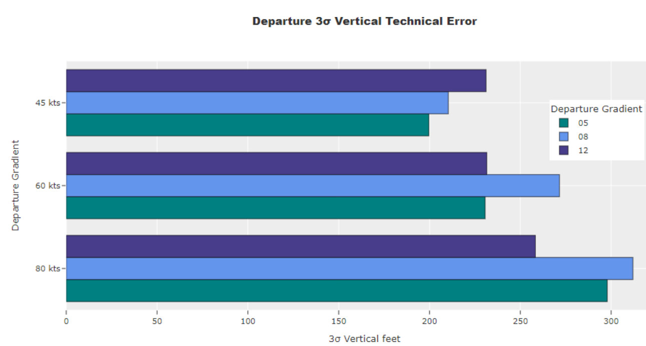
Assumptions:

- Vertical TSE must be less than a specified performance limit (160 ft below 5000 ft) 99.7% of flying time.
- Vertical FTE data will be pooled, and standard deviation calculated.
- Validate 2-sigma vertical airspace volume (containment area required) to meet outbound route structure to ensure Required Obstacle Clearance (ROC) over the Obstacle Clearance Slope (OCS) (ROC/OCS).
- Required airspace volume is less than standard IFR profiles; measure vertical pilot deviations.

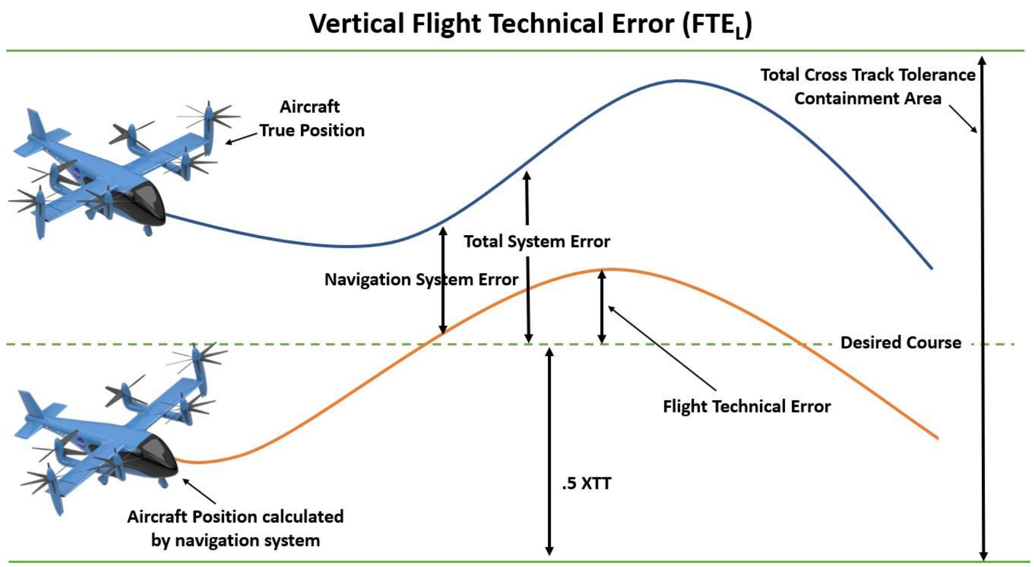
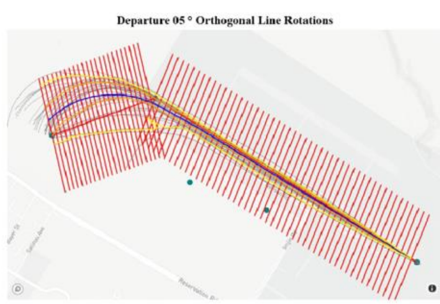
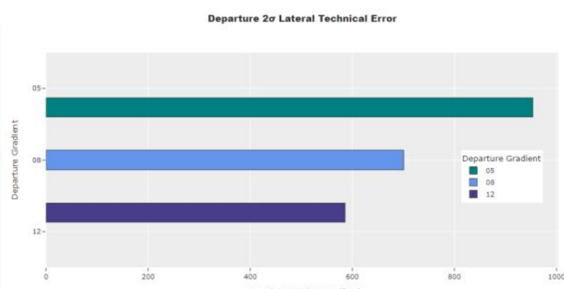
Example:

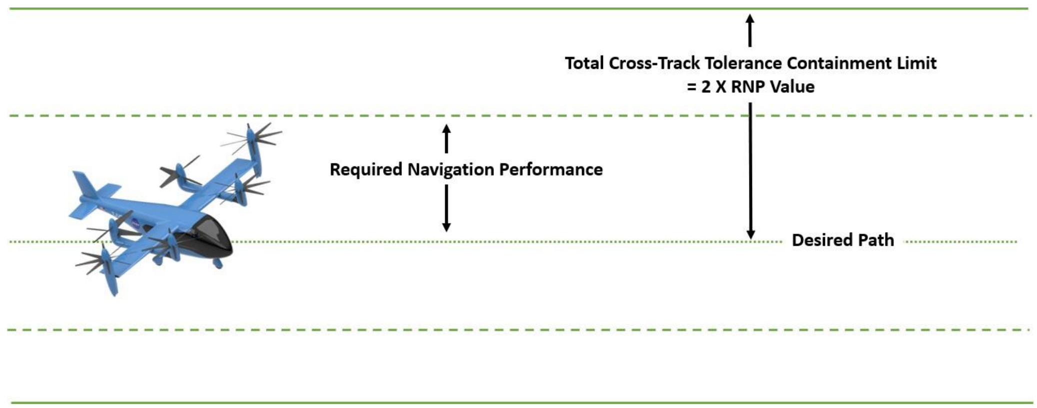


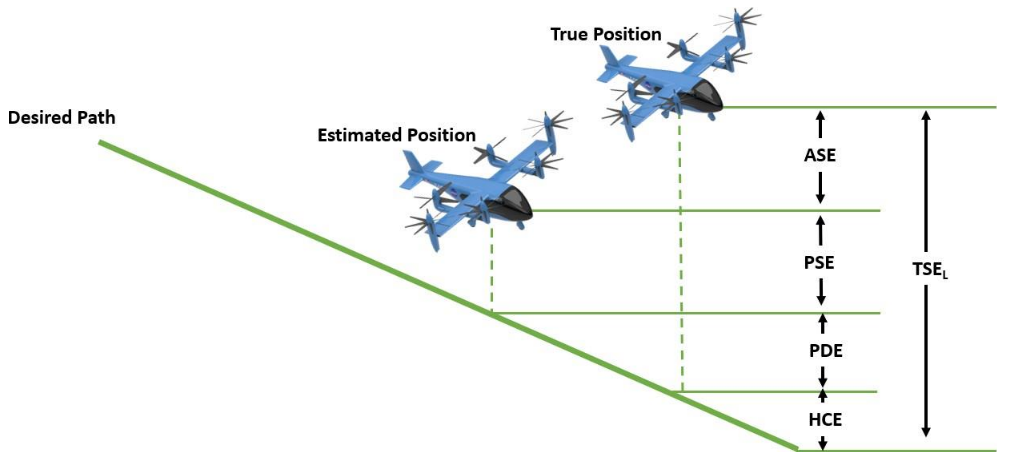
	Technique	RF	Max_Speed	Vertical_Deviation mean	Vertical_Deviation std
0	Vertical Takeoff	05	45 kts	53.52	48.70
1	Vertical Takeoff	05	60 kts	61.79	56.27
2	Vertical Takeoff	05	80 kts	81.14	72.23
3	Vertical Takeoff	08	45 kts	61.02	49.77
4	Vertical Takeoff	08	60 kts	70.27	67.10
5	Vertical Takeoff	08	80 kts	89.72	74.08
6	Vertical Takeoff	12	45 kts	71.16	53.32
7	Vertical Takeoff	12	60 kts	76.93	51.53
8	Vertical Takeoff	12	80 kts	77.27	60.34



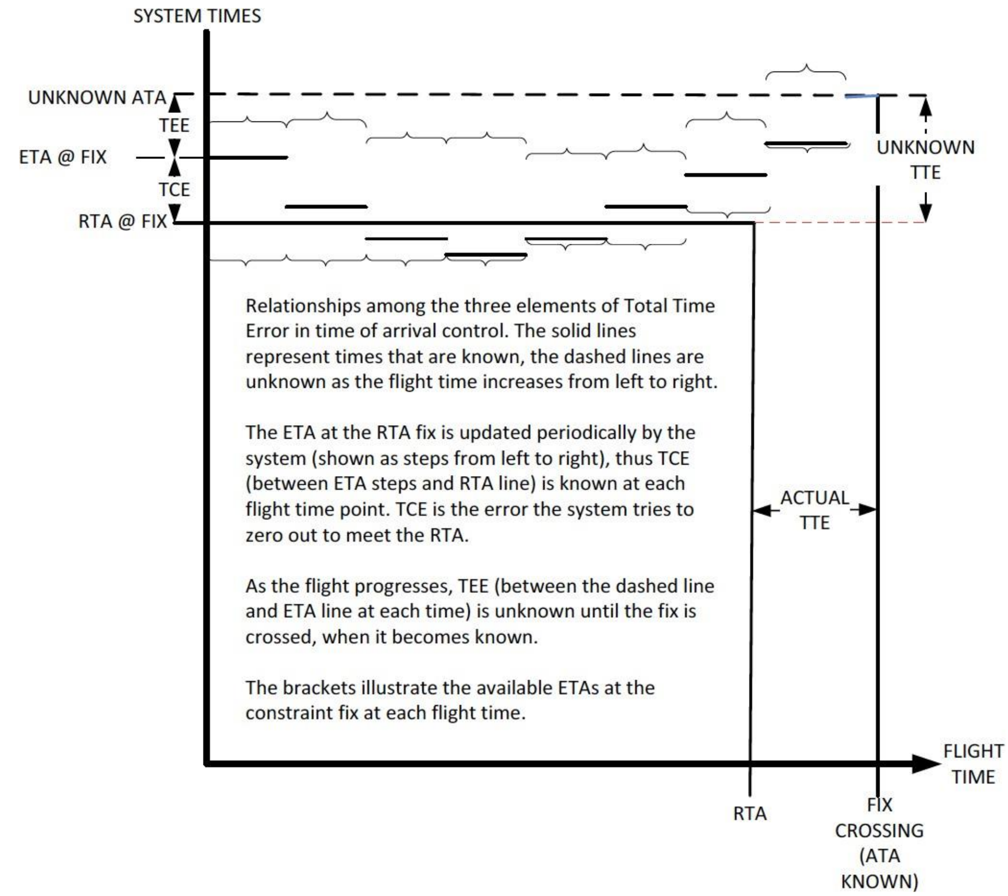
MOP 1.3.05	**Lateral flight technical error** (FTE_L) (for aircraft or simulator-based validation of lateral accuracy of navigation, and calculation of horizontal containment limit C = 2*RNP)
Safety Evaluation Criteria	Characterize FTE (and use as aircraft or simulator-based proxy of TSE) for validation of lateral accuracy of navigation and containment limit. In RNP, TSE in cross-track and along-track directions must be less than RNP 95% of flying time. FTE data will be pooled, and standard deviation calculated. The RNP that could be possible (based on TSE only, not covering other RNP requirements) will be assessed from the 2-sigma 95% TSE value (ballpark approximated from the aircraft or simulator tests using FTE). (TSE must be < RNP value for 95% of flying time.) Containment limit is 2 * RNP in each direction from reference flight path (4*RNP full left to right containment limit). Better than RNP AR 0.1 navigation accuracy and containment limit for obstacle clearance considering data scatter.

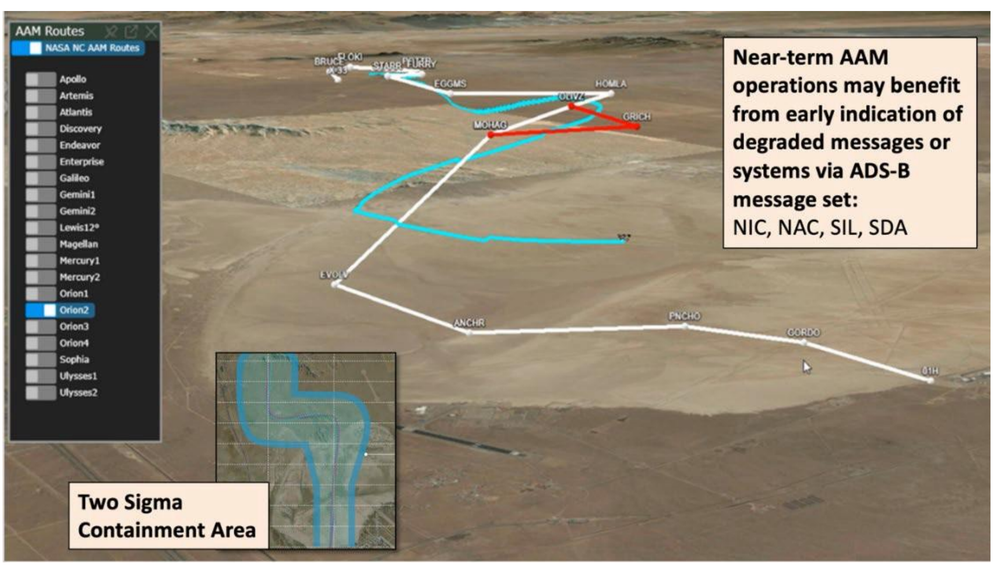
	FTE will be used to validate 2-sigma lateral containment area for reduced RNP criteria for UAM use case. Assumptions/Questions: If this document uses the term containment, it refers to the region within which the aircraft will remain 95% of the time (two sigma). The associated terms "containment value" or "containment distance" refer to the related airspace protection on either side of an RNAV ATS route. Example:   
MOP 1.3.06	**<u>Total system error</u>** (TSE) and breakdown of error sources (to the extent possible and/or supplemented by additional avionics data/analysis)
Safety Evaluation Criteria	Characterize lateral & vertical TSE (difference between true position and desired) and breakdown of all error sources. 1*RNP=2*sigma, where sigma is TSE statistical standard deviation Assumptions/Questions: Does the eVTOL OEM or their avionics supplier have the analytical data that characterizes the components/breakdown of navigation errors? Can these artifacts be leveraged to characterize expected TSE, in conjunction with FTE from simulator or flight test? Example:

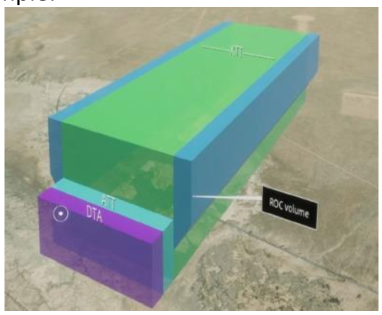
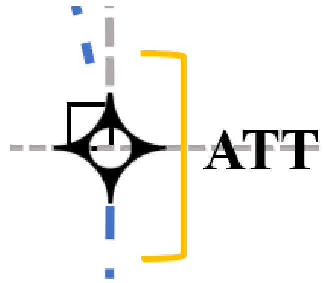
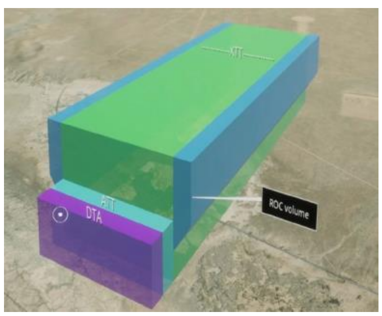
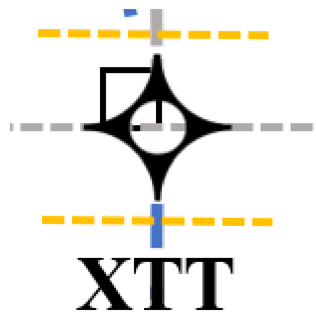




