Noise Modeling Methods for Urban Air Mobility Vehicles in the Federal Aviation Administration's Aviation Environmental Design Tool

September 30, 2022

U.S. Department of Transportation
John A. Volpe National Transportation Systems Center
Volpe

REPORT DOCUMENTATION PAGE			*Form Approved OMB No. 0704-0188*

1. AGENCY USE ONLY (Leave blank)	2. REPORT DATE September 30, 2022	3. REPORT TYPE AND DATES COVERED Final Report, Oct. 2021 – Sept. 2021

4. TITLE AND SUBTITLE Noise Modeling Methods for Urban Air Mobility Vehicles in the Federal Aviation Administration's Aviation Environmental Design Tool	5a. FUNDING NUMBERS 51VXV1A322 / VN245
6. AUTHOR(S) (ORCID) Bradley Nicholas (0000-0002-6929-4305), Sarasina Tuchen (0000-0002-8761-1466), and Eric Boeker (0000-0002-9034-8574)	5b. CONTRACT NUMBER NASA NNL22OB03A
7. PERFORMING ORGANIZATION NAME(S) AND ADDRESS(ES) U.S. Department of Transportation (USDOT) John A. Volpe National Transportation Systems Center (Volpe) 55 Broadway Cambridge, MA 02142	8. PERFORMING ORGANIZATION REPORT NUMBER DOT-VNTSC-NASA-22-02
9. SPONSORING/MONITORING AGENCY NAME(S) AND ADDRESS(ES) National Aeronautics and Space Administration Langley Research Center Hampton, VA 23681	10. SPONSORING/MONITORING AGENCY REPORT NUMBER
11. SUPPLEMENTARY NOTES	
12a. DISTRIBUTION/AVAILABILITY STATEMENT	12b. DISTRIBUTION CODE

13. ABSTRACT (Maximum 200 words)

USDOT Volpe, The National Transportation Systems Center, supported the National Aeronautics and Space Administration (NASA) through a technical exchange process to facilitate the use of the Federal Aviation Administration (FAA) Aviation Environmental Design Tool (AEDT) for predictions of Urban Air Mobility (UAM) fleet noise. Volpe assessed the functional requirements for UAM fleet noise modeling, evaluated the capabilities of AEDT, and documented methods to utilize existing AEDT capabilities for UAM fleet noise modeling.

14. SUBJECT TERMS	15. NUMBER OF PAGES: 21 16. PRICE CODE

17. SECURITY CLASSIFICATION OF REPORT	18. SECURITY CLASSIFICATION OF THIS PAGE	19. SECURITY CLASSIFICATION OF ABSTRACT	20. LIMITATION OF ABSTRACT
Unclassified	Unclassified	Unclassified	

NSN 7540-01-280-5500

Standard Form 298 (Rev. 2-89)
Prescribed by ANSI Std. 239-18
298-102

Table of Contents

List of Tables

1. Introduction

Studies conducted as a part of the National Aeronautics and Space Administration's (NASA's) Advanced Air Mobility (AAM) mission estimate that by 2035 significant numbers of new air vehicles will be operating to support Urban Air Mobility (UAM). These vehicles will differ in size, speed, and configuration depending on the purpose, which may include final-mile delivery, new forms of public transportation, cargo delivery and air taxi services. Many of these vehicles use new eVTOL (electric Vertical TakeOff and Landing) technologies that are developed to be quieter than traditional aircraft and helicopters.

UAMs will operate in high density populated urban areas, and aviation noise remains a primary concern for these communities. UAMs will also primarily fly between vertiport to vertiport that will be located on top of buildings or parking garages. With the introduction of a new, unfamiliar, noise source it is important that the characteristics of the noise be quantified and understood. The Federal Aviation Administration (FAA) requires the use of the Aviation Environmental Design Tool (AEDT) for all noise, fuel burn and emissions modeling for FAA actions under the National Environmental Policy Act (NEPA) as well as other FAA approved studies, such as those under 14 CFR Part 150 and Part 161.'

Moreover, air vehicles serving the UAM market will operate in communities away from conventional airports, which are not accustomed to aircraft noise. Tools and metrics are not currently available to assess the impact of UAM fleet noise on these communities, and noise assessments are needed before deployments to prevent overly restrictive noise constraints that limit the growth of the market which the White House deems as an important new industry for the United States to maintain its global aviation leadership[1]. A recent white paper by the NASA/FAA led UAM Noise Working Group (UNWG), "Urban Air Mobility Noise: Current Practice, Gaps, and Recommendations," recommended that:

> *Research be conducted to more fully explore limitations in methods for assessing community noise impact of UAM vehicles in their operational environments, and to generate a software development plan that addresses the limitations of current models over time.*

In recognition of that need, the NASA Revolutionary Vertical Lift Technology (RVLT) Project initiated research to develop a method to assess the acoustic impact of UAM fleet operations on the community and demonstrate that for representative UAM operations. The approach has three tracks:

1. UAM vehicle noise database generation through analysis
2. Fleet noise assessments using AEDT
3. Human response and metrics

---

[1] https://www.whitehouse.gov/ostp/news-updates/2022/08/05/readout-of-the-white-house-summit-on-advanced-air-mobility/

The USDOT Volpe center is supporting NASA in the second track as they evaluate AEDT for the modeling of community noise from UAM vehicles. This report compares different approaches to using AEDT for UAM noise computation in the particular context of Volpe's understanding of NASA's work to-date on UAM community noise assessment. For an AEDT user that possesses trajectory (x, y, z, and t), state (thrust, configuration), and noise emission (noise-power-distance curves, directivity) data for a new vehicle, the report compares options for AEDT vehicle-type selection and profile specification.

