Gen-1 UAM Fleet Noise Assessments Using the FAA Aviation Environmental Design Tool (AEDT)

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Outline

- Motivation and Approach
- Operational State Determination
- Calculation of NPD data (previous talk)
- Modeling Approach
  - Mini-Studies
  - Procedures for determining track and profile points
- Gen-1 Assessment

Goal and Approach

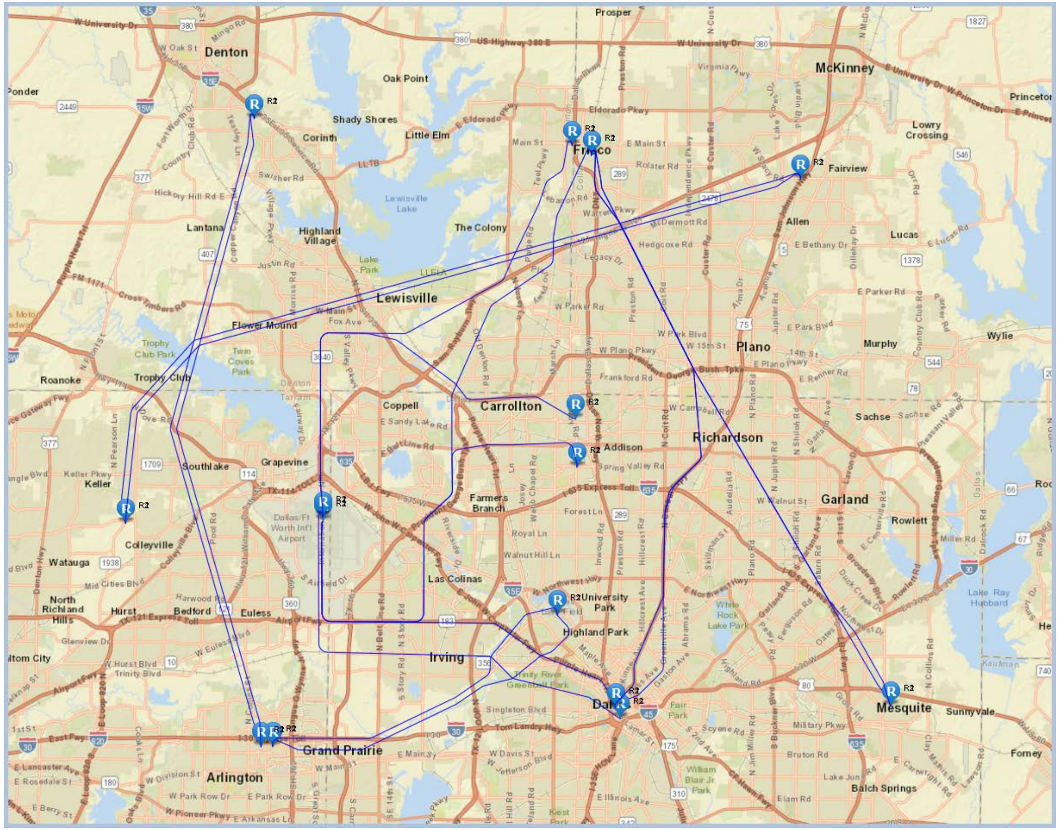
Goal

Assess the effectiveness of current commonly-used tools for the evaluation of UAM community noise.

Approach

- Develop methodology utilizing the FAA Aviation Environmental Design Tool (AEDT).
  - Lack of AEDT Aircraft Noise and Performance (ANP) Model for UAM requires user-supplied Noise-Power-Distance (NPD) data and use of fixed-point flight profiles.
  - Verify results using alternative tools, e.g., Aircraft Noise Prediction Program 2 (ANOPP2) and Advanced Acoustic Model (AAM).
  - Identify limitations and possible future enhancements.
- Demonstrate on representative route case.