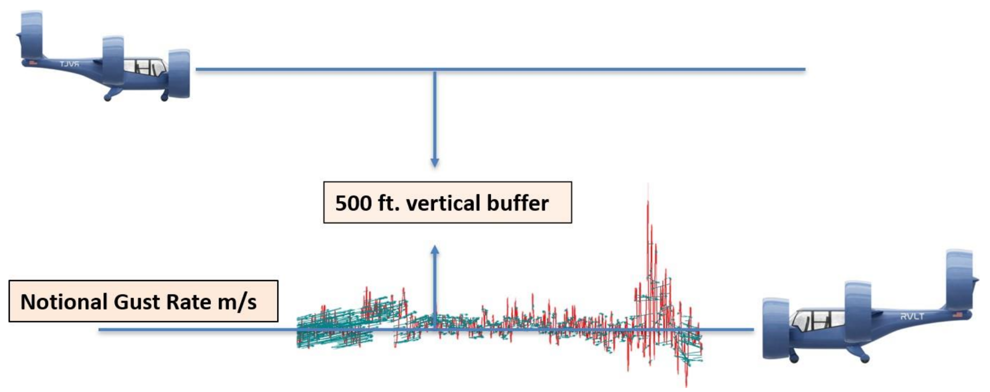
MOP 1.3.07	**<u>4D trajectory conformance</u>** (predicted vs. actual)
Safety Evaluation Criteria	- Collect data to characterize the 3D navigation performance (navigation accuracy/ TSE 95% of the time in cross-track and along-track directions <RNP, and vertical TSE 99.7% of the time less than given vertical path performance limit [e.g., <5000’: 150’ level, 160’ descent]). - No time control/ time of arrival control requirements currently used in RNP. To support the UAM vision, 4D Trajectory control will be required. Thresholds for aircraft operators and PSUs will need to be established. Assumptions/Questions: Does the mission planning process/ capabilities currently calculate estimated time of arrival for all the waypoints in a flight plan? Including non-enroute phases? How frequently are the waypoint ETAs recalculated, and based on what influencing variables? What is accuracy/tolerance of ETA (predicted vs actual, including the dynamic phases of flight, effect of real time adjustments, environmental/wind/weather effects, etc.)? Example:

<table>
<tr><td></td><td>


</td></tr>
<tr><td>MOP 1.3.08</td><td><u>Along-track tolerance</u> (ATT)</td></tr>
<tr><td>Safety
Evaluation
Criteria</td><td>- A distance specified in nautical miles or feet along a defined track to an area navigation fix.
- Define the amount of possible longitudinal fix position error on a specified track expressed as a +/- value.</td></tr>
</table>

	Example: 
MOP 1.3.09	**<u>Cross-track tolerance</u>** (XTT)
Safety Evaluation Criteria	- The amount of possible lateral positioning error expressed as a +/- value. - A value as a function of a projected required navigation performance (RNP). Assumptions/Questions: Define wide body geometry or controlling dimension of the vehicle that maintains the same ratio of containment clearance. Example: 
MOP 1.3.10	**<u>Vertical-track tolerance</u>** (VTT)
Safety Evaluation Criteria	- The amount of possible vertical positioning error expressed as a +/- value in altitude. - A value as a function of an altimeter setting error (ASE) and gust rejection tolerances for a vehicle to maintain vertical velocity. Assumptions/Questions: How accurately can updrafts and downdrafts be modeled? Example:

Vertical Separation			
Gust Updraft	*Feet per second*	*100 ft.*	*150 ft.*
1000 fpm	**16.7**	**5.9**	**8.9**
1500 fpm	**25**	**4.0**	**6.0**
2000 fpm	**33.3**	**3.0**	**4.5**



MOP 1.3.11 Flight plan **conformance timing**

Safety Evaluation Criteria

- Define waypoint passage as a +/- time value from planned time, distance, and heading (TDH) from the flight plan.
- Accuracy is dependent upon winds aloft, temperature and adequate performance planning.

Assumptions/Questions: Apply +/- 30 seconds for manual flight and +/- 10 seconds for automated flight.

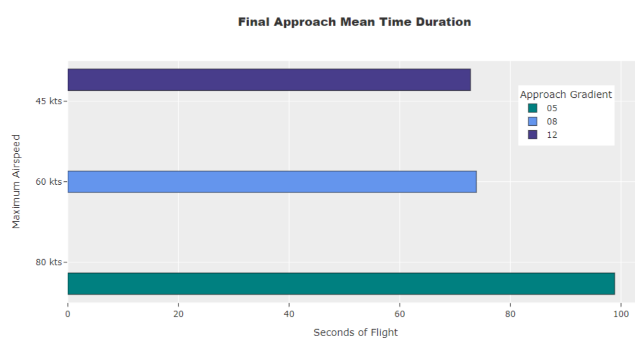
Example:

Final Approach Mean Time Duration Normalized for Distance (sec/ft)

05° = 0.0141
08° = 0.0169
12° = 0.0279

Final Approach Mean Time Duration Summary

	RF	Technique	Max_Speed	duration mean	duration std
0	05	Delayed Decel	80 kts	91.95	12.31
1	05	FAF Decel	80 kts	107.75	13.39
2	08	Delayed Decel	60 kts	74.28	10.62
3	08	FAF Decel	60 kts	76.41	9.96
4	12	Delayed Decel	45 kts	88.67	27.17
5	12	FAF Decel	45 kts	75.36	25.24

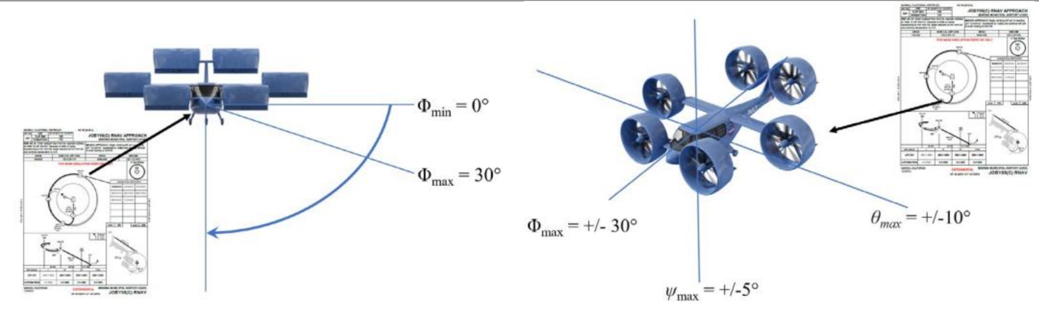


MOP 1.3.12 Flight plan conformance **required bank angles**

Safety Evaluation Criteria

Assess bank angle required to execute turn based on speed and altitude restrictions.
Assumptions/Questions: Tailor evaluation criteria per vehicle design and configuration which may change bank angle optimization with given airspeeds.

Example:



MOP 1.3.13 — Predicted NIC-NAC-SIL-SDA **message reporting**

Safety Evaluation Criteria

- Determine NIC-NAC-SIL-SDA tolerance for a given UAM operation against current categories are within tolerable limits through ADS-B flight tracking systems:
  NAC coding (10+), NIC coding (10+), SIL coding (1-2), SDA rating (0-1)

Pressure Altitude	28800
Geometric Altitude	29675
Heading	245.7
NIC / NAC_p	8 / 9
SIL / SDA	3 / 2
Sensor	APV

NIC Value	Radius of Containment (R_C)	Airborne: Airborne Position TYPE Code	Airborne: NIC Supplement Codes A	Airborne: NIC Supplement Codes B	Surface: Surface Position TYPE Code	Surface: NIC Supplement Codes A	Surface: NIC Supplement Codes C
0	R_C unknown	0, 18 or 22	0	0	0, 8	0	0
1	R_C < 20 NM (37.04 km)	17	0	0	N/A	N/A	N/A
2	R_C < 8 NM (14.816 km)	16	0	0	N/A	N/A	N/A
3	R_C < 4 NM (7.408 km)	16	1	1	N/A	N/A	N/A
4	R_C < 2 NM (3.704 km)	15	0	0	N/A	N/A	N/A
5	R_C < 1 NM (1852 m)	14	0	0	N/A	N/A	N/A
6	R_C < 0.6 NM (1111.2 m)	13	1	1	8	0	1
	R_C < 0.5 NM (926 m)	13	0	0	N/A	N/A	N/A
	R_C < 0.3 NM (555.6 m)	13	0	1	8	1	0
7	R_C < 0.2 NM (370.4 m)	12	0	0	8	1	1
8	R_C < 0.1 NM (185.2 m)	11	0	0	7	0	0
9	R_C < 75m	11	1	1	7	1	0
10	R_C < 25m	10 or 21	0	0	6	0	0
11	R_C < 7.5m	9 or 20	0	0	5	0	0
12	Reserved						
13	Reserved						
14	Reserved						
15	Reserved						

Table A-13: Encoding of Navigation Accuracy Category for Position (NAC_P)

Coding (Binary)	Coding (Decimal)	Meaning = 95% Horizontal Accuracy Bounds (EPU)
0000	0	EPU ≥ 18.52 km (10 NM) - Unknown accuracy
0001	1	EPU < 18.52 km (10 NM) - RNP-10 accuracy
0010	2	EPU < 7.408 km (4 NM) - RNP-4 accuracy
0011	3	EPU < 3.704 km (2 NM) - RNP-2 accuracy
0100	4	EPU < 1852 m (1NM) - RNP-1 accuracy
0101	5	EPU < 926 m (0.5 NM) - RNP-0.5 accuracy
0110	6	EPU < 555.6 m (0.3 NM) - RNP-0.3 accuracy
0111	7	EPU < 185.2 m (0.1 NM) - RNP-0.1 accuracy
1000	8	EPU < 92.6 m (0.05 NM) - e.g., GPS (with SA)
1001	9	EPU < 30 m - e.g., GPS (SA off)
1010	10	EPU < 10 m - e.g., WAAS
1011	11	EPU < 3 m - e.g., LAAS
1100 - 1111	12 - 15	Reserved

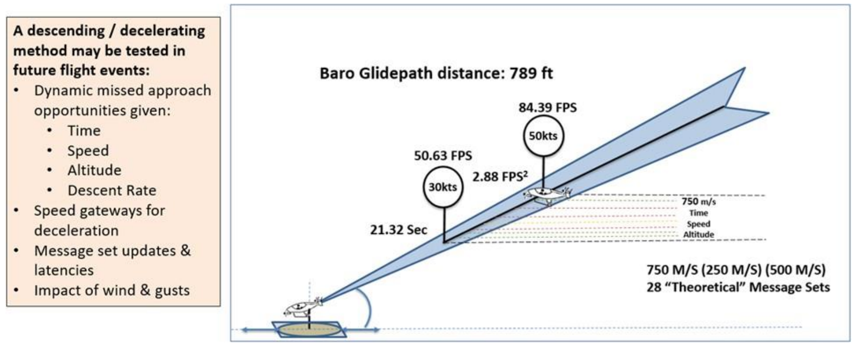
SIL Supplement	Basis for SIL Probability
1	Probability of exceeding NIC containment radius is based on per sample
0	Probability of exceeding NIC containment radius is based on per hour

SDA Value	Supported Failure Condition Note 2	Probability of Failure causing transmission of False or Misleading Information Note 3,4	Software & Hardware Design Assurance Level Note 1,3
3	Hazardous	≤ $1x10^{-7}$ Per Hour	B
2	Major	≤ $1x10^{-5}$ Per Hour	C
1	Minor	≤ $1x10^{-3}$ Per Hour	D
0	Unknown/ No safety effect	> $1x10^{-3}$ Per Hour or Unknown	N/A

MOP 1.3.14 — Predicted NIC-NAC-SIL-SDA **message latencies**

Safety Evaluation Criteria

- Evaluate discrepancies as they occur to provide each message portion from the vehicle to the radar received.
  Calculate NIC-NAC-SIL-SDA message latencies given 750 m/s descent
  Example:

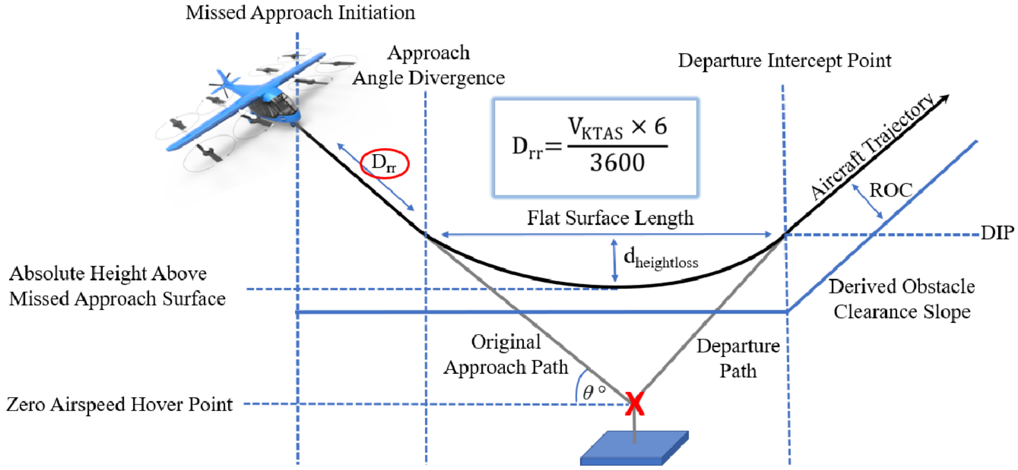


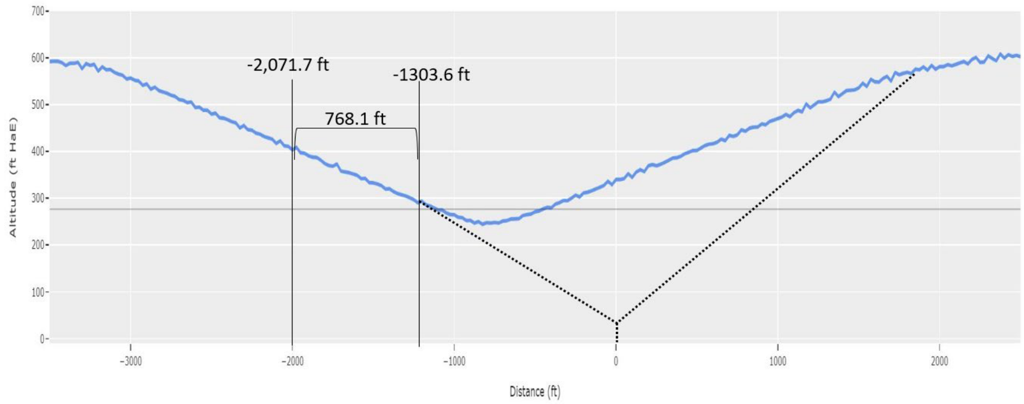
MOP 1.3.15 — Distance of **Reaction and Roll** (DRR)

Safety Evaluation Criteria

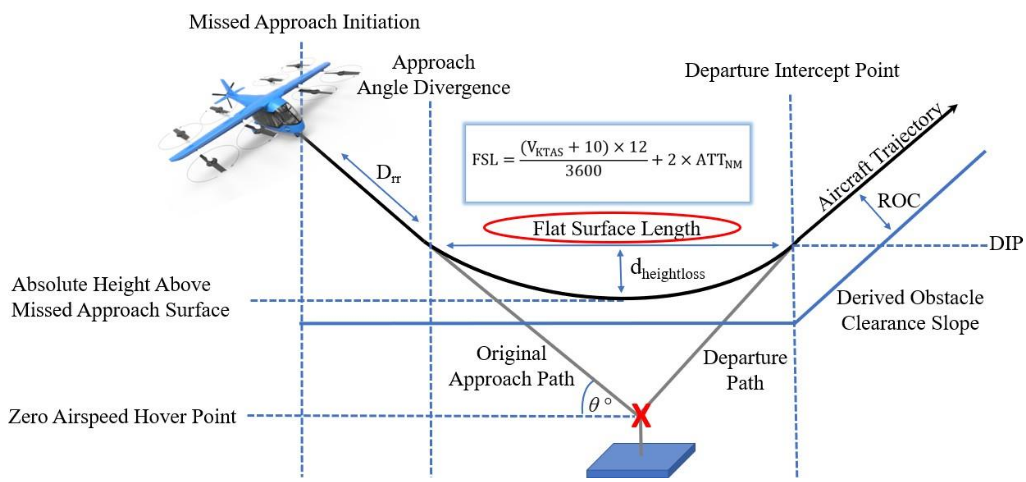
Measure the distance (time of deceleration at airspeed) from where the missed approach is initiated to the when divergence from approach angle is achieved. Traditionally this distance is the summation of the avionic system display and the averages pilot's reaction to the annunciation.