AEDT provides the ability to model two vehicle types: helicopters and fixed-wing aircraft. Though many aspects of the AEDT noise modeling methodology are shared for these vehicle types, the flight profile specification and acoustical definition differ in important ways. This paper looks at three different UAM modeling methodologies in AEDT: modeling as fixed-wing aircraft; modeling as helicopters; and modeling as a combination of fixed-wing aircraft and helicopters. Sections 2 and 3 of this memorandum discuss AEDT's fixed-wing and helicopter methodologies, respectively. Section 4 compares the methods and Section 5 presents multiple methods to utilize aspects of both methods to model UAM vehicle operations.

All analyses presented in this document utilize AEDT version 3e.

2. Fixed-Wing Methodology

The AEDT 3e fleet database contains noise and performance data for nearly three hundred fixed-wing aircraft representing over three thousand unique real-world airframe-engine combinations. The database contains profiles for arrival, departure, touch and go, and circuit operations. The flight performance of fixed-wing aircraft in AEDT can either be computed by a comprehensive performance model (procedural profile method) or directly specified as a set of thrust, speed, and altitude values as a function of track distance (fixed-point profile method). For UAM vehicles, where the performance characteristics are unlikely to be well-represented by AEDT's current fixed-wing performance algorithms, the use of the latter, fixed-point profile method, is recommended.

Fixed-point profiles do not leverage AEDT's performance models which dynamically account for airfield altitude and weather conditions. They only reflect the result of the atmospheric conditions under which they were developed. Fixed-point profiles can be defined using the elements provided in Table 1.

Table 1 Fixed-Point Profile Definition

Element	Description
Point Number	Fixed-point profile point number.
Operational Mode	Noise operational modes – Approach, Departure, or Afterburner.
Altitude AFE (ft)	Altitude above field elevation.
Track Distance (ft)	Horizontal distance value from a reference point (where the reference point is at track distance=0). Track distance can be positive or negative, and increases as the airplane flies the profile.
Speed TAS (kt)	True airspeed (KTAS).
Thrust Setting	For most civil airplanes, this parameter is corrected net thrust per engine in pounds; but some civil airplanes use percent of static thrust.

2.1 Method F1: Fixed Wing Aircraft with Thrust-Based Fixed-Point Profiles

Method F1, below, describes the use of AEDT for UAM modeling in a manner consistent with typical modeling of fixed-wing aircraft with fixed-point profiles. This method is presented to discuss the difficulties of modeling UAM in AEDT.

- Create and import general vehicle information
  - Compute NPD curves for each noise operational mode (arrival, departure), power setting (thrust), and metric combination
  - Compute representative spectrum for each noise operational mode
  - Import one vehicle to AEDT
- Create and import flight-specific information
  - Create airports and runways for origin and destination vertiports
  - Create departure flight tracks associated with origin vertiports and arrival flight tracks associated with destination vertiports
  - Create fixed-point departure and arrival profiles matching the flight tracks
  - Import airports, runways, tracks, and profiles into AEDT
- Run AEDT
  - Use weather data and SAE-ARP-5534 atmosphere for modification of atmospheric absorption

AEDT's fixed wing noise modeling methodology relies on the assumption that the vehicles noise emissions can be adequately represented by a single spectrum each for arrival and departure (level flight spectra are not used for fixed wing aircraft), and that the noise emissions rise or fall as a continuous function of thrust only. For a vehicle with many flight states (e.g. number of rotors operating, angle of nacelles), noise levels cannot be characterized by a single input variable. Additionally, the spectrum may change dramatically between vehicle states. Noise levels computed using Method F1 would be compromised by the non-representative thrust-to-noise relationship as well as the atmospheric absorption based on a single spectrum that may not represent many vehicle states.

2.2 Method F2: Fixed Wing Aircraft with Mode-Based Fixed-Point Profiles

When modeling fixed-wing aircraft in AEDT, the profiles specify thrust values that are then used to reference noise data on the NPD curves. When a thrust value is specified that is not directly on an NPD curve, AEDT interpolates or extrapolates the noise to the specified thrust level. NASA's current methodology approximates a mode-based approach with fixed-wing aircraft by using many NPD curves with thrust values exactly matching the thrust values in the profile points. The AEDT profile thrust value does not correspond to an actual thrust value, but is simply used as an identifier for a particular NPD curve. Interpolation of thrust values during the sub-segmentation of flight path segments is limited by rapidly transitioning the thrust values from one NPD thrust value to another. The points that are inserted into the profile to cause these rapid transitions are called guard points.

AEDT's ground-based directivity function for fixed-wing aircraft start of take-off roll is bypassed by making the altitude for the second track point greater than zero. For fixed-wing aircraft this second point is typically at 0 ft above field elevation (AFE) The limited number of spectral shapes per aircraft is bypassed by creating all NPD curves at the desired atmospheric conditions (rather than reference conditions) and running AEDT without atmospheric absorption corrections (SAE 1845 atmosphere). In addition, the vehicle is coded as a propeller airplane in order to avoid unwanted adjustments for engine installation effects that AEDT applies to jet airplanes. This methodology requires that the NPD curves and profiles be developed for the specific atmospheric conditions desired in the AEDT modeling runs, since AEDT will not use user-supplied weather data to modify the aircraft performance or noise propagation.