Gen-1 Simulated Baseline Routes†



† Routes provided by ATM-X UAM X2 team

- 16 routes around DFW
- 2 vehicles

RVLT Quadrotor

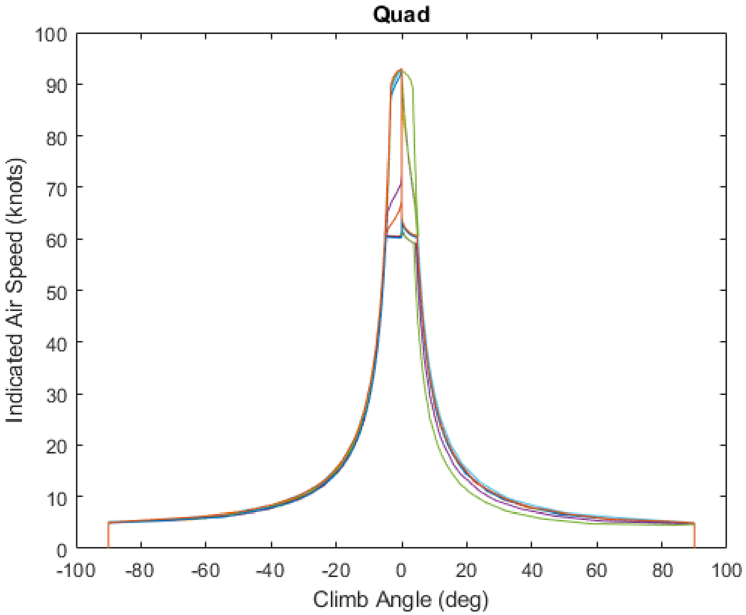
RVLT Lift + Cruise

Operational State Determination

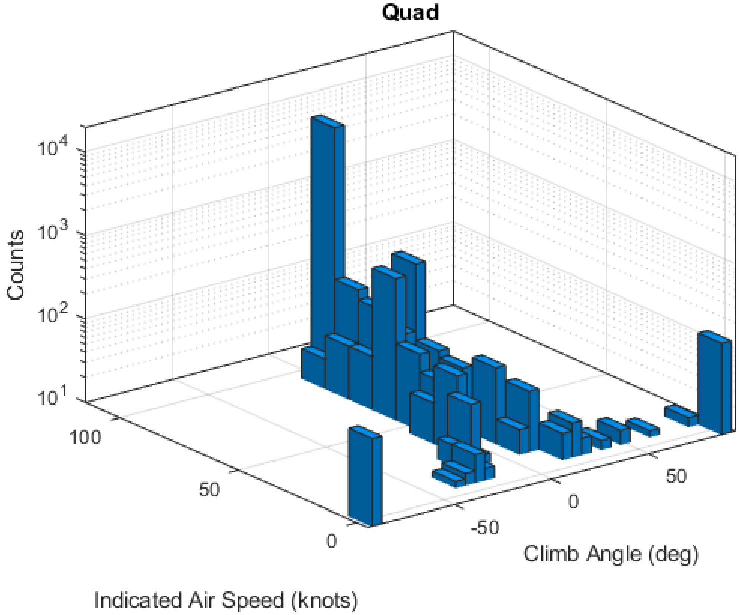
- 4-D trajectory data were provided at a 1 Hz sampling rate.
  - Each route contained ~ 1000 pts on average… too many to generate an NPD for each point.
- **Indicated air speed (IAS)** and **climb angle (CA)** are calculated from trajectory data and together define the operating state.
- For each aircraft, generate histogram of operating state data for 16 routes.
  - IAS and CA increments selected based on what we think we can afford computationally.
  - For Gen-1 assessment, we chose IAS increment = 10 knots, CA increment = 5 deg. Each generates a set of NPD data.
- Counts > 10 at bin centers define operating states at which NPD data are calculated.
  - Zero speed treated as single NPD irrespective of climb angle (+/- 90).

Operational States

Distribution of X2 Trajectory Data



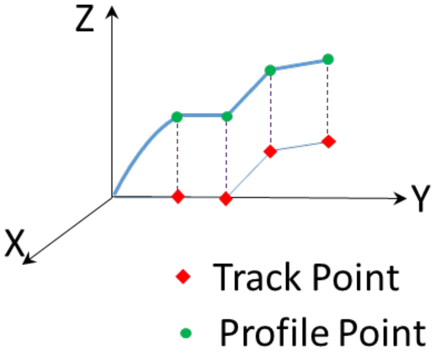
1 Hz data from 16 routes



42 Operating States for Quadrotor
44 Operating States for L+C

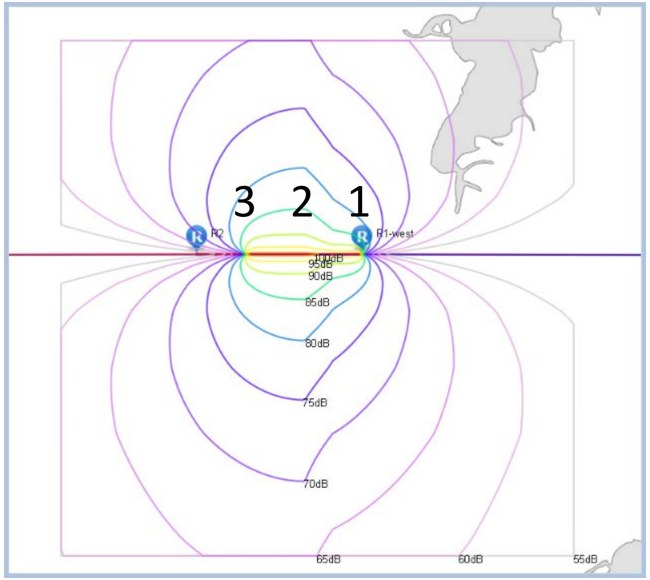
Modeling Approach

- The following information is needed as input to AEDT to operate in fixed-point profile mode:
  - Lat/long coordinates, elevation of vertiports (direct from X2 data)
  - **Set of track points defining the 2-D (X-Y) routes <u>departing</u> from each vertiport**
  - Aircraft noise and performance data – our calculated NPD data
  - **Set of profile points defining aircraft distance along track, altitude (Z), speed, and thrust set (our operating state index) from start to finish**



- A series of mini-studies were performed to inform development of initial (Gen-1) modeling approach using fixed-point profiles within AEDT, including
  - Guard points – to maintain constant operating state along each segment
  - Track segmentation – as means for reducing number of track and profile pts.
  - Segment velocity – to understand how choice of segment velocity affects results.