Example:

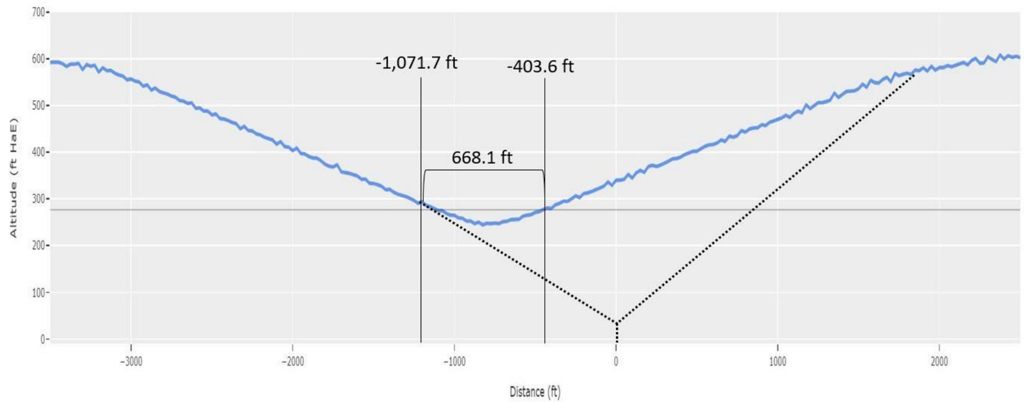
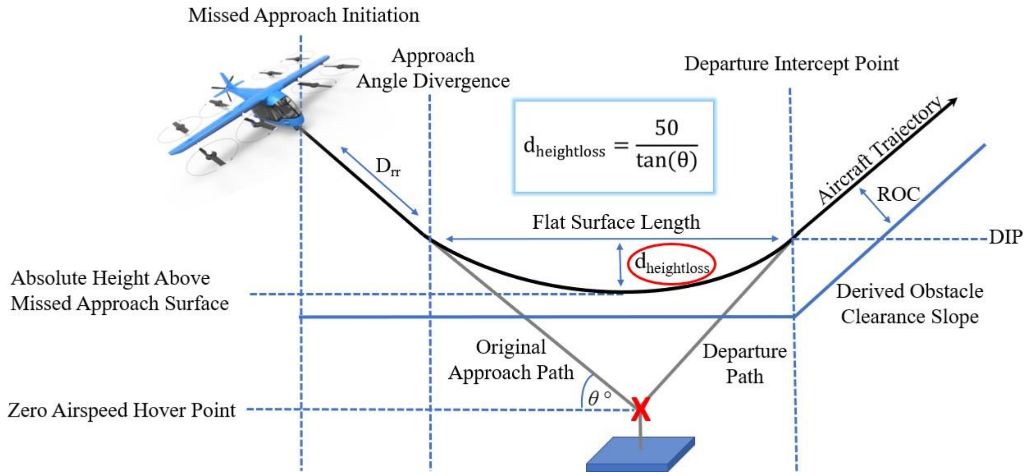
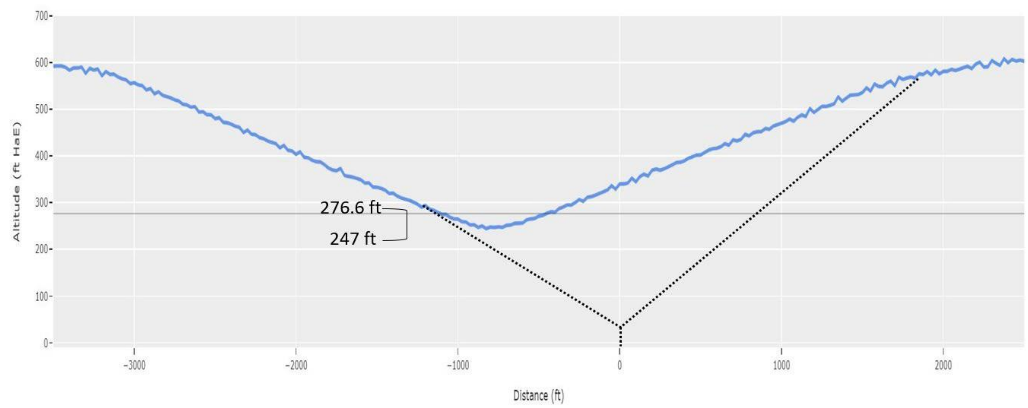
<table>
<tr><td></td><td>




</td></tr>
<tr><td>MOP 1.3.16</td><td><u>Flat surface length</u> (FSL)</td></tr>
<tr><td>Safety
Evaluation Criteria</td><td>Measure the distance from arrested descent (zero vertical speed indicator (VSI)) in transition to vertical ascent (positive VSI) and acceleration (positive airspeed) into established climb gradient per missed approach maneuver. Demonstrate the transition to climb for each missed approach profile.

Example:


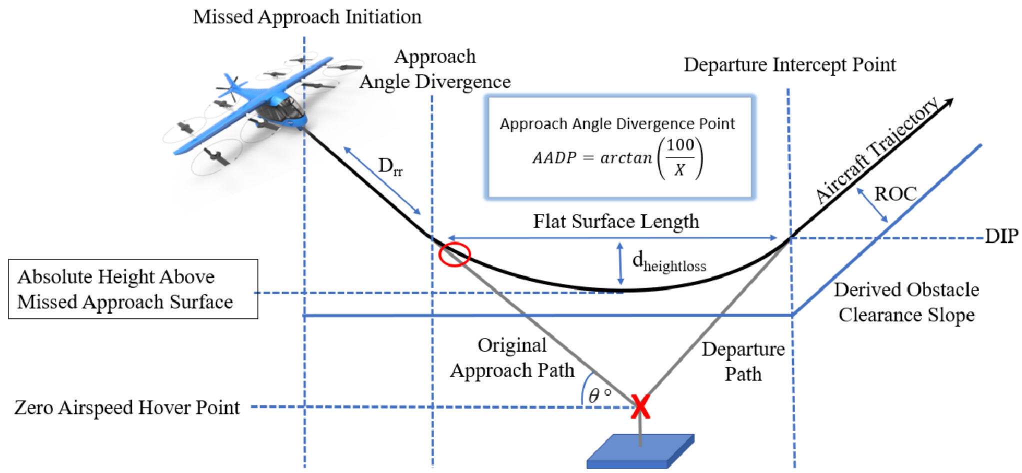
</td></tr>
</table>

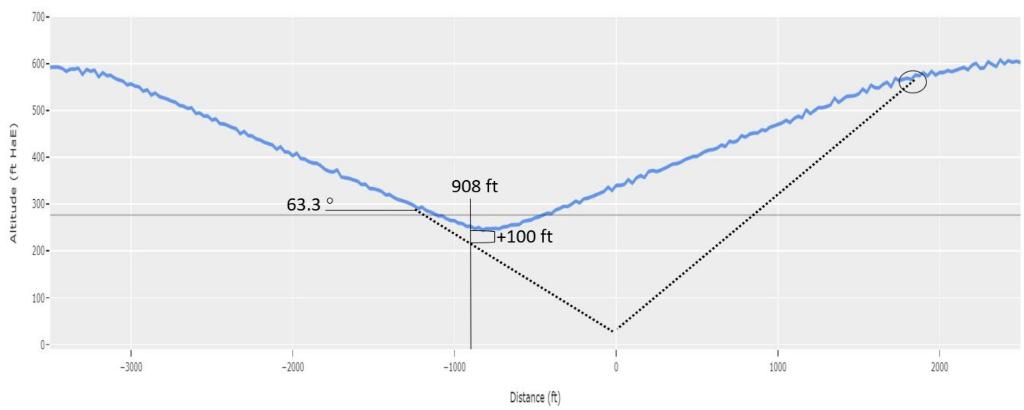
	
MOP 1.3.17	Distance of **Height Loss** (2σ)
Safety Evaluation Criteria	Assess Height Loss from Decoupling Point at a constant airspeed and a constant deceleration in 5°, 8° and 12° Glidepath Angles. Example:  
MOP 1.3.18	**Approach Angle Divergence**

<table>
<tr>
<td>Safety
Evaluation
Criteria</td>
<td>

- Assess deviations from approach angle divergence point at a constant airspeed and a constant deceleration in 5°, 8° and 12° glidepath angles
- Maintain limits of full-scale deflection within [0.35°] Vertical Deviation Angular to 50’ Total, Lateral Deviation 3° Angular to 0.1 NM, and demonstrate the glidepath for each approach profile
- Establish glidepath divergence once 100 feet separation is achieved from original approach path.

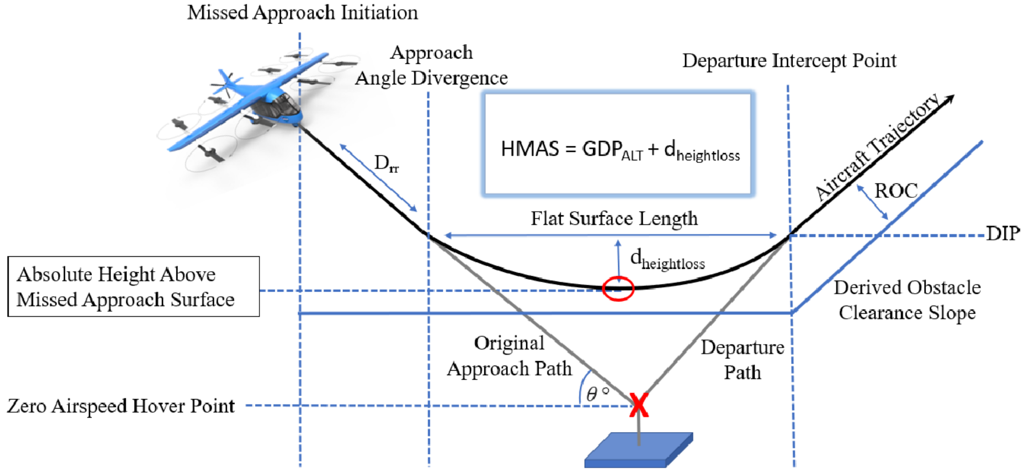
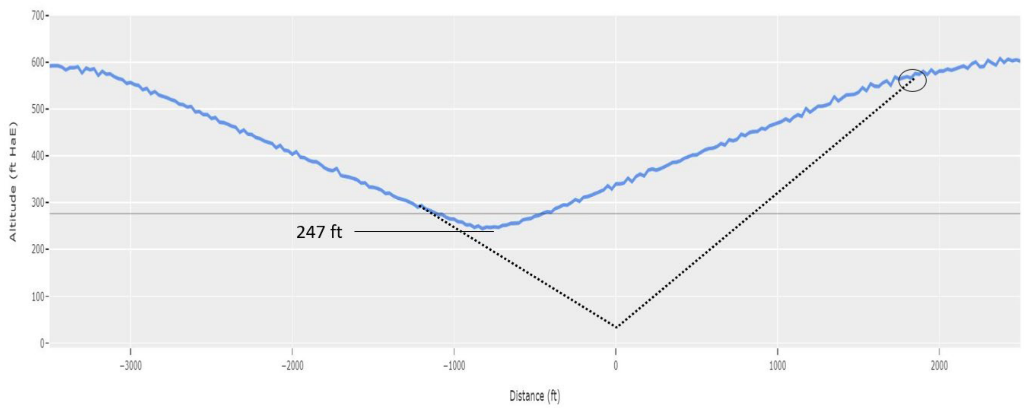
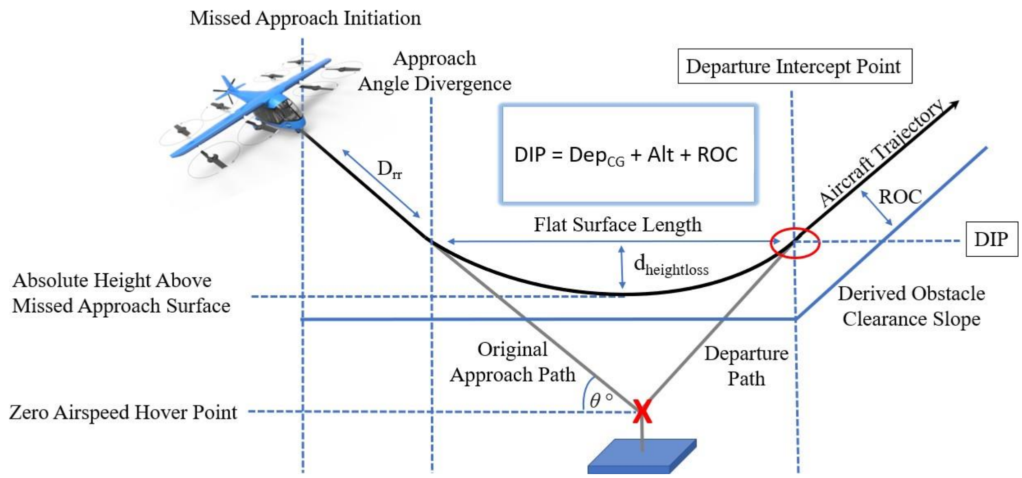
Example:

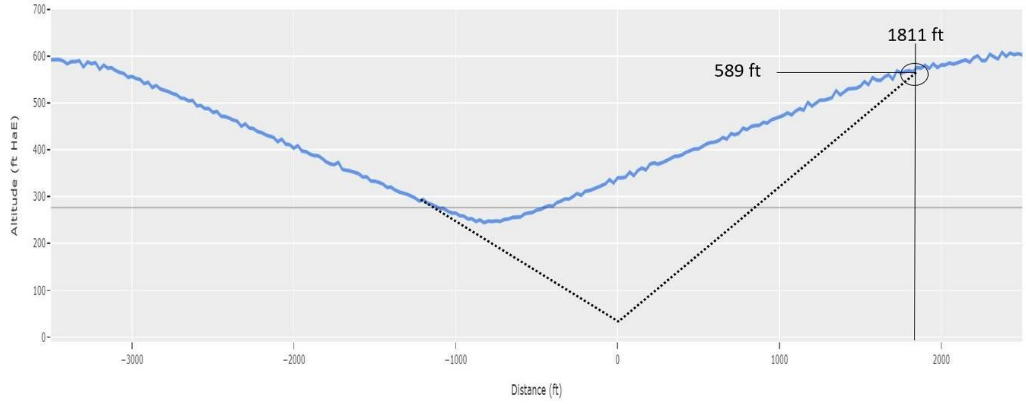
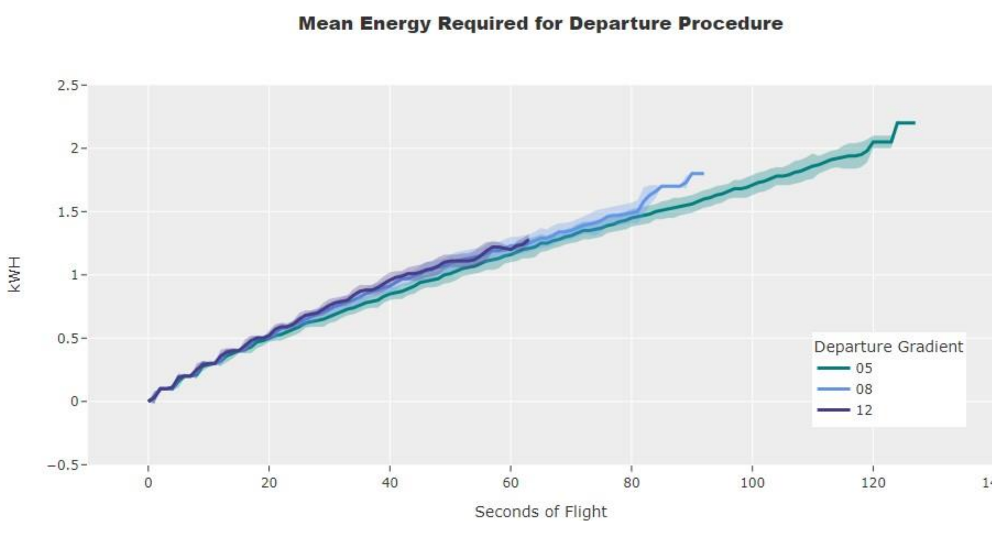