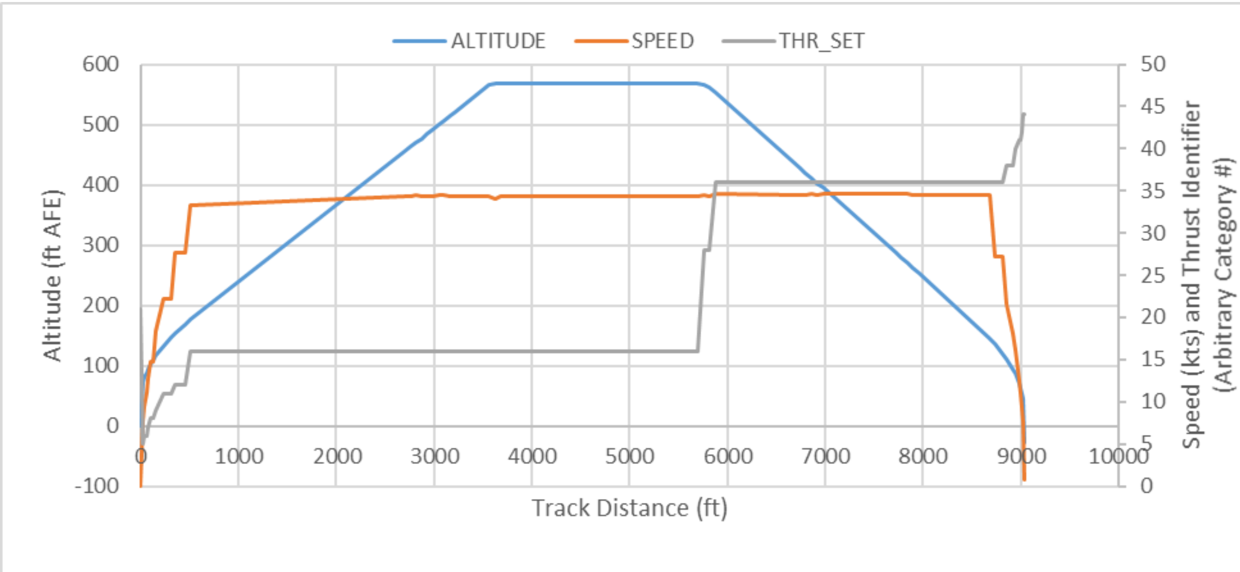

Figure 1 Example NASA UAM Flight Profile (LCDF1 DF1_DF14)

Figure 1 shows the flight profile for an operation provided by NASA. Note that the thrust values are simply an identifier and rapidly transition from one arbitrary value to another. The profile includes take-off, en-route, and landing portions. The entire operation is modeled as a single AEDT departure operation with all portions of the flight shown in Figure 1 contained within the same AEDT profile. All operations in NASA's methodology were modeled in this manner as AEDT departure operations.

The fixed-wing modeling method used to-date by NASA can be summarized as:

- Create and import general vehicle information
  - Characterize noise for each vehicle configuration / flight state mode
  - Reduce list to a representative set of modes
  - Compute NPD curve for each representative mode and metric combination
  - Import one vehicle to AEDT
- Create and import flight-specific information
  - Create airports and runways for origin vertiports
  - Create departure flight tracks associated with origin vertiports
  - Create fixed-point departure profiles matching the flight tracks
  - Import airports, runways, tracks, and profiles into AEDT
- Run AEDT
  - Use SAE-1845 (unadjusted) atmosphere to avoid modification of atmospheric absorption assumption in the NPDs

3. Helicopter Methodology

The AEDT 3e fleet database contains noise and performance data for 26 helicopters representing 77 unique real-world airframe-engine combinations. With one exception (the McDonnell Douglas MD-600N), each helicopter in AEDT has one arrival, one departure, and one taxi profile.

3.1 Helicopter Procedure Steps

AEDT does not have a performance model for helicopters, but defines the fixed-trajectory profiles using procedure steps. Each procedure step correlates with a helicopter flight operational mode (e.g., constant speed level flight for a user-provided speed and distance) that results in a fixed-geometry segment. Each mode has its own set of NPD data. There is no interpolation or extrapolation for power setting off the operational mode-based NPD set. The use of these steps includes some restrictions as follows: Altitude and speed can only be constant or increasing for departures and constant or decreasing for arrivals. Overflights allow for all combinations of altitude and speed changes allowed for both arrivals (e.g., constant speed or decelerating descent) and departures (e.g., constant speed or accelerating climb) with the exception of the initial takeoff and final landing steps (e.g., ground idle).

Table 2 summarizes AEDT's helicopter procedure steps. This table largely reflects the content of the AEDT User's Guide and Technical manual. It also reflects results of recent testing:

- AEDT will generate an error for any non-zero final altitude for vertical descent. This makes use of overflight profiles (where altitude is expressed in MSL) non-viable for the landing portion of a flight.
- AEDT will generate an error for a zero speed for the start step. This makes use of overflight profiles ill-suited for the takeoff portion of a flight. Though a small non-zero value can overcome this problem, it is not recommended due to the next finding.
- AEDT will use 0 ft MSL for the starting altitude of the vertical ascent segment for overflight profiles regardless of the altitude given in start segment and not 0 ft AFE .

Due to the problems noted above, it is not recommended to model the landing and take-off portions of a flight using overflight profiles. Additionally, note that the ground effect altitude is defined as 1.5 times the main rotor diameter. If the procedure step stays below the ground effect altitude, the procedure step correlates with the corresponding In Ground Effect flight operational mode. If the step stays at or above the ground effect altitude the procedure correlates with the corresponding Out of Ground Effect flight operational mode. Since overflight profiles altitudes are defined in MSL, this altitude distinction is not appropriate and the user should not expect to use the In Ground Effect NPDs on an overflight operation.

AEDT accounts for acoustic directional effects of helicopter by left-center-right NPD curves for the dynamic modes in the table below. Full directivity is assumed for static modes. Spectral data are grouped into classes for arrivals, departures, and level flight.