Guard Point Mini-Study

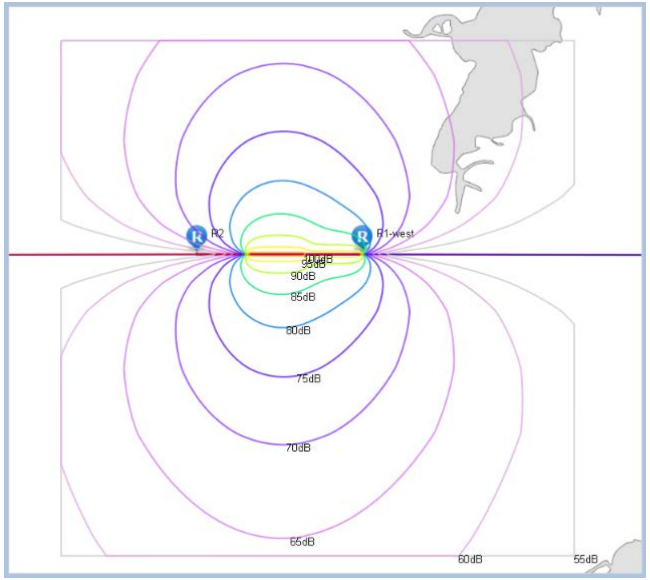


Track Point	Cum. Dist. along Path (ft)	NPD ID	IAS (knots)
1	0	103	60
2	2000	105	60
3	4000	105	60

No guard point – AEDT interpolates between NPD IDs 103 and 105 over a 2000 ft distance between track points 1 and 2.

Direction of flight

Guard Point Mini-Study



Direction of flight

Track Point	Cum. Dist. along Path (ft)	NPD ID	IAS (knots)
1	0	103	60
2	1988	103	60
3	2000	105	60
4	4000	105	60

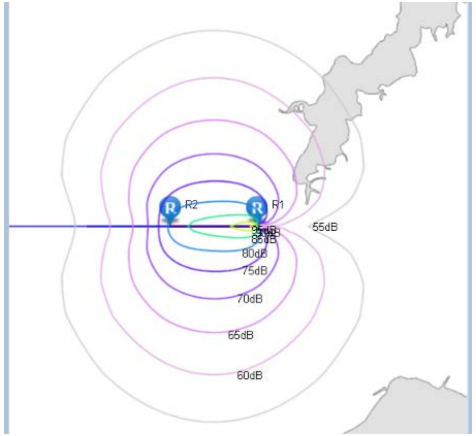
Add guard point 2 – AEDT interpolates between NPD IDs 103 and 105 over a 12 ft (transition) segment between track points 2 and 3.

Track Segmentation Mini-Study

Flight Profile

Distance (ft)	Speed (kts)	thrustSet	Altitude (ft)
0	60	103	50
5681	60	103	1000

Lateral Attenuation Off
Single/Many Segments

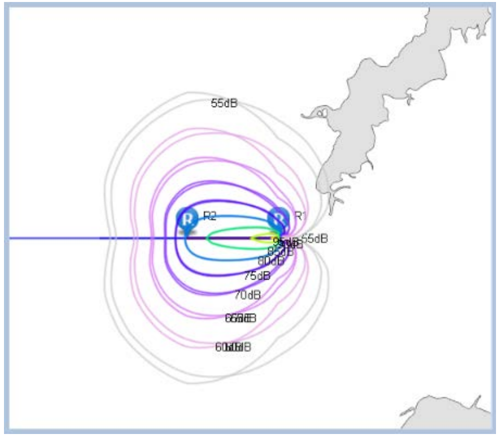


Two different track point definitions

Track point case 1:
- Point 1 (origin, x=0)
- Point 2 (west, x=100 kft)

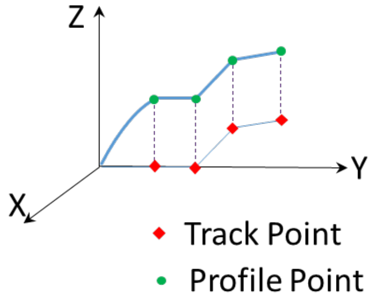
Track point case 2:
- Point 1 (origin, x=0)
- Point 2 (west, x=2 kft)
- Point 3 (west, x=4 kft)
- Point 4 (west, x=6 kft)
- Point 5 (west, x=8 kft)
- Point 6 (west, x=10 kft)
- Point 