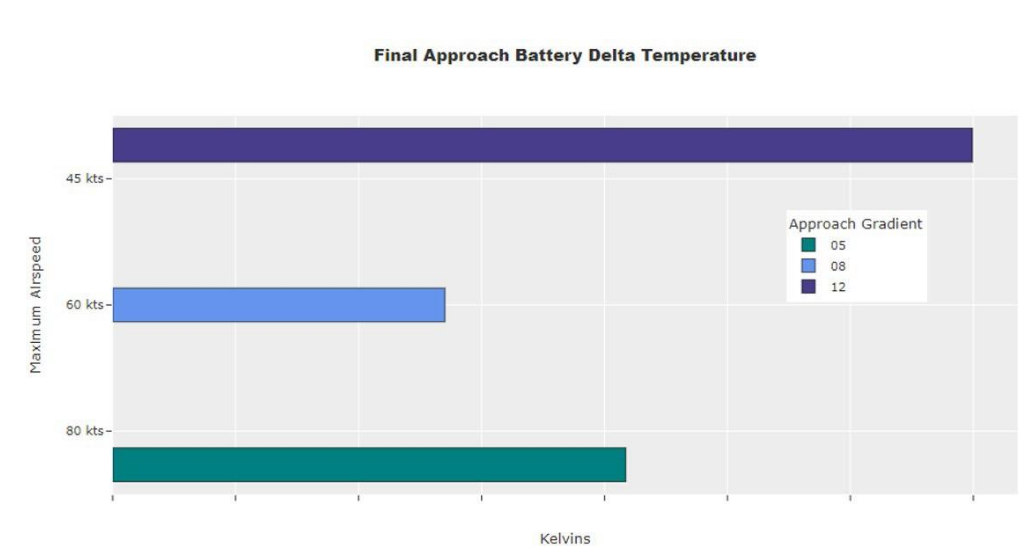


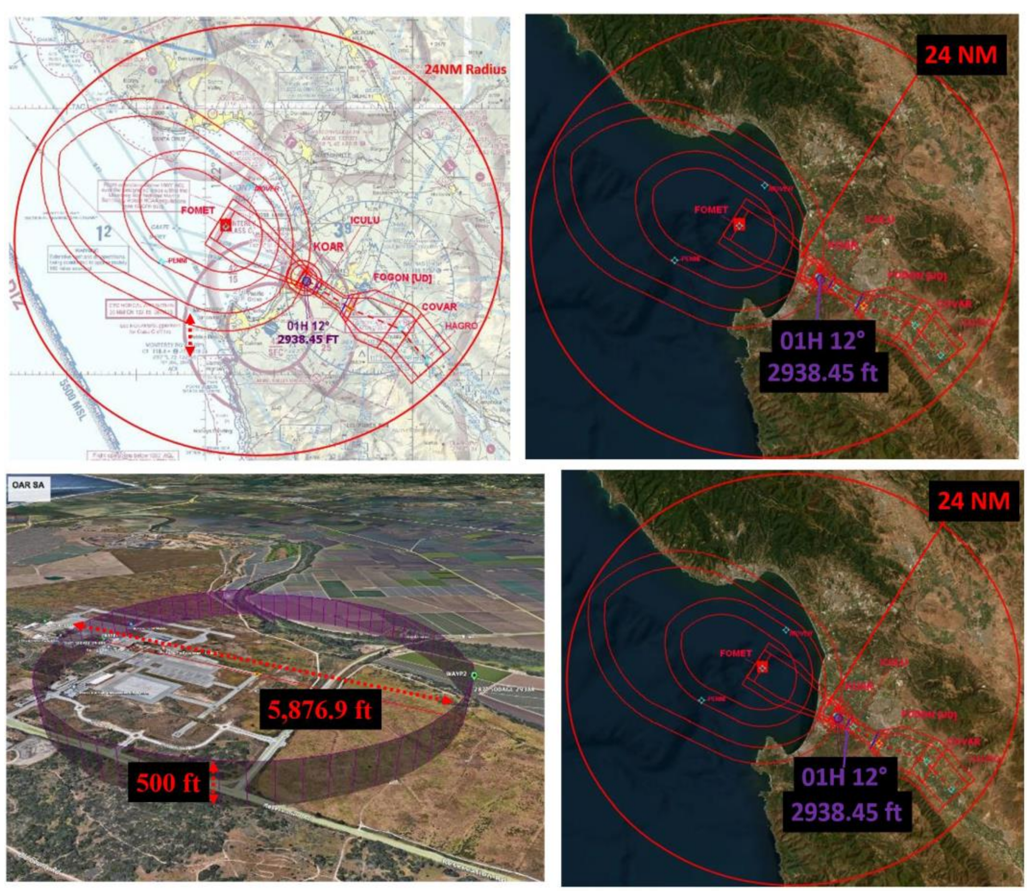
</td>
</tr>
<tr>
<td>MOP 1.3.19</td>
<td>Height of <u>Missed Approach Surface</u> (HMAS)</td>
</tr>
<tr>
<td>Safety
Evaluation
Criteria</td>
<td>Assess suitability of the assumed Height Above Missed Approach Surface for the 5°, 8° and 12° Glidepath Angles with variable airspeed and deceleration constraints

Example:</td>
</tr>
</table>

	 
MOP 1.3.20	**<u>Departure Intercept Point</u>** (DIP)
Efficiency Evaluation Criteria	Measure the deviations in time, vertical speed, airspeed, and energy required to successfully maneuver from the glidepath decoupling point to the departure intercept point and enter holding ring to terminate missed approach sequence. Example: 

	
MOP 1.3.21	**<u>Energy required</u>**
Efficiency Evaluation Criteria	Minimization of energy: Collect power levels/ state of charge/ depth of discharge across entirety of each flight profile (kwh). Include battery temperatures and power time history and peak power loads (Celsius (TBD), kws, kws over time). Collect atmospheric/environmental conditions and any other pertinent variables if being varied across different test flight or simulator runs. Energy consumption in kwh (preferred) or J averaged for each flight profile test point. As supporting data, battery temperature increases, current, voltage, power and endurance may also be averaged for each test point and plotted over time. Determine which profile(s) have the least energy consumption/ best energy conservation. Outside of this single MOP, in consideration of all the other MOPs, energy consumption will be weighed against the other variables and conflicting UAM scalability goals. Example: 
MOP 1.3.22	**<u>Battery temperature increase</u>**
Efficiency Evaluation Criteria	Minimization of battery temp increase – compare delta T (stop minus start) of each test point. Lowest temp increase is best, largest temp increase is worst Example:

<table>
<tr><td></td><td>
</td></tr>
<tr><td>MOP 1.3.23</td><td>Minimization of <u>airspace volume</u></td></tr>
<tr><td>Efficiency
Evaluation Criteria</td><td>Qualitatively verify airspace volume required can meet UAM use case. Compare candidate airspace volume with traditional IFR profiles and characterize the 2D & 3D percentage reduction.

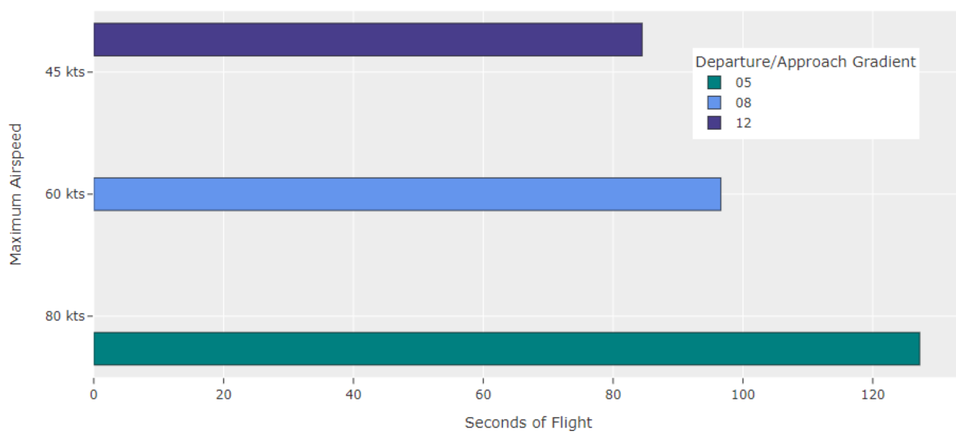
Example:

</td></tr>
</table>

MOP 1.3.24	Minimization of **time duration**
Efficiency Evaluation Criteria	Quantify timing from a starting point of a phase to a final point within the phase to compare the fastest/ result in the shortest time. Pass/fail goal is that candidate UAM IFR departure timing is less (faster) than standard Rotorcraft IFR departure procedures. Ensure test points across varied glidepaths start and end at an identical point for one-to-one comparisons.

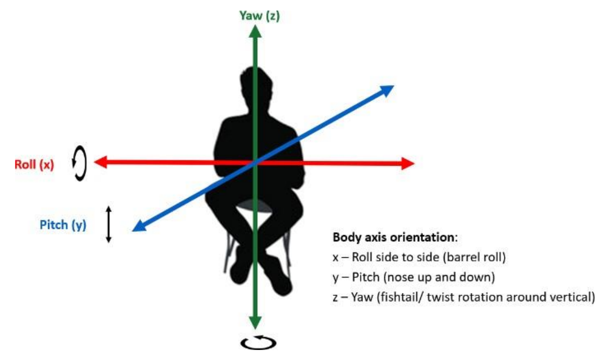
Example:

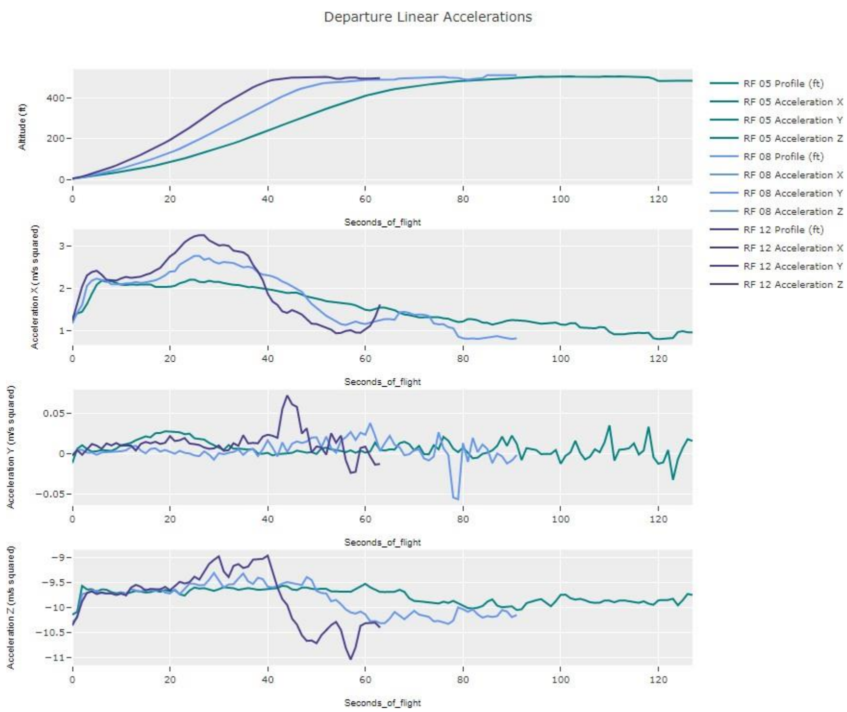
	RF	Technique	Max_Speed	seconds_duration	
				mean	std
0	05	Delayed Decel Coordinated Turn	80 kts	134.10	10.56
1	05	Delayed Decel On Course	80 kts	131.52	19.05
2	05	FAF Decel Coordinated Turn	80 kts	110.79	43.44
3	05	FAF Decel On Course	80 kts	136.39	12.97
4	08	Delayed Decel Coordinated Turn	60 kts	96.68	7.85
5	08	Delayed Decel On Course	60 kts	94.32	11.59
6	08	FAF Decel Coordinated Turn	60 kts	99.71	10.73
7	08	FAF Decel On Course	60 kts	95.55	10.43
8	12	Delayed Decel Coordinated Turn	45 kts	83.35	10.94
9	12	Delayed Decel On Course	45 kts	84.71	12.64
10	12	FAF Decel Coordinated Turn	45 kts	87.25	11.56
11	12	FAF Decel On Course	45 kts	82.56	14.79

Missed Approach Mean Time Duration



MOP 1.3.25	**Linear acceleration**
Pax Comfort Evaluation Criteria	A key component for the instrument flight procedure analysis is to ensure that candidate procedures are well within expected levels of comfort for passengers and cargo. Known linear and rotational rates and acceleration limits have been applied to the data to ascertain if the aircraft or simulator output is expected to produce acceptable levels of navigational impact for the flight experience. Assess by collecting subjective pilot/FTE responses, and analyze data to ensure roll angles, pitch angles, pitch attitude change rates, and airspeeds prior to aggressive maneuvers are sufficiently limited. (1) Roll angles less than 30° (NC) (2) No severe changes in roll rate (NC)

	(3) No overly aggressive/uncommon pitch angles (NC) (4) No abrupt pitch attitude changes (NC) (5) Airspeed appropriate for comfortable maneuvering (NC) (6) Subjective responses do not note any unacceptable issues (NC) (7) linear acceleration along the vertical, lateral, and longitudinal vehicle axes (8) jerk (the rate of change of acceleration) along the vertical, lateral, and longitudinal vehicle axes (9) angular rate and acceleration about the roll, pitch and yaw axes Linear forces upon the body are congruent with forces exerted upon the aircraft frame. The navigational forces modeled within the aircraft or simulator serve as a surrogate for the expected experience upon the human body. The force is measured in three primary locations: Acceleration X is between the shoulder at the chest, Acceleration Y affects at center mass near the human seated weight and Acceleration Z is experienced between the feet at the ground. Forces occur in the x (forward) plane, the y (starboard) plane and the z (vertical) plane. The linear accelerations are in planes X, Y and Z and are measured in m/sec2. Earth's gravity (9.807 m/s²) is subtracted from the Z plane. These measures of motion would be processed to yield average values, root mean squared (RMS) values and peak values in the time and frequency domains including acceleration spectral density, etc., for verification against historical passenger comfort requirements, thresholds and curves. Example: 



MOP 1.3.26 **Rotational acceleration**

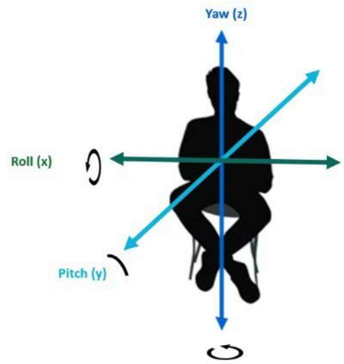
Pax Comfort Evaluation Criteria

Rotational Accelerations

The rotational effect of the planes due to rotation are calculated through the kinematic forces X (roll), Y (pitch) and Z (yaw) as cross-coupled pairs:

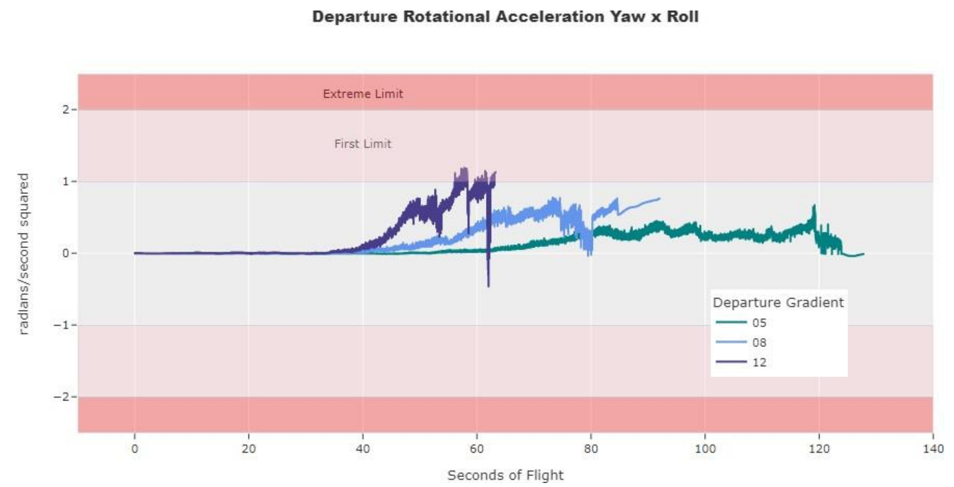
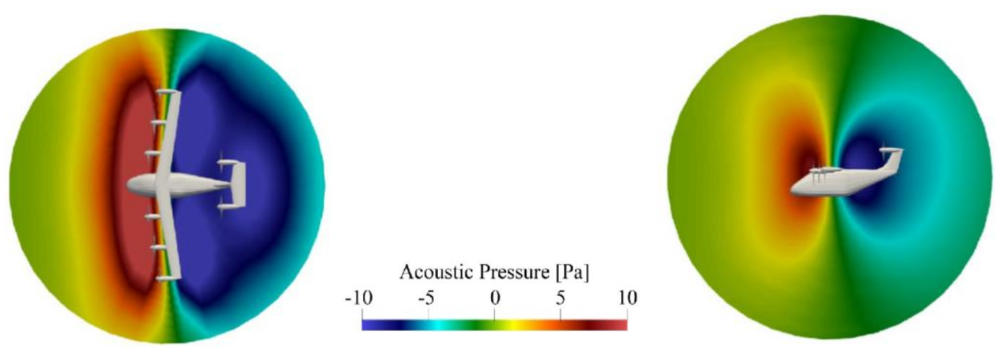
rotational acceleration roll x pitch
rotational acceleration roll x yaw
rotational acceleration pitch x yaw

For reference, 1 radian/second 2 is the equivalency of a twisting, rough amusement park ride and 2 radians/second 2 is a more extreme limit found for a NASA space flight.



Departure Rotational Accelerations Summary rad/sec²

RF	pitch_roll_mean	pitch_roll_std	roll_yaw_mean	roll_yaw_std	pitch_yaw_mean	pitch_yaw_std
05	-0.01	0.01	0.12	0.13	-0.16	0.03
08	-0.01	0.01	0.22	0.26	-0.17	0.05
12	-0.01	0.02	0.22	0.33	-0.19	0.06

	
MOP 1.3.27	**Acoustic signature** (Peak db / Average db)
Acoustics Evaluation Criteria	The expected acoustic signatures of the different IFP designs will be characterized after flight or simulator testing to enable comparisons of different airspeed, altitude, and transition mode profiles. The research will measure the prescribed flight path profile tradeoffs between passenger comfort, aircraft energy efficiency, and acoustic signatures to maximize public acceptance for a scalable UAM airspace architecture. Weighted decibels (dBA) for a specific altitude and airspeed profile during planned take-off and landing profiles to be below a target dBA (normal conversation) at a specified distance from the flight path. Additional information may be required: A-weighted sound level (Lmax), Sound Exposure Level (overall, C-, A-weighted) (SEL), Perceived Noise Level (PNL), Tone-Corrected Perceived Noise Level (PNLT), Effective Perceived Noise Level (EPNL), Day-Night Average Sound Level (DNL), Community Noise Equivalent Level (CNEL). 

Departure Overview

The departure flight phases tested in this test will research three different departure profiles. Additional consideration will be needed for the aircraft pre-departure configuration utilizing a rolling, hover, or grounded vertical takeoff:

<u>Airspeed over altitude</u> – optimize horizontal axis over the vertical axis (gain airspeed (40-80 kts) in ground effect (IGE) under 20 ft. AGL over the runway before initiating climb)

<u>Altitude over airspeed</u> – optimize vertical component over the horizontal component (confined area departure; remain under 10 knots (kts) until reaching 50 ft. AGL)

<u>Prescribed climb gradient and path point definition</u> – test a precise climb gradient departing from vertipoint (maintain angle via vertical speed indicator (VSI) and airspeed)

All departure sequences will end in a terminating altitude while simultaneously entering holding. The ‘dynamic procedure design’ model includes rings of waypoints that galvanize the holding pattern, alignment and final rollout point for the vertiport airspace architecture. Figure 8 below provides an example of distance and time duration of each phase of flight and required information for the particular phase. Phase of flight limitation and subsequent projections can and will change based on environmental factors, and operations for each aircraft design and control scheme.

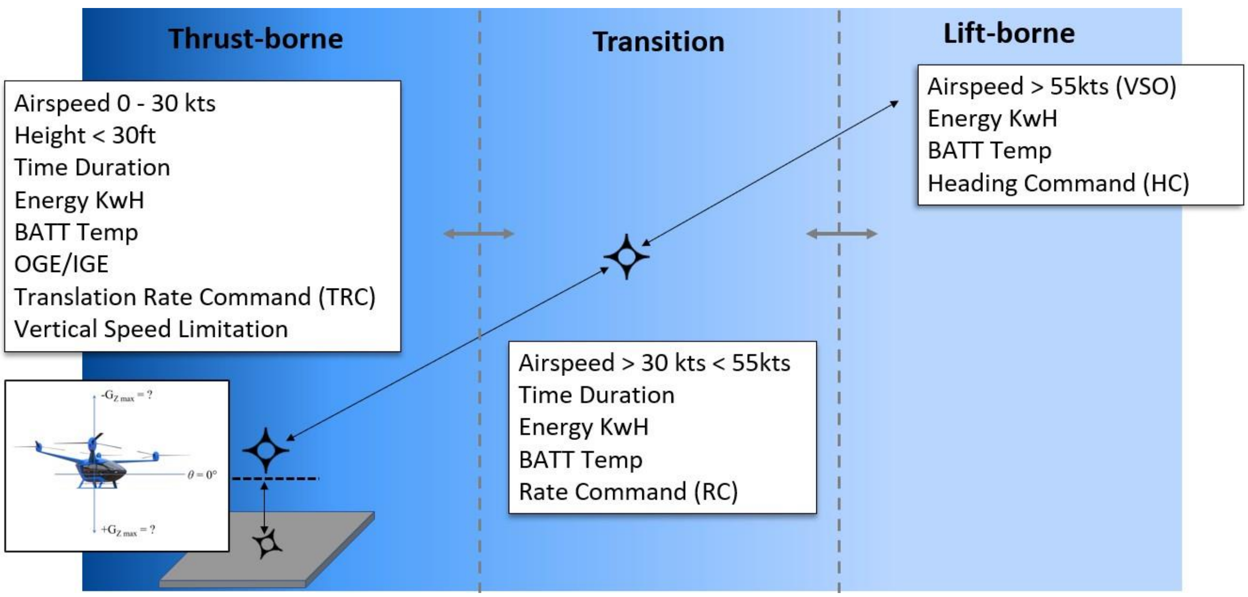


Figure 8. Sample eVTOL departure phases

<u>Departure Assumptions</u>

No engine out or downwash are considered for the simulator test. All departures will occur in nominal environmental conditionings. Given many eVTOL vehicles perform enroute as a fixed wing but perform as a rotary wing in the final approach, splitting the difference between the mandated 400ft/nautical mile climb gradient restraint for rotary wing and 200ft/nautical mile for fixed wing results in an assumed 300ft/nautical mile for these tests. Wind spirals as applied to a turn can be modeled in simulation or predicted for live flight and confirmed via flight conformance data. This applies to the lift-borne, thrust-born, and transition modes of the candidate vehicle in the departure sequence (Figure 9).

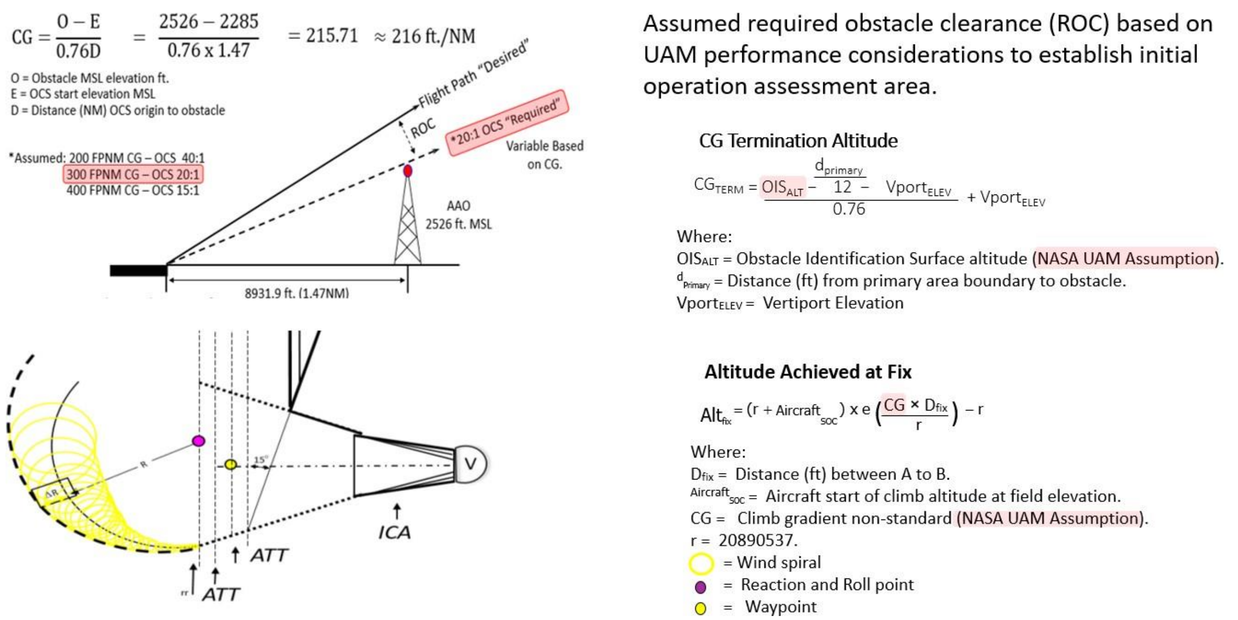


Figure 9. Sample departure climb gradient

Departure Test and Procedures

Departure test details are found in Table 15 and the test departure procedure sequence is found within Table 16.

Table 15. Departure test details

COMPONENT	DEPARTURE TEST DETAILS	
Test Methodology	1. Initiate test with stationary aircraft engines on with takeoff clearance at center of vertipad or runway. 2. Confirm aircraft or simulator weight, altitude, temperature & wind configuration settings. 3. Execute takeoff and departure per assigned Test Point given max speed. 4. Test point complete when aircraft reaches terminating altitude at the vertiport holding pattern airspeed and altitude.	
Success Criteria	Minimum: Execute each test point once and confirm data collection is successful. Desired: Every pilot executes all manual test points once.	
Data Requirements	Simulator/ Aircraft	1. Simulator or aircraft data logs 2. Evaluation for navigation data verification (MOP 1.3.01) 3. Pilot evaluation for flyability (MOP 1.3.03)
Asset Requirements	1. Simulator or flight test asset	
Data Analysis Ex.	1. Identify Climb Gradient (MOP 1.3.02) 2. Identify Vertical FTE standard deviation (MOP 1.3.04) 3. Identify Lateral FTE standard deviation (MOP 1.3.05) 4. TSE Calculations (MOP 1.3.06) 5. Identify Power Peaks by IFP (MOP 1.3.21) 6. Calculate and overlay area upon map (MOP 1.3.23)	

	7. Identify total time by procedure (MOP 1.3.24) 8. Calculate assumed comfort (MOP 1.3.25-1.3.26)
Final Data Products Ex.	1. Qualitative Assessment for Navigation Data Verification (MOP 1.3.01) 2. Climb Gradient Departure Chart (MOP 1.3.02) 3. Qualitative Pilot Flyability Assessment (MOP 1.3.03) 4. Vertical FTE & splay (MOP 1.3.04) 5. Lateral FTE & splay (MOP 1.3.05) 6. TSE (MOP 1.3.06) 7. Power Range Statistical Summary by IFP (MOP 1.3.21) 8. Airspace Volume Overlay (conventional vs. 'dynamic procedure design') (MOP 1.3.23) 9. Time Chart (MOP 1.3.24) 10. Accelerations & Rates Statistical Summary (MOP 1.3.25-1.3.26)
Departure Test Points Agnostic	1.3.001 Manual Vertical Takeoff with Airspeed/Altitude Climb Gradient
	1.3.002 Manual Hover Takeoff with Airspeed/Altitude Climb Gradient
	1.3.003 Manual Rolling Takeoff with Airspeed/Altitude Climb Gradient
	1.3.004 Autopilot Vertical Takeoff with Airspeed/Altitude Climb Gradient
	1.3.005 Autopilot Hover Takeoff with Airspeed/Altitude Climb Gradient
	1.3.006 Autopilot Rolling Takeoff with Airspeed/Altitude Climb Gradient
	1.3.007 Manual Vertical Takeoff with Altitude/Airspeed Climb Gradient
	1.3.008 Manual Hover Takeoff with Altitude/Airspeed Climb Gradient
	1.3.009 Manual Rolling Takeoff with Altitude/Airspeed Climb Gradient
	1.3.010 Autopilot Vertical Takeoff with Altitude/Airspeed Climb Gradient
	1.3.011 Autopilot Hover Takeoff with Altitude/Airspeed Climb Gradient
	1.3.012 Autopilot Rolling Takeoff with Altitude/Airspeed Climb Gradient
	1.3.013 Manual Vertical Takeoff with 300 ft/NM Climb Gradient
	1.3.014 Manual Hover Takeoff with 300 ft/NM Climb Gradient
	1.3.015 Manual Rolling Takeoff with 300 ft/NM Climb Gradient
	1.3.016 Autopilot Vertical Takeoff with 300 ft/NM Climb Gradient
	1.3.017 Autopilot Hover Takeoff with 300 ft/NM Climb Gradient
	1.3.018 Autopilot Rolling Takeoff with 300 ft/NM Climb Gradient

Table 16. Example departure procedure sequence

STEP	EXAMPLE DEPARTURE PROCEDURE SEQUENCE	KIAS	ALTITIUDE	ANGLE	VSI/GRADIENT
1	Initiate test with stationary aircraft engines on with takeoff clearance at center of vertipad or runway.	0 kt	0 ft AGL		
2	Confirm aircraft (simulator) weight, altitude, temperature, wind configuration setting, battery state of charge and data for recording.				
3	Establish 10 ft hover over vertipoint		10 ft AGL or ft mean sea level (MSL)		
4	Initiate take off				
	Increase speed: Push throttle or use automation	040 kts 060 kts 080 kts 040 kts 060 kts 080 kts 040 kts 060 kts		12° 12° 12° 08° 08° 08° 05° 05°	

		080 kts		05°	
	Confirm positive climb	040 kts 060 kts 080 kts 040 kts 060 kts 080 kts 040 kts 060 kts 080 kts		12° 12° 12° 08° 08° 08° 05° 05° 05°	480 VSI 700 VSI 960 VSI 350 VSI 500 VSI 700 VSI 200 VSI 300 VSI 400 VSI
5	Achieve & maintain assigned speed, pitch attitude & VSI @ terminating altitude (TA)	040 kts 060 kts 080 kts 040 kts 060 kts 080 kts 040 kts 060 kts 080 kts	500 ft AGL or ft MSL	12° 12° 12° 08° 08° 08° 05° 05° 05°	480 VSI 700 VSI 960 VSI 350 VSI 500 VSI 700 VSI 200 VSI 300 VSI 400 VSI

Depending upon vehicle operating procedures, achieve desired flight path using flight path marker guidance or by managing speed and VSI.