Table 2 Summary of Helicopter Procedure Steps

Profile Step Type	NPD Step Type	NPD Step Type Substitution	NPD Step Type Substitution Adjustment	Operational Mode Description	State	AEDT Input Values[4]				Step Usage		
						Duration (s)	Distance (ft)	Altitude (ft)	Speed (kts)	Arr	Dep	Ovf
A	A			Approach at constant speed	Dynamic	0	Value	Value	0	X		X
B	B	A	DB_DEC_HOR	Approach with horizontal deceleration	Dynamic	0	Value	0	Value	X		X
C	C	A	DB_DEC_DSC	Approach with descending deceleration	Dynamic	0	Value	Value	Value	X		X
D	D			Depart at constant speed	Dynamic	0	Value	Value	0		X	X
E	E	D	DB_ACC_HOR	Depart with horizontal acceleration	Dynamic	0	Value	0	Value		X	X
F	F	D	DB_ACC_CLM	Depart with climbing acceleration	Dynamic	0	Value	Value	Value		X	X
L	L			Level flyover at constant speed	Dynamic	0	Value	0	0	X	X	X
S				Start altitude[1] at constant speed	--	0	0	Value	Value	X		X
G	G	H	none	Ground idle	Static	Value	0	0	0	X	X	[3]
H	H	G	none	Flight idle	Static	Value	0	0	0	X	X	[3]
I	I	J	none	Hover in ground effect	Static	Value	0	0	0	X	X	[3]
	J	I	none	Hover out of ground effect	Static	Value	0	0	0	X	X	X
V	V	I	DB_VER_ASC	Vertical ascent in ground effect	Static[2]	Value	0	Value	0		X	[3]
	W	J	DB_VER_ASC	Vertical ascent out of ground effect	Static[2]	Value	0	Value	0		X	[3]
X	X	H (wheels), I (no wheels)	none	Taxi at constant speed	Static[2]	0	0	0	Value			
Y	Y	I	DB_VER_DES	Vertical descent in ground effect	Static[2]	Value	0	Value	0	X		[3]
	Z	J	DB_VER_DES	Vertical descent out of ground effect	Static[2]	Value	0	Value	0	X		[3]

1 Altitude is specified as AFE for arrivals and MSL for overflights

2 Though the aircraft moves during these modes, the noise is characterized with a single NPD curve and angular directivity

3 See the bullets related to altitude computations for overflights above

4 AEDT uses the value of zero in the profile input for parameters that are not utilized in the profile step. Zero can be valid input for parameters marked as “Value”.

In addition to the testing results noted above, Volpe tested flight transitions for overflight operations for comparison to the AEDT 3e User's Guide's Figure L- 9, Helicopter Overflight Step Transition Diagram (shown here as Figure 2). The tests included attempts to fully replicate arrival and departure operations using overflights and tests of likely transition combinations.

The step transition diagrams use the following conventions to represent procedures:

- Ellipses represent procedure steps.
- Arrows represent a valid transition from one step to another.
  - Arrows point in the direction of the allowed transition – e.g. you can go from Start to App.Desc.Decel, but not back.
  - A double sided arrow means that the transition is valid in both directions.
  - An arrow looping back to a step indicates that the step can be repeated.
- A box surrounding two or more steps is used to simplify the diagram.
  - Arrows connected to the box apply to each step within.
  - Each step within the box can transition to any other within the box. However, speeds and altitudes must be compatible. For example, on an approach a transition from an App.Horiz.Decel step to a Hover step is valid only when the App.Horiz.Decel step has a speed of 0 knots.

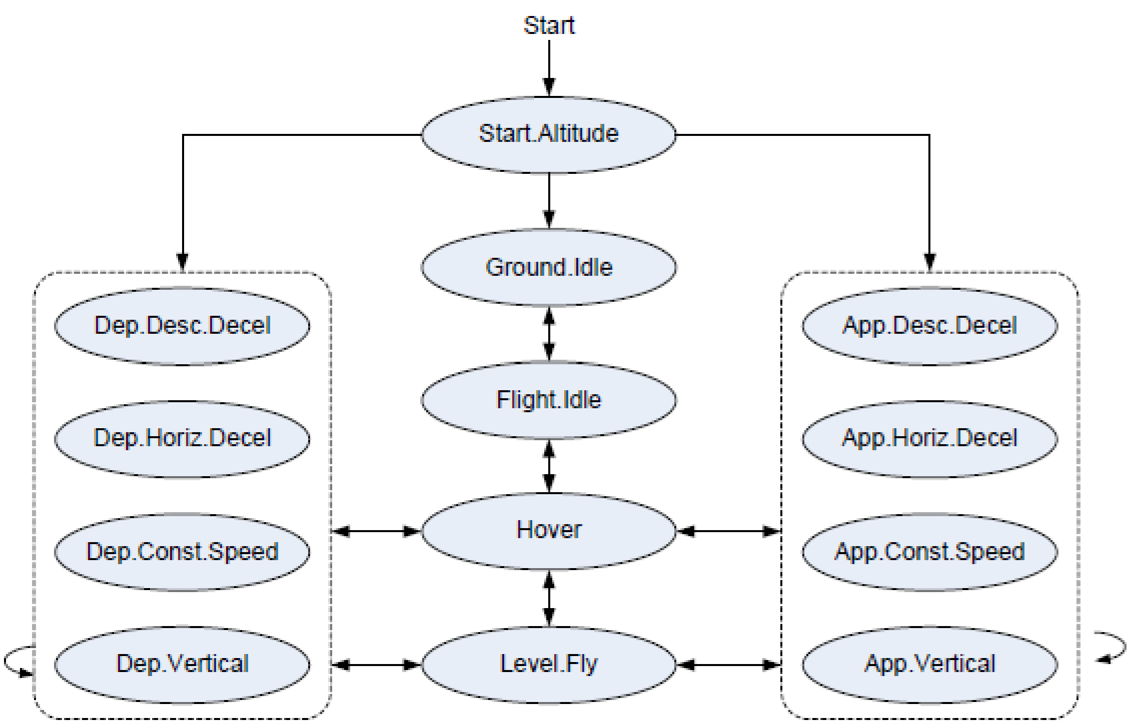

Figure 2 AEDT 3e User's Guide Figure L- 9 Helicopter Overflight Step Transition Diagram

In addition to the transition modeling guidance in Figure 2, the presence of a level segment directly following the start segment was necessary to successfully run overflight profiles. Additionally, the presence of a level segment at the end of the profile ensured that the previous segment was included in the modeling without being dropped. As noted above, the use of the segments related to take-off and landing either caused the profile to fail or produced un-usable results.

Additional tests pushing the boundaries of the step type definitions revealed that some counter-intuitive uses of the steps are possible, but not recommended. For example, entering the same final speed or altitude in a segment that's name indicated a change in speed or altitude caused errors in some cases, but not others. The error messages that were generated indicated that the use of the segments in this way is not desired.

Figure 3 replaces Figure 2 and displays the updated, recommended helicopter overflight transitions. Note that tests showed it is possible to directly transition between the left and right sides of the diagram without passing through a hover or level step. There are also no intuitive reasons why these transitions should not be physically possible, so they are recommended.

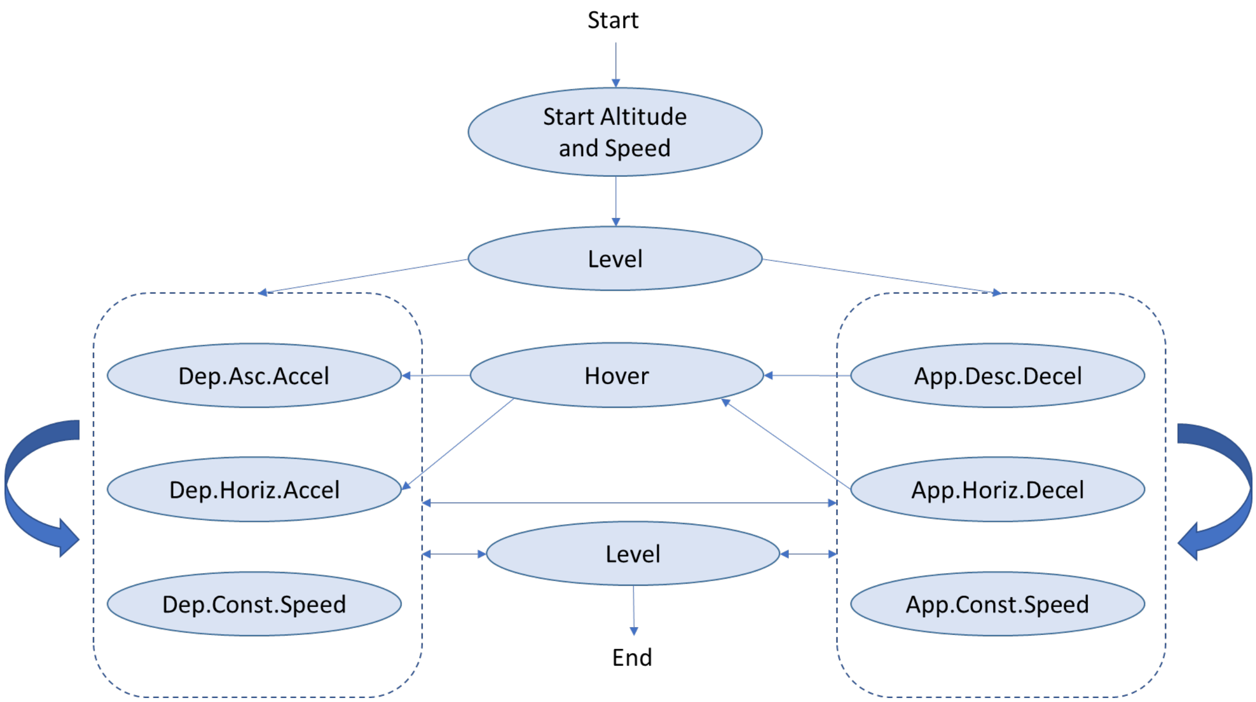

Figure 3 Recommended Helicopter Overflight Step Transitions

3.2 Modeling Unavailable Procedure Steps

Volpe reviewed the fixed-wing profiles for two vehicles provided by NASA, a quadrotor and a lift plus cruise vehicle. The profiles consisted largely of a climb from the origin runway to one or more level steps and a descent to the destination airfield elevation. Table 3 presents a categorization of the flight segments using the descriptions from Table 2. Guard points are excluded from the categorized segments.

Table 3 Categorization of NASA Fixed-Point Profile Segments

Description*	Profile Segments	
	Count	Percent
Approach at constant speed	2,094	12.2%
Approach with descending acceleration	70	0.4%
Approach with descending deceleration	3,951	23.1%
Approach with horizontal deceleration	249	1.5%
Depart at constant speed	2,635	15.4%
Depart with climbing acceleration	3,516	20.6%
Depart with climbing deceleration	314	1.8%
Depart with horizontal acceleration	912	5.3%
Level flyover at constant speed	3,365	19.7%
Total	**17,106**	**100%**

* Changes in altitude of less than 1 ft or speed of less than 0.5 kts on a segment are characterized as level and constant speed, respectively

Two categories not found in Table 2, approach with descending acceleration and depart with climbing deceleration, are included in Table 3 and marked with red text. Helicopters in AEDT are not able to perform these step types. Figure 4 shows an example of a profile with segments where the aircraft climbs and reduces speed. Approximately 1.8% of the flight segments in the NASA profiles are of this type.