Enroute Overview

The enroute structure will consist of a route or corridor bound together by precision navigational waypoints. The lateral dimensions of the route will be based on a reduced RNP of 0.1 (1215.2 ft width) and will be truncated to 8 -15 nautical miles to represent a UAM use case. Current lowest allowable enroute RNP is 0.3 NM. Shorter routes at lower altitude will also be required to minimize climb and descents with respect to obstacle evaluation and required vertical separation. The primary leg types will be Track-to-Fix to ensure the vehicle navigation system is traced to a ground reference point since operations will be at a lower altitude for future Air Traffic Management. Candidate UAM waypoint distances, RNP and vertical separation values are parallel to current day intermediate segments in length of route, RNP cross-track tolerance, and required obstacle clearance altitudes.

Enroute Assumptions

The aircraft will navigate out of the reserved vertiport holding pattern towards the approved route of flight and adhere to the waypoint airspeed, altitude and fly by/over restrictions per the coding and/or test card.

Enroute Test and Procedures

The enroute test details are found within Table 17 and the test departure procedure sequence is found within Table 18.

Table 17. Enroute test details

COMPONENT	ENROUTE TEST DETAILS
Test Methodology	1. Initiate test with aircraft at holding pattern airspeed and altitude above vertiport. 2. Maneuver to departing waypoint in 12° holding pattern. 3. Depart vertiport holding pattern. Commence flight path to destination. 4. Execute enroute assigned Test Point.

	5. Test point complete when aircraft reaches destination vertiport 12° holding pattern and stabilizes in the Instrument Approach Plate ring at airspeed and altitude.	
Success Criteria	Minimum: Execute each test point once and confirm data collection is successful. Desired: Each pilot executes all test points once.	
Data Requirements	Simulator/ Aircraft	1. Data Logs 2. Evaluation for Navigation Data Verification (MOP 1.3.01)
Asset Requirements	1. Simulator or flight test asset	
Data Analysis Ex.	1. Identify Vertical FTE standard deviation (MOP 1.3.04) 2. Identify Lateral FTE standard deviation (MOP 1.3.05) 3. TSE Calculations (MOP 1.3.06) 4. Calculate assumed comfort (MOP 1.3.25-1.3.26)	
Data Products Ex.	1. Qualitative Assessment for Navigation Data Verification (MOP 1.3.01) 2. Vertical FTE & splay (MOP 1.3.04) 3. Lateral FTE & splay (MOP 1.3.05) 4. TSE (MOP 1.3.06) 5. Accelerations & Rates Statistical Summary (MOP 1.3.25-1.3.26)	
Enroute Test Points	1.4.001 Manual Enroute 'Dynamic procedure design' Structure with Tailwind Component	
	1.4.002 Autopilot Enroute 'Dynamic procedure design' Structure with Tailwind Component	
	1.4.003 Manual Enroute 'Dynamic procedure design' Structure with Headwind Component	
	1.4.004 Autopilot Enroute 'Dynamic procedure design' Structure with Headwind Component	
Enroute Test Points	1.4.001 Manual Enroute Structure with Tailwind Component 'Dynamic procedure design' Departure	
	1.4.002 Manual Enroute Structure with Headwind Component 'Dynamic procedure design' Departure	
	1.4.003 Autopilot Enroute Structure with Tailwind Component 'Dynamic procedure design' Departure	
	1.4.004 Autopilot Enroute Structure with Headwind Component 'Dynamic procedure design' Departure	
	1.4.005 Manual Enroute Structure with Tailwind Component 'Dynamic procedure design' Arrival	
	1.4.006 Manual Enroute Structure with Headwind Component 'Dynamic procedure design' Arrival	
	1.4.007 Autopilot Enroute Structure with Tailwind Component 'Dynamic procedure design' Arrival	
	1.4.008 Autopilot Enroute Structure with Headwind Component 'Dynamic procedure design' Arrival	

Table 18. Example enroute procedure sequence

STEP	EXAMPLE ENROUTE PROCEDURE SEQUENCE	KIAS	ALTITIUDE	ANGLE	VSI/GRADIENT
1	Initiate test with aircraft established in terminal area in holding or on departure path away from vertiport.	100 kt	500 ft AGL		
2	Once cleared (simulated) to leave the vertiport terminal area, the aircraft or pilot will accept nav guidance to enroute structure.	100 kt	500 ft AGL		
3	Pilot or remote operator will cross-monitor aircraft conformance to route and waypoint to waypoint navigation. Any deviations in time, speed, heading or altitude will be noted and reported accordingly.	As directed	As assigned		

4	Engage Autopilot (if applicable)	KIAS	ALTITUDE	HEADING	TIME
	Monitor: Manual Autopilot Remote Pilot Estimated time of Arrival Required Time of Arrival (if applicable)	 +/-10 kts +/-05 kts +/-10 kts	 +/-100 ft +/-50 ft +/-80 ft	 +/-10° +/-5° +/-8°	 +/-30 sec +/-10 sec +/-15 sec +/-05 sec

Final Approach Overview

Unique final approach segments will be executed with various combinations of:

Glidepath Angle
Constant Rate of Deceleration
Variable Rate of Deceleration

All final approach segments will begin with the aircraft in the holding pattern that will transition from a hold above the vertiport to a final rollout point (FROP) in optimum wind alignment, wings level, at assigned altitude and specified airspeed to begin the approach. The approach will consist of a fixed altitude and entry airspeed with a variable glidepath angle entry in 5°, 8° and 12° approach segments (Figure 8).

Different deceleration profiles should be explored. One deceleration profile could involve initiating the deceleration earlier at the precision final approach fix (PFAF) and maintaining a constant rate of deceleration from the entry airspeed to the touchdown culminating at zero airspeed.

Another type of final approach deceleration profile could involve a late deceleration profile with an established (variable) deceleration point at the bottom of the approach, with higher speeds being maintained potentially as long as possible, for example to maximize time on the wing.

Final Approach Assumptions

The vehicle will start out at the airspeed and altitude within the holding pattern boundaries on the ring associated with the glide path angle that is intended to be flown. No emergency procedures, crosswind, or off-nominal environmental conditions are currently included. Special attention will need to be given to the vehicle design and configuration in the final approach phases for the procedure. As depicted in the approach (Figure 10) below, the candidate vehicle variables in propulsion mechanism, flight control scheme and operating limitations will need to be addressed and assigned before a procedure is constructed.

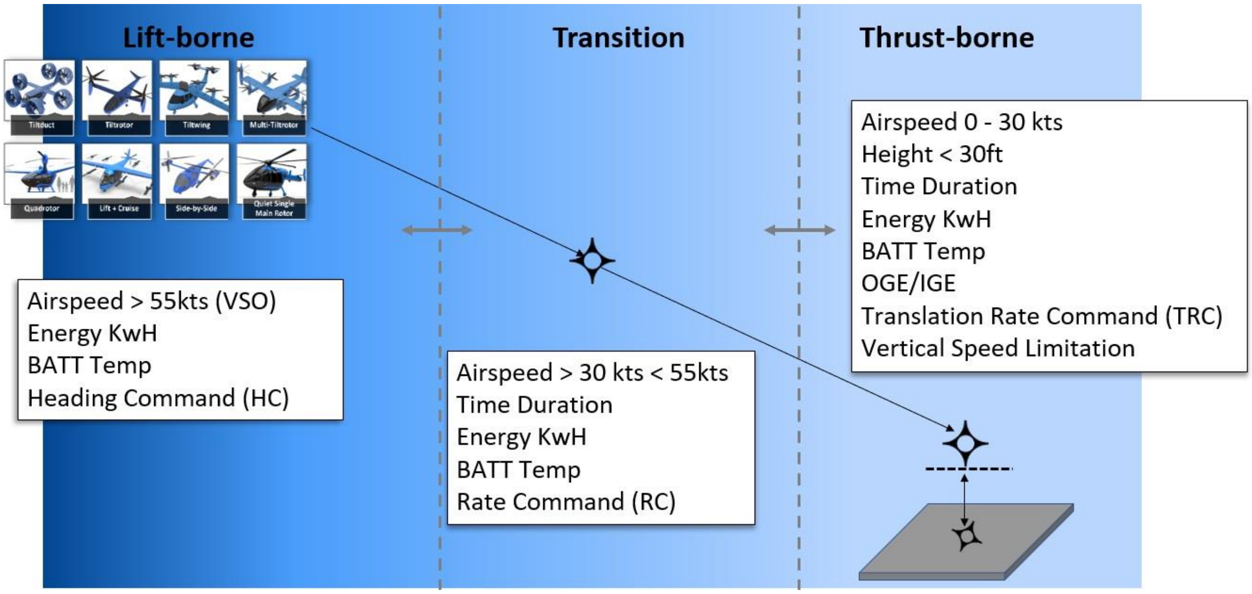


Figure 10. Sample final approach phases

Final Approach Test and Procedures

Once a vehicle is selected for procedure validation in live flight or simulation an airspeed to angle approach constraint chart needs to be considered for the maximum descent and deceleration profiles given a specific approach angle as depicted in Figure 11 below. Given the example, the assigned airspeed and descent rate mission rules can be derived based on the automation or pilot conformance to the maneuver. Additional attention will be needed for the tradition "Height-Velocity" diagram (located on the left side of the figure below) that will outline duration times, descent rates, airspeeds, and thermal ranges that can aide in mission rule planning beyond the "vortex ring state" or single engine operation caution areas. Final approach test details are found in Table 18 and the final approach procedure sequence is within Table 19.

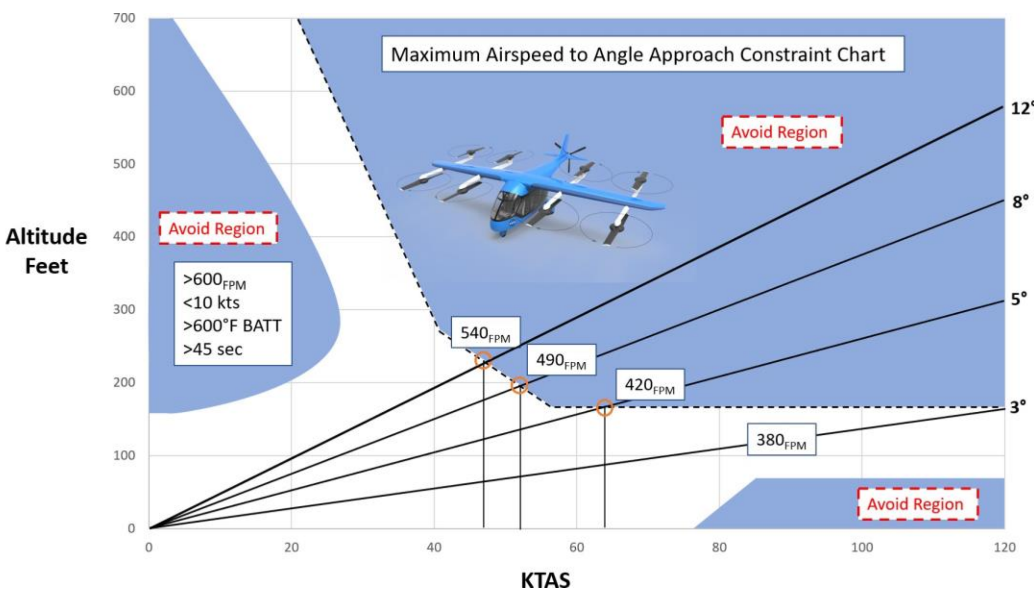


Figure 11. Example Final Approach Constraint Chart

Table 19. Example Final Approach Constraint Chart

COMPONENT	FINAL APPROACH TEST DETAILS	
Test Methodology	1. Initiate test with aircraft wing's level, at airspeed and on glidepath angle above Minimum Decoupling Point at Precision Final Approach Fix (PFAF). 2. Test Point complete when aircraft reaches vertipoint.	
Success Criteria	1. Minimum: Execute each test point once and confirm data collection is successful. Desired: Each pilot executes all test points once. 2. Stay within limits of the procedure and full-scale deflection geometry.	
Data Requirements	Simulator/ Aircraft	1. Simulator/aircraft data logs 2. Evaluation for navigation data (MOP 1.3.01) 3. Pilot evaluation for flyability (MOP 1.3.03)
Asset Requirements	1. Simulator or flight test asset	
Data Analysis Ex.	1. Identify Vertical FTE standard deviation (MOP 1.3.04) 2. Identify Lateral FTE standard deviation (MOP 1.3.05) 3. TSE Calculations (MOP 1.3.06) 4. Identify Power Peaks by IFP (MOP 1.3.321) 5. Calculate and overlay area upon map (MOP 1.3.23) 6. Identify total time by procedure (MOP 1.3.24) 7. Calculate assumed comfort (MOP 1.3.25-1.3.26)	
Data Products Ex.	1. Qualitative Assessment for Navigation Data Verification (MOP 1.3.01) 2. Qualitative Pilot Flyability Assessment (MOP 1.3.02) 3. Vertical FTE & splay (MOP 1.3.04) 4. Lateral FTE & splay (MOP 1.3.05) 5. TSE (MOP 1.3.06) 6. Power Range Statistical Summary by IFP (MOP 1.3.21) 7. Airspace Volume Overlay (conventional vs. 'dynamic procedure design') (MOP 1.3.23) 8. Time Chart (MOP 1.3.24) 9. Accelerations & Rates Statistical Summary (MOP 1.3.25-1.3.26)	
Test Points	1.5.001 Manual FAF (80 kts) Decel 5° Approach	
	1.5.002 Manual Delayed (80 kts) Decel 5° Approach	
	1.4.003 Autopilot FAF (80 kts) Decel 5° Approach	
	1.5.004 Autopilot Delayed (80 kts) Decel 5° Approach	
	1.5.005 Manual FAF (60 kts) Decel 8° Approach	
	1.5.006 Manual Delayed (60 kts) Decel 8° Approach	
	1.5.007 Autopilot FAF (60 kts) Decel 8° Approach	
	1.5.008 Autopilot Delayed (60 kts) Decel 8° Approach	
	1.5.009 Manual FAF (45 kts) Decel 12° Approach	
	1.5.010 Manual Delayed (45 kts) Decel 12° Approach	
	1.5.011 Autopilot FAF (45 kts) Decel 12° Approach	
	1.5.012 Autopilot Delayed (45 kts) Decel 12° Approach	

Table 20. Example final approach procedure sequence

STEP	EXAMPLE FINAL APPROACH PROCEDURE SEQUENCE	KIAS	ALTITIUDE	GPA	VSI/GRADIENT
1	Maintain airspeed for given GPA	45 kts 75 kts 90 kts	500 ft AGL or ft MSL	12° 08° 05°	
2	Initiate glideslope intercept @ PFAF for given GPA (PFAF 05 I PFAF 08 I PFAF12)	45 kts 75 kts 90 kts	500 ft AGL or ft MSL	12° 08° 05°	-500 fpm -500 fpm -500 fpm

3	Reduce airspeed for variable decel approach or constant decel approach @ delayed deceleration point (DDP) and maintain assigned GPA	manual		12° 08° 05°	-500 fpm -500 fpm -500 fpm
4	For 05°, 08° and 12° approaches, follow placarded maximum approach speeds per glidepath angle (overlined on approach plate)	manual	10 ft AGL or ft MSL		
5	Arrest aircraft descent and deceleration to 0 kts and 10ft AGL hover above vertipoint	0 kts	10 ft AGL or ft MSL		
6	Descend to 0 ft AGL	0 kts	00 ft AGL or ft MSL		

Additional Final Approach Segment Considerations

Additional considerations and factors need to be evaluated when testing the suitability of a vehicle executing a descending/decelerating precision approach procedure. Important factors include assessing field of view of the landing site (given steeper approach path angles), power required, temperature limitations (given electric propulsion systems), and workload. Several factors may play into the suitability of the procedure assessment. These include controllability at different airspeed, nacelle and/or approach angle. Testing the tailwind abuse case is also paramount. The rule of thumb is 2 degrees steeper with calm winds or 15-20kt tailwind component. Figure 12 is a graphical depiction of developing incremental crosswind component limitation test points.