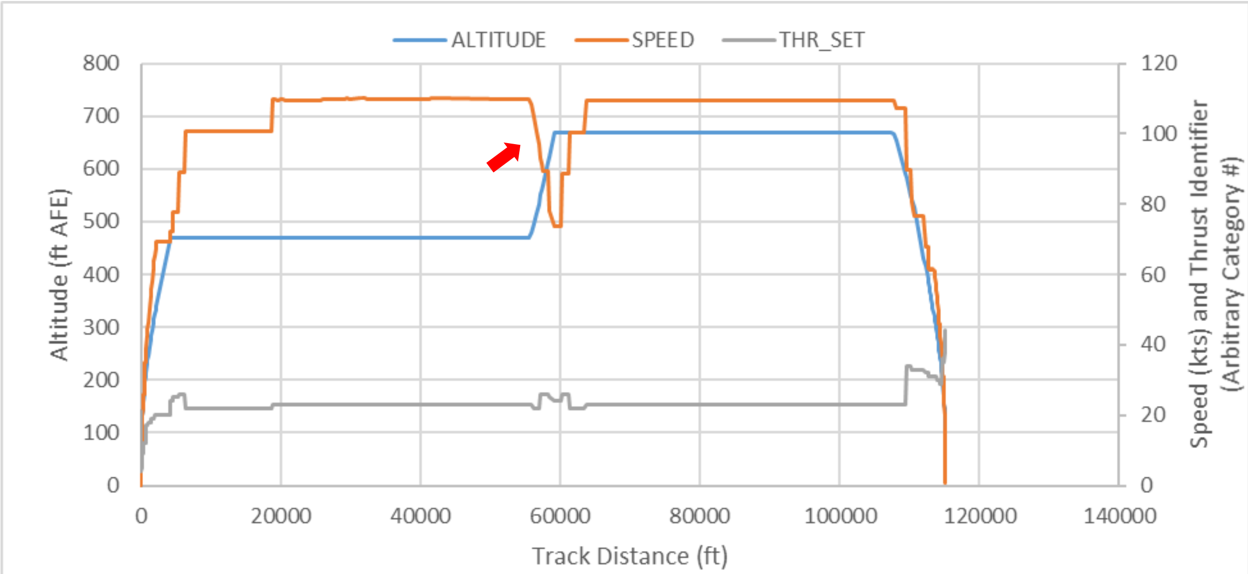

Figure 4 NASA UAM Flight Profile with Decelerating Ascent (LCDF1 DF1_DF16)

Figure 5 shows an example of a profile with segments where the aircraft descends and increases speed. Although less common, 0.4% of the flight segments in the NASA profiles are of this type. The percentage representation using track length or time for these segments are in the range of 0.1% to 0.3% depending on the aircraft and segment type.

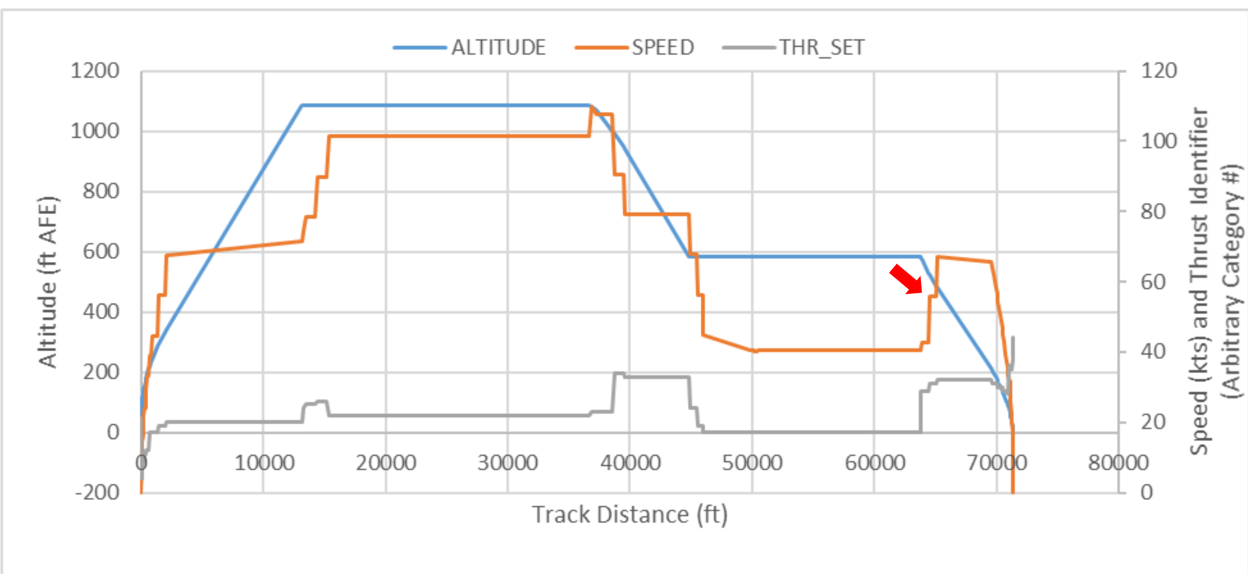

Figure 5 NASA UAM Flight Profile with Accelerating Descent (LCDF1 DF29_DF1)

To model these operations as helicopters, the profile must be modified to include only allowed step types:

- If the change in speed is negligible, the step(s) can be replaced by an approach at constant speed or depart at constant speed. The length of the segment can be increased to correspond to

Volpe

- the point at which the speed is again at that value (with the appropriate shortening of the following segment(s).
- If the change is speed occurs over a relatively short period of time, the segment can be replaced by a very short level segment with an increase or decrease in speed followed by a constant speed ascent or descent.

Changes to the mode will result in changes in the referenced NPD curves. Additionally, the duration of the segment will be changed, resulting in changes in exposure-based metrics.

3.3 Method H1: One Helicopter

Due to the restrictions on the types of steps available for each type of operation and the limited number of overall step types, the methodology for modeling UAM vehicles in AEDT is more involved. Note that the steps below do not include the use of the step substitution adjustments listed in Table 2. Given the limited number of available helicopter modes, the computation of full NPD curves for these modes is recommended rather than the use of a single offset to other NPD curves.

- Create and import general vehicle information
    - Characterize noise for each vehicle configuration / flight state mode
    - Reduce list of input trajectory states to the available set of AEDT modes
    - Compute NPD curves (and directivity values for static modes) for each AEDT mode
    - (Optional) Compute Mach number adjustment for level segments
    - Import one vehicle to AEDT
- Create and import flight-specific information
    - Create airports and heliports for origin and destination vertiports
    - Divide the trajectory into departure, arrival, and (possibly) overflight regions
        - Categorize each trajectory segment using its change in distance, altitude, and speed
        - (Optional) Consolidate similar segments into longer single segments
        - Starting at the beginning, proceed along the trajectory until a segment is found that is invalid for a departure profile. This is the departure region.
        - Starting at the end, proceed along the trajectory until a segment is found that is invalid for an arrival profile or the departure region is reached. This is the arrival region.
        - Any remaining segments are the overflight region.
    - Create profiles to match each of the regions identified above
    - Create arrival, departure, and overflight tracks to match each of the regions
    - Create operations for each region
    - Import airports, runways, tracks, and profiles into AEDT
- Run AEDT
    - Use SAE-1845 (unadjusted) atmosphere to avoid modification of atmospheric absorption assumption in the NPDs

3.4 Method H2: Three Helicopters

In method H1, overflights are used only as necessary. Some flights can be modeled as the combination of an arrival and a departure if the trajectory allows. This reduces the complexity of the AEDT study by reducing the number of profiles, tracks, and operations. For method H2, the characterization of an overflight region is preferred in order to access more noise modes.

For a complete flight, method H1 requires two to three sets of profiles, tracks, and operations that reference the same aircraft. This method allows the use of 16 distinct NPD modes. The organizational complexity of the AEDT study is only moderately increased by using three vehicles to model the flight, one for each flight region. For method H1, each row of Xs in the final three columns of Table 2 represents an NPD set. For method H2 each of the 30 Xs in Table 2 is its own NPD set. For trajectories that are already divided into three regions in method H1, method H2 will not increase the number of profiles, tracks, or operations relative to method H1.

One way to apply this method is to utilize the overflight region as the high-speed regime. The boundary between the arrival, departure, and overflight regions is determined by the transition from one speed regime to another[2]. Careful examination of the trajectories will be required to determine if all segments in the low-speed regime can be modeled solely by the allowed AEDT arrival and departure step types.

- See Method H1 with the following **additions**
    - Reduce list of input trajectory states to the available set of AEDT modes **separately for the arrival, departure, and overflight/high-speed regimes**
    - Import **three** vehicle**s** to AEDT
    - Starting at the beginning, proceed along the trajectory until a segment is found that is invalid for a departure profile **or the speed crosses into the high-speed regime**. This is the departure region.
    - Starting at the end, proceed along the trajectory until a segment is found that is invalid for an arrival profile **or the speed crosses into the high-speed regime** or the departure region is reached. This is the arrival region.

3.5 Method H3: Arbitrary Number of Helicopters

The logic of method H2 could be extended further to allow the specification of additional speed or flight-state regimes. Method H3 would include the use of one low-speed/arrival, one low-speed/departure, and any number of higher-speed/overflight regimes. The regimes must be defined so that the low-speed regions are defined to include only trajectory step types that are allowed for AEDT arrival and departure procedures. All trajectory segments between these regimes would be modeled using one or more overflight-specific aircraft. Each regime would require its own vehicle, profiles, tracks, and operations. The noise modeling fidelity improvements of this method would need to be weighed against its logistical complexity.

[2] The discussion uses the phrase “high speed regime”, under the assumption that noise levels may be speed-dependent. The method would work equally well for breaking flights into different representative noise vehicles when the overall configuration changes (e.g. a lift plus cruise vehicle). The modeler must examine the acoustic data for their vehicle to determine which vehicle parameters may be reliably used to divide the trajectory.

4. Fixed-Wing and Helicopter Comparison

Table 4 compares modeling UAM vehicles in AEDT based on NASA's current fixed-wing modeling methodology and the helicopter methodology H1 presented above. The table focuses on the major differences in the methods and does not include items that are similar such as ground type, terrain modeling and atmospheric absorption.

Table 4 Comparison of AEDT Fixed-Wing and Helicopter Methods for UAM Noise Modeling

Category	Item	Fixed-Wing	Helicopter
Static modes	Ground operations and hover	Can be modeled with run-ups or very low speed flight track segments	**Ground idle, flight idle, and hover modes**
	Number of vehicle states	**Unlimited**	Limited
	Directivity	Airplane algorithms	**Full directivity**
	Vertical liftoff and landing	Can be modeled with small changes in track distance	**Vertical ascent and descent modes**
Dynamic modes	Climb and decelerate / Descend and accelerate	**Yes**	Must work-around
	Directivity	Airplane algorithms	**Left-Right-Center**
	Number of vehicle states	**Unlimited**	Limited
Overall	Logistics	**Can model with one operation**	Requires two to three operations and a more complex analysis and breakdown of the trajectory
	Mode-based noise	Guard points required to avoid interpolation between curves	**Yes (noise mode is used for full profiles segment)**

Bold text with yellow highlights in the table indicates that one methodology has advantages over the other for a particular item. Both near the ground and en-route the helicopter method is superior in relation to directivity. It also has direct modeling for ground operations, vertical operations, and hovering that require workarounds in the fixed-wing method. The helicopter method is also mode-based and does not require the use of guard points (to avoid interpolations between NPD curves).

The fixed wing method is generally logistically easier and has the flexibility afforded by virtually unlimited noise modes. To the extent that method H2 (or H3) can reasonably represent the necessary noise modes, the main drawback of the helicopter method is additional complexity.

An ideal solution would be a new vehicle type similar to a helicopter vehicle type, but with unlimited vehicle states (each with its own NPD curves and spectral class assignment), the addition of approach with descending acceleration and depart with climbing deceleration step types, and modifications to the overall logistics to allow for an entire flight to modeled with a single operation. In addition, the use of a stretch level step such as AEDT uses for touch and go and circuit profiles would allow a profile to be used for multiple track lengths in situations where the trajectories for multiple flights only differ in the length of the highest altitude level flight segment.

5. Hybrid Methodologies

To the extent that unavailable helicopter step types (climb and decelerate / descend and accelerate) are crucial or that the logistical complexity of achieving enough noise modes with helicopter methods H2 or H3 makes the analysis infeasible, the following hybrid methodologies could be utilized.