1. Determine maximum crosswind component with given sideslip (β).
2. Subtract 10% of control margin of crosswind angle.
3. Fly final approach segment at 90% maximum left/right margin.
4. Report field of view, controllability, power required, and workload.
5. Incrementally increase glide path angle, airspeed, nacelle angle (α).
6. Repeat for opposite side.

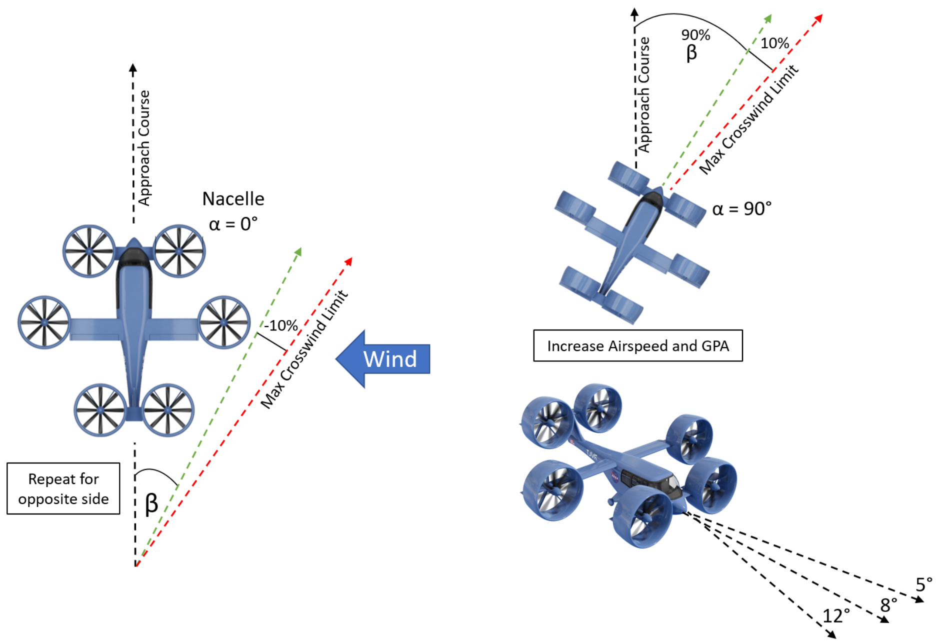


Figure 12. Max Crosswind Component and Nacelle Angle

When compiling final approach segment data, it is important to consider the wholistic evaluation of the procedure. Given the example in Figure 13, the procedure was first flown in the simulator as highlighted by the green trendline. Secondly, it was manually (orange trendline) flown without use of any flight director, autopilot, or automation. This is to baseline the procedure for tailwind abuse case suitability and environmental assessment. Finally, the procedure was flown with automation which creates two trend lines: the commanded path (blue trendline) and the actual path (yellow trend). This analysis can show deviation in conformance within software coding or divergence from commanded path given an environmental impact. This lifecycle comparison will inform simulator, flight check validation, approach coding and/or automation tuning.

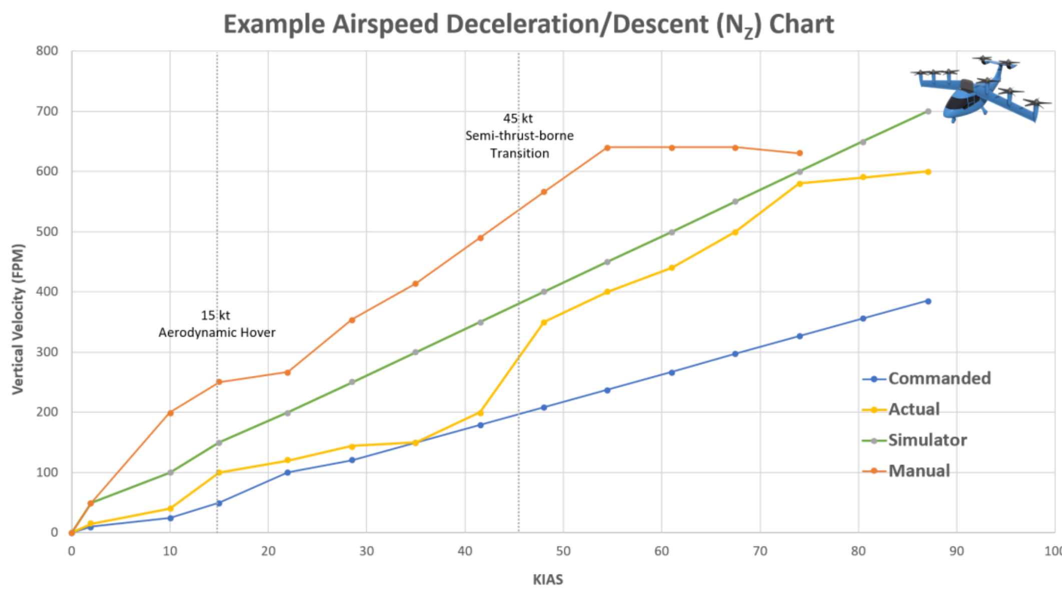


Figure 13. Example N_Z Descent Deceleration Compilation

<u>Missed Approach Overview</u>

Traditional approach procedures are conducted using one specified approach speed category 1.3x the V_{so} and missed approach maneuvers simplified to a one-axis climb out maintaining airspeed and azimuth. However, if constant rate decelerations or constant airspeed variable deceleration point approaches and urban operations with severe airspace constraints are introduced, the need to research and test multi-axis missed approach procedures that include a descending, decelerating or curved approach becomes necessary for the safe, scalable standardization of a UAM airspace architecture. This missed approach section involves exploring the impact of accelerating, climbing and changing course after decoupling from the glidepath as part of a missed approach sequence. The missed approach data will impact the required obstacle evaluation unique to a vertical lift and transition-capable aircraft, where lift-borne to thrust-born and back to lift-borne flight to climb up and away from the intended Point in Space (PinS) landing is possible. Evaluation will include the distance of height loss from the decoupling point, as well as the distance of the flat surface length required for the aircraft to return to lift-borne flight after transitioning to thrust-born flight in a descent and deceleration while on a 5 °, 8° or 12° glidepaths (Figures 14 & 15).

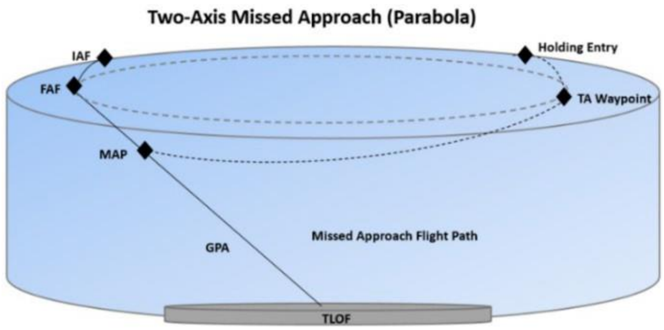


Figure 14. Two-Axis Missed Approach

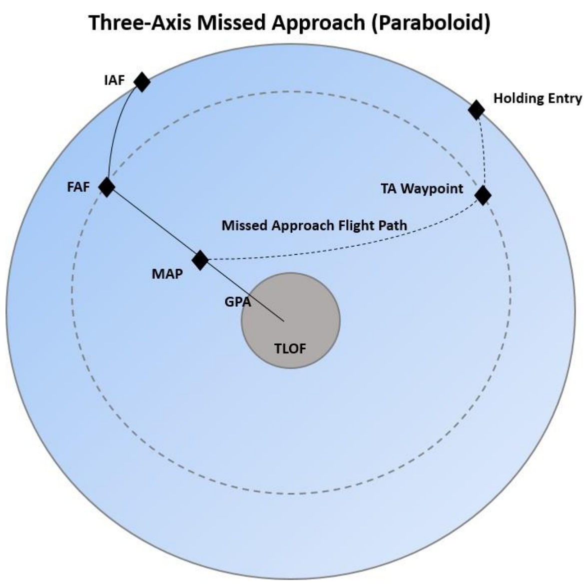


Figure 15. Three-Axis Missed Approach

Missed Approach Assumptions

Assumptions may include the aircraft is on-course and on-glidepath at the nominal airspeed before conducting the missed approach sequence. This sequence will include a missed approach or decoupling point, transition area or flat surface length, and climb gradient to a holding entry waypoint that is free from terrain, obstacles, traffic or airspace penetrations.

Missed Approach Test and Procedures

Missed approach test details are found in Table 21 and the test missed sequence is found within Table 22.

Table 21. Missed approach test details

COMPONENT	MISSED APPROACH TEST DETAILS
Test Methodology	1. Initiate test with aircraft wing's level, at airspeed and on glidepath angle above Minimum Decoupling Point at Precision Final Approach Fix (PFAF). 2. Pilot commands/monitors aircraft to descend to Missed Approach Point (MAP). 3. Pilot determines or is informed that Runway Not visually acquired.

	4. Execute Missed Approach maneuver at Minimum Glidepath Decoupling Point. 5. Aircraft reaches Departure Intercept Point. 6. Test Point complete when aircraft enters and completes one circuit in holding.
Data Requirements	1. Data Logs 2. Evaluation for Navigation Data (MOP 1.3.01) 3. Pilot Evaluation for Flyability (MOP 1.3.02)
Asset Requirements	1. eVTOL simulator or flight test asset
Data Analysis Ex.	1. Calculate approach angle divergence (MOP 1.3.18) 2. Calculate distance of height loss (MOP 1.3.17) 3. Calculate missed approach surface (MOP 1.3.19) 4. Calculate flat surface length (MOP 1.3.16) 5. Calculate climb gradients (MOP 1.3.02) 6. Calculate departure intercept point deviations (MOP 1.3.20) 7. Identify Vertical FTE standard deviation (MOP 1.3.04) 8. Identify Lateral FTE standard deviation (MOP 1.3.05) 9. TSE Calculations (MOP 1.3.06) 10. Identify Power Peaks by IFP (MOP 1.3.21) 11. Calculate and overlay area upon map (MOP 1.3.23) 12. Identify total time by procedure (MOP 1.3.24) 13. Calculate assumed comfort (MOP 1.3.25-1.3.26)
Data Products Ex.	1. Divergence Splay (MOP 1.3.18) 2. Height Loss Summary Chart (MOP 1.3.17) 3. HMAS Chart (MOP 1.3.19) 4. Flat Surface Length Chart (MOP 1.3.16) 5. Climb Gradient Missed Approach Chart (MOP 1.3.02) 6. DIP Chart (MOP 1.3.20) 7. Qualitative Assessment for Navigation Data Verification (MOP 1.3.01) 8. Qualitative Pilot Flyability Assessment (MOP 1.3.02) 9. Vertical FTE & splay (MOP 1.3.04) 10. Lateral FTE & splay (MOP 1.3.05) 11. TSE (MOP 1.3.06) 12. Power Range Statistical Summary by IFP (MOP 1.3.21) 13. Airspace Volume Overlay (conventional vs. 'dynamic procedure design') (MOP 1.3.23) 14. Time Chart (MOP 1.3.24) 15. Accelerations & Rates Statistical Summary (MOP 1.3.25-1.3.26)
Test Points	1.6.001 Manual FAF (80 kts) Decel 5° Maintain On-course Heading
	1.6.002 Manual Delayed (80 kts) Decel 5° Maintain On-course Heading
	1.6.003 Autopilot FAF (80 kts) Decel 5° Maintain On-course Heading
	1.6.004 Autopilot Delayed (80 kts) Decel 5° Maintain On-course Heading
	1.6.005 Manual FAF (80 kts) Decel 5° Execute Coordinated Turn
	1.6.006 Manual Delayed (80 kts) Decel 5° Execute Coordinated Turn
	1.6.007 Autopilot FAF (80 kts) Decel 5° Execute Coordinated Turn
	1.6.008 Autopilot Delayed (80 kts) Decel 5° Execute Coordinated Turn
	1.6.009 Manual FAF (60 kts) Decel 8° Maintain On-course Heading
	1.6.010 Manual Delayed (60 kts) Decel 8° Maintain On-course Heading
	1.6.011 Autopilot FAF (60 kts) Decel 8° Maintain On-course Heading
	1.6.012 Autopilot Delayed (60 kts) Decel 8° Maintain On-course Heading
	1.6.013 Manual FAF (60 kts) Decel 8° Execute Coordinated Turn
	1.6.014 Manual Delayed (60 kts) Decel 8° Execute Coordinated Turn
	1.6.015 Autopilot FAF (60 kts) Decel 8° Execute Coordinated Turn

	1.6.016 Autopilot Delayed (60 kts) Decel 8° Execute Coordinated Turn
	1.6.017 Manual FAF (45 kts) Decel 12° Maintain On-course Heading
	1.6.018 Manual Delayed (45 kts) Decel 12° Maintain On-course Heading
	1.6.019 Autopilot FAF (45 kts) Decel 12° Maintain On-course Heading
	1.6.020 Autopilot Delayed (45 kts) Decel 12° Maintain On-course Heading
	1.6.021 Manual FAF (45 kts) Decel 12° Execute Coordinated Turn
	1.6.022 Manual Delayed (45 kts) Decel Approach 12° Execute Coordinated Turn
	1.6.023 Autopilot FAF (45 kts) Decel Approach 12° Execute Coordinated Turn
	1.6.024 Autopilot Delayed (45 kts) Decel Approach 12° Execute Coordinated Turn
	1.6.025 Tailwind Manual FAF (45 kts) Decel 12° Maintain On-course Heading
	1.6.026 Tailwind Manual Delayed (45 kts) Decel 12° Maintain On-course Heading
	1.6.027 Tailwind Autopilot FAF (45 kts) Decel 12° Maintain On-course Heading
	1.6.028 Tailwind Autopilot Delayed (45 kts) Decel 12° Maintain On-course Heading
	1.6.029 Tailwind Manual FAF (45 kts) Decel 12° Execute Coordinated Turn
	1.6.030 Tailwind Manual Delayed (45 kts) Decel 12° Execute Coordinated Turn
	1.6.031 Tailwind Autopilot FAF (45 kts) Decel 12° Execute Coordinated Turn
	1.6.032 Tailwind Autopilot Delayed (45 kts) Decel 12° Execute Coordinated Turn

Table 22. Example Missed Approach Procedure Sequence

STEP	EXAMPLE MISSED APPROACH PROCEDURE SEQUENCE	KIAS	ALTITIUDE	GPA	VSI/GRADIENT
1	Maintain airspeed for given GPA	45 kts 75 kts 90 kts	500 ft AGL or ft MSL	12° 08° 05°	
2	Initiate glideslope intercept @ PFAF for given GPA (PFAF 05 I PFAF 08 I PFAF 12)	45 kts 75 kts 90 kts	500 ft AGL or ft MSL	12° 08° 05°	-500 fpm -500 fpm -500 fpm
3	Reduce airspeed for variable decel approach or constant decel approach @ decision point (DP)	manual			
4	Initiate missed approach @ MAP				
	Increase airspeed (forward accel/left throttle)	80 kts			
	Initiate climb; set trim for assigned climb gradient (Ex. 5° pitch up attitude)			05°	+400 fpm
	Initiate right turn to assigned waypoint (displace inceptor to right with zero yaw)				
5	Intercept course to enter right traffic holding ring Accelerate to holding airspeed @ terminating altitude (TA)	100 kts	500 ft AGL or ft MSL		

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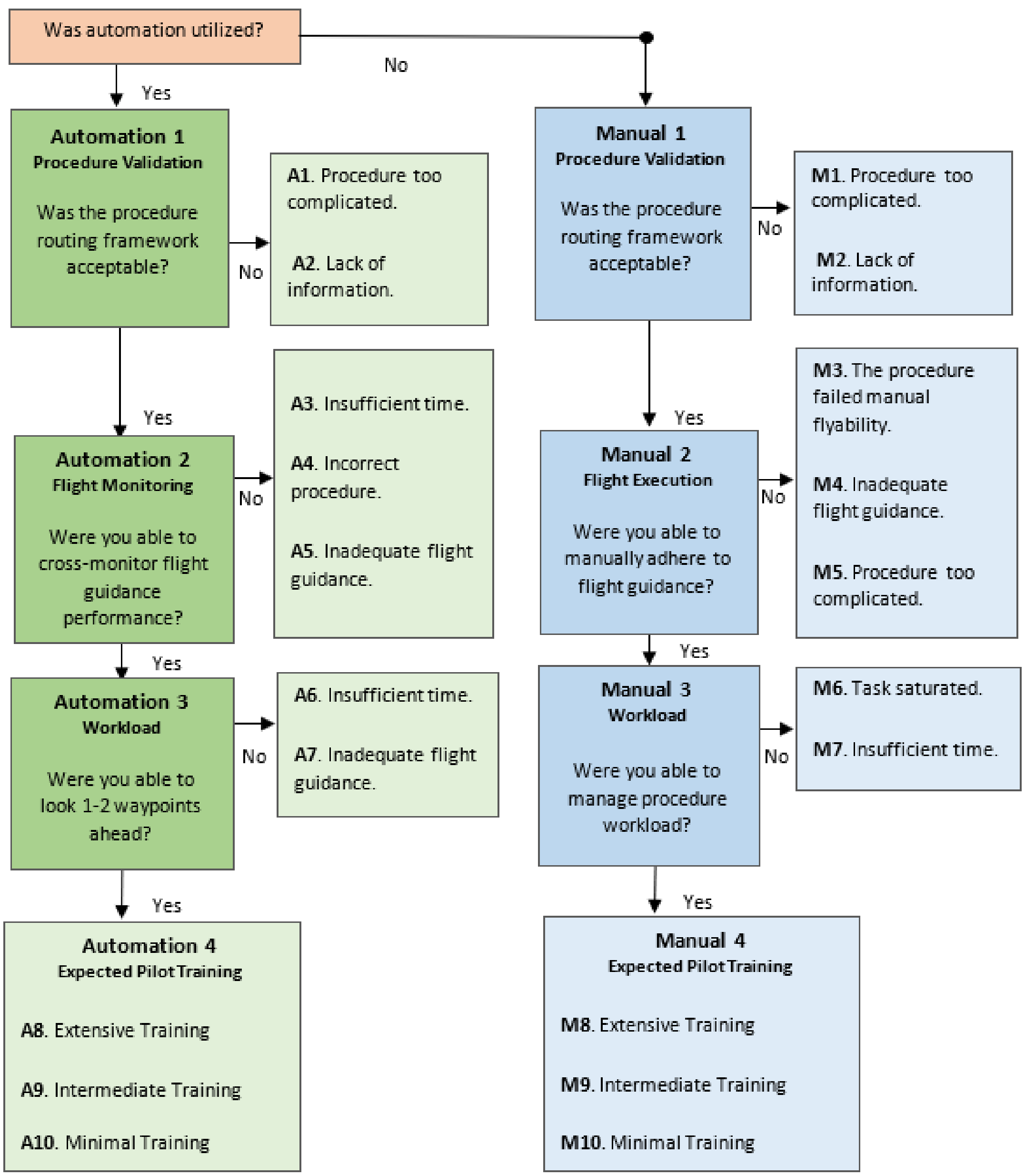
Appendix A – Procedure Automation Rating Criteria (PARM)

IFP Safety MOP 1.3.03 corresponds with Qualitative pilot assessment of procedure flyability, safety and design. For the metrics, NC designed the Procedure Automation Rating Matrix (PARM), a matrix to evaluate UAM instrument flight procedure design, flyability and interoperability of candidate departure, enroute, and approach architectures in live flight or simulation. The PARM is a multi-dimensional rating scale designed to provide direct feedback from test pilots and operators to airspace procedure designers developing airspace constructs for the integration and scalability of AAM operations in the NAS. The PARM is assessed using a hierarchical decision tree that guides the operator through a ten-point alpha-numeric rating scale initiated either with or without the use of automation. For more information, reference *Procedure Automation Rating Matrix AAM Document Number: AAM-NC-112-001*.



Appendix B – Example Test Points & Requirements Matrix

Flight Segment 01

Climb Gradient & Glidepath	Departure Test Point	Final Approach Test Point
05°	1.3.001 Manual Vertical Takeoff 5° Climb Angle at 45 kt (200 fpm VSI)	1.5.001 Manual FAF (80 kts) Decel 5° Glide Path Angle
	1.3.002 Manual Vertical Takeoff 5° Climb Angle at 60 kt (300 fpm VSI)	1.5.002 Manual Delayed (80 kts) Decel 5° Approach
	1.3.003 Manual Vertical Takeoff 5° Climb Angle at 80 kt (400 fpm VSI)	
	1.3.004 Pilot-Assist Vertical Takeoff 5° Climb Angle at 45 kt (200 fpm VSI)	1.5.003 Pilot-Assist FAF (80 kts) Decel 5° Approach
	1.3.005 Pilot-Assist Vertical Takeoff 5° Climb Angle at 60 kt (300 fpm VSI)	1.5.004 Pilot-Assist Delayed (80 kts) Decel 5° Approach
	1.3.006 Pilot-Assist Vertical Takeoff 5° Climb Angle at 80 kt (400 fpm VSI)	
08°	1.3.007 Manual Vertical Takeoff 8° Climb Angle at 45 kt (350 fpm VSI)	1.5.005 Manual FAF (60 kts) Decel 8° Approach
	1.3.008 Manual Vertical Takeoff 8° Climb Angle at 60 kt (500 fpm VSI)	1.5.006 Manual Delayed (60 kts) Decel 8° Approach
	1.3.009 Manual Vertical Takeoff 8° Climb Angle at 80 kt (700 fpm VSI)	
	1.3.010 Pilot-Assist Vertical Takeoff 8° Climb Angle at 45 kt (350 fpm VSI)	1.5.007 Pilot-Assist FAF (60 kts) Decel 8° Approach
	1.3.011 Pilot-Assist Vertical Takeoff 8° Climb Angle at 60 kt (500 fpm VSI)	1.5.008 Pilot-Assist Delayed (60 kts) Decel 8° Approach
	1.3.012 Pilot-Assist Vertical Takeoff 8° Climb Angle at 80 kt (700 fpm VSI)	
12°	1.3.013 Manual Vertical Takeoff 12° Climb Angle at 45 kt (480 fpm VSI)	1.5.009 Manual FAF (45 kts) Decel 12° Approach
	1.3.014 Manual Vertical Takeoff 12° Climb Angle at 60 kt (700 fpm VSI)	1.5.010 Manual Delayed (45 kts) Decel 12° Approach
	1.3.015 Manual Vertical Takeoff 12° Climb Angle at 80 kt (960 fpm VSI)	
	1.3.016 Pilot-Assist Vertical Takeoff 12° Climb Angle at 45 kt (480 fpm VSI)	1.5.011 Pilot-Assist FAF (45 kts) Decel 12° Approach
	1.3.017 Pilot-Assist Vertical Takeoff 12° Climb Angle at 60 kt (700 fpm VSI)	1.5.012 Pilot-Assist Delayed (45 kts) Decel 12° Approach
	1.3.018 Pilot-Assist Vertical Takeoff 12° Climb Angle at 80 kt (960 fpm VSI)	

Flight Segment 02

Wind Component	Enroute Test Point
Tailwind	1.4.001 Manual Enroute Tailwind Component 12° 'Deproach'
	1.4.002 Pilot-Assist Enroute Tailwind Component 12° 'Deproach'
Headwind	1.4.003 Manual Enroute Headwind Component 12° 'Deproach'
	1.4.004 Pilot-Assist Enroute Headwind Component 12° 'Deproach'

Flight Segment 03

Glidepath	Missed Approach Test Point
05°	1.6.003 Pilot-Assist FAF (80 kts) Decel 5° Maintain On-course Heading
	1.6.004 Pilot-Assist Delayed (80 kts) Decel 5° Maintain On-course Heading
	1.6.001 Manual FAF (80 kts) Decel 5° Maintain On-course Heading
	1.6.007 Pilot-Assist FAF (80 kts) Decel 5° Execute Coordinated Turn
	1.6.008 Pilot-Assist Delayed (80 kts) Decel 5° Execute Coordinated Turn
	1.6.002 Manual Delayed (80 kts) Decel 5° Maintain On-course Heading
	1.6.005 Manual FAF (80 kts) Decel 5° Execute Coordinated Turn
	1.6.006 Manual Delayed (80 kts) Decel 5° Execute Coordinated Turn
	1.6.007 Pilot-Assist FAF (80 kts) Decel 5° Execute Coordinated Turn
	1.6.008 Pilot-Assist Delayed (80 kts) Decel 5° Execute Coordinated Turn
08°	1.6.011 Pilot-Assist FAF (60 kts) Decel 8° Maintain On-course Heading
	1.6.012 Pilot-Assist Delayed (60 kts) Decel 8° Maintain On-course Heading
	1.6.009 Manual FAF (60 kts) Decel 8° Maintain On-course Heading
	1.6.010 Manual Delayed (60 kts) Decel 8° Maintain On-course Heading
	1.6.015 Pilot-Assist FAF (60 kts) Decel 8° Execute Coordinated Turn
	1.6.016 Pilot-Assist Delayed (60 kts) Decel 8° Execute Coordinated Turn
	1.6.013 Manual FAF (60 kts) Decel 8° Execute Coordinated Turn
	1.6.014 Manual Delayed (60 kts) Decel 8° Execute Coordinated Turn
12°	1.6.019 Pilot-Assist FAF (45 kts) Decel 12° Maintain On-course Heading
	1.6.020 Pilot-Assist Delayed (45 kts) Decel 12° Maintain On-course Heading
	1.6.017 Manual FAF (45 kts) Decel 12° Maintain On-course Heading
	1.6.018 Manual Delayed (45 kts) Decel 12° Maintain On-course Heading
	1.6.023 Pilot-Assist FAF (45 kts) Decel Approach 12° Execute Coordinated Turn
	1.6.024 Pilot-Assist Delayed (45 kts) Decel Approach 12° Execute Coordinated Turn
	1.6.021 Manual FAF (45 kts) Decel 12° Execute Coordinated Turn
	1.6.022 Manual Delayed (45 kts) Decel Approach 12° Execute Coordinated Turn
Tailwind 12°	1.6.027 Tailwind Pilot-Assist FAF (45 kts) Decel 12° Maintain On-course Heading
	1.6.028 Tailwind Pilot-Assist Delayed (45 kts) Decel 12° Maintain On-course Heading
	1.6.025 Tailwind Manual FAF (45 kts) Decel 12° Maintain On-course Heading
	1.6.026 Tailwind Manual Delayed (45 kts) Decel 12° Maintain On-course Heading
	1.6.031 Tailwind Pilot-Assist FAF (45 kts) Decel 12° Execute Coordinated Turn
	1.6.032 Tailwind Pilot-Assist Delayed (45 kts) Decel 12° Execute Coordinated Turn
	1.6.029 Tailwind Manual FAF (45 kts) Decel 12° Execute Coordinated Turn
	1.6.030 Tailwind Manual Delayed (45 kts) Decel 12° Execute Coordinated Turn

Appendix C - Abbreviations, Acronyms & New Terms

ABBREVIATION	DESCRIPTION
AAM	Advanced Air Mobility
AFR	Automated Flight Rules
AGL	Above Ground Level
AIRNAV	Air Navigation Database (FAA)
ARINC	Aeronautical Radio, Incorporated
ATT	Across-track Tolerance
ATS	Air Traffic Services
CAD	Computer-aided Design
DAPD	Dynamic Airspace Procedure Design **(New Term)**
dB	Decibels
DDP	Delayed Deceleration Point
DIP	Departure Intercept Point **(New Term)**
DP	Decision Point
DTED	Digital Terrain Elevation Data
EB	Engineering Brief
ETA	Estimate Time of Arrival
eVTOL	Electric Vertical Take Off and Land
FAA	Federal Aviation Administration
FAS	Final Approach Segment
FATO	Final Approach and Takeoff Area
FIAPA	Flight Inspection Airborne Processing Application
FMS	Flight Monitoring System
FPM	Feet per Minute
FROP	Final Rollout Point
FTE_L	Flight Technical Error (Lateral)
FTE_V	Flight Technical Error (Vertical)
GTO	General Test Objective
HMAS	Height of Missed Approach Surface
IAF	Initial Approach Fix
IMC	Instrument Meteorological Conditions
IFP	Instrument Flight Procedures
IFPA	Instrument Flight Procedures Automation
IFR	Instrument Flight Rules
IGE	In Ground Effect
IMC	Instrument Meteorological Conditions
MA	Missed Approach
MAP	Missed Approach Point
MFD	Multi-function Display
MOP	Measure of Performance
MSL	Mean Sea Level

NAC	Navigational Accuracy Category (Position or Velocity)
NAS	National Airspace System
NASA	National Aeronautics and Space Administration
NAVAIDS	Navigational Aids
NC	National Campaign
NIC	Navigational Integrity Category
NM	Nautical Mile
NSE	Navigational System Error
OCS	Obstacle Clearance Slope
OEA	Obstacle Evaluation Assessment
OEAA	Obstacle Evaluation Assessment Area
OE / AAA	Obstruction Evaluation/ Airport Airspace Analysis
OEM	Original Equipment Manufacturer
PARM	Procedure Automation Rating Matrix **(New Term)**
PBN	Performance-based Navigation
PFAF	Precision Final Approach Fix
PFD	Primary Flight Display
PIN	Point-in -Space
PSU	Provider of Service for UAM
RF	Radius-to-Fix
RMS	Root Mean Squared
RNAV	Area Navigation
RNP	Required Navigation Performance
ROC	Required Obstacle Clearance
RVLT	Revolutionary Vertical Lift Technology
SA	Safety Area
SDA	System Design Assurance
STO	Specific Test Objective
SIAP	Standard Instrument Approach Procedures
SIL	Surveillance Integrity Level
SME	Subject Matter Expert
TA	Terminating Altitude
TARGETS	Terminal Area Route Generation Evaluation and Traffic Simulation
TERPS	Terminal Instrument Procedures
TF	Track-to-Fix
TLOF	Touchdown and Liftoff
TSE	Total System Error
UAM	Urban Air Mobility
UAS	Unmanned Aircraft System
VFR	Visual Flight Rules
VSI	Vertical Speed Indicator
XTT	Cross-track Tolerance

New Terms

NEW TERM	DESCRIPTION
‘DAPD’	Dynamic Airspace Procedure Design: a modular approach to customize precision flight procedures to the aircraft, location and operation
‘Dynamic Procedure Design’	Candidate UAM/eVTOL departure and approach IFP concept with omni-directional takeoff and landing and scalable airspace architecture
‘DIP’	Departure Intercept Point: a point at which a missed approach intersects with a departure
‘PARM’	Procedure Automation Rating Matrix: ‘Cooper-Harper’-like subjective pilot evaluation for rating procedures via manual and automation augmented flight
‘vertipoint’	Surveyed center point of vertipad from which UAM/eVTOL airspace procedures are anchored