5.1 Method FH1: One Helicopter for Arrival and Departure with Fixed-Wing En-Route

- Create and import general vehicle information
    - Characterize noise for each vehicle configuration / flight state mode
    - Split modes into departure, en-route, and arrival categories
    - Reduce list to a representative set of modes
        - Corresponding to AEDT helicopter modes for departure and arrival
        - To an arbitrary number sufficient for accurate modeling for the en-route modes
    - Compute helicopter NPD curves (and directivity values for static modes) for the departure and arrival modes
    - Compute fixed-wing NPD curves for the en-route modes
    - (Optional) Compute Mach number adjustment for level segments associated with the helicopter arrival or departure portion of the flight
    - Import two vehicles to AEDT: one fixed-wing and one helicopter
- Create and import flight-specific information
    - Create airports and heliports for origin and destination vertiports
    - Divide the trajectory into departure, arrival, and overflight regions
        - For the arrival and departure regions associated with the vertiports
            - Categorize each trajectory segment using its change in distance, altitude, and speed
            - (Optional) Consolidate similar segments into longer single segments
        - For the en-route region
            - Retain the distance (relative to the start of the en-route region), altitude, and speed
    - Create helicopter and fixed-wing profiles to match each of the regions identified above
    - Create helicopter arrival and departure tracks and fixed-wing overflight tracks to match each of the regions
    - Create operations for each region
- Run AEDT
    - Use SAE-1845 (unadjusted) atmosphere to avoid modification of atmospheric absorption assumption in the NPDs

The downside of the lack of left-center-right directivity during the en-route portions of flights may be mitigated to the extent that the vehicle does not exhibit strong directivity in this phase of flight. Additionally, if the flight routes consist of roughly equal numbers of vehicles in similar flight states transiting in opposite directions, the aggregate noise exposure will not exhibit a strong left-right disparity. On the other hand, in the NASA modeling reviewed by Volpe, approximately 76% of the flight path length for the lift+cruise vehicle and 80% of the flight path length for the quadrotor were modeled using a single constant speed level noise mode. If the helicopter representation of these segments is substantially superior to the fixed-wing representation (due to superior directivity and static operation modes), the use of a hybrid method rather than a full helicopter method will decrease accuracy in most of the study area.

5.2 Method FH2: Two Helicopters for Arrival and Departure with Fixed-Wing En-Route

To the extent that the noise from the ground idle, flight idle, hover, and level differ for the departure and arrival regions, separate helicopters could be used for each region. This would result in no increase in the number of profiles, tracks, or operations in the analysis. The additional complexity would be in the number of NPDs computed and the number of aircraft imported into the study. This modification to method FH1 is presented here as method FH2

- See Method H1 with the following **additions** and ~~deletions~~
- Create and import general vehicle information
  - Characterize noise for each vehicle configuration / flight state mode
  - Split modes into departure, en-route, and arrival categories
  - Reduce list to a representative set of modes
    - Corresponding to **separate** AEDT helicopter modes for departure and arrival
    - To an arbitrary number sufficient for accurate modeling for the en-route modes
  - Compute helicopter NPD curves (and directivity values for static modes) **separately** for the departure and arrival modes
  - Compute fixed-wing NPD curves for the en-route modes
  - (Optional) Compute Mach number adjustments **separately** for level segments associated with the helicopter arrival or departure portion of the flight
  - Import ~~two~~ **three** vehicles to AEDT

To the extent that one of the helicopter methods can represent the necessary noise modes, a hybrid methodology is not recommended. A defining feature of UAM vertiports will be their closer integration into spaces not currently experiencing near-ground aircraft operations. The additional fidelity provided by the helicopter static and dynamic directivity will improve the quality of assessments near vertiports where the noise exposure will be greatest.

If additional noise modes are required for the en-route portion of the flight, methods H2 or H3 can expand the possibilities. To the extent that future AEDT developments reflect the recommendations of prior collaboration between Volpe and NASA (i.e., a new vehicle type with arbitrary/unlimited assignment of noise mode for each segment), the noise results of using the helicopter methods will be similar to those from an updated AEDT.

6. Abbreviations, Initialisms, and Acronyms

Abbreviation	Description
AAM	Advanced air mobility
ACRP	Airport Cooperative Research Program
AIRNOISEUAM	NASA-developed tool for urban air mobility noise prediction
AEDT	Aviation Environmental Design Tool (FAA model)
AFE	Above field elevation
ANP	Aircraft noise and performance
ASIF	AEDT standard input file
BADA	Base of aircraft data (Eurocontrol model and dataset)
eVTOL	Electric vertical vake-off and landing
ft	Feet
INM	Integrated Noise Model (FAA model, predecessor to AEDT)
MSL	Mean sea level
NEPA	National Environmental Policy Act
NPD	Noise power distance
RVLT	NASA Revolutionary Vertical Lift Technology
s	Seconds
SQL	Structured query language
TAS	True airspeed
UAM	Urban air mobility
UNWG	UAM Noise Working Group

7. References

Federal Aviation Administration, *FAA Order 1050.1F Environmental Impacts: Policies and Procedures*, July 2015.

Lee, Cynthia, et al., *Aviation Environmental Design Tool (AEDT) Technical Manual Version 3e*, Report No. DOT-VNTSC-FAA-22-04, Washington, D.C.: Federal Aviation Administration, May 2022

Lee, Cynthia, et al., *Aviation Environmental Design Tool (AEDT) User Manual Version 3e*, Report No. DOT-DOT-VNTSC-FAA-22-03, Washington, D.C.: Federal Aviation Administration, May 2022.

Nicholas, B., Thrasher, T., & Tuchen, S., *Software Scoping Document for Integration of Urban Air Mobility Vehicles into the Federal Aviation Administration's Aviation Environmental Design Tool*, DOT-VNTSC-NASA-21-01, U.S. Department of Transportation John A. Volpe National Transportation Systems Center, September 2021.

Rizzi, Stephen A., et al. *Urban Air Mobility Noise: Current Practice, Gaps, and Recommendations*, NASA/TP–2020-5007433, National Aeronautics and Space Administration, October 2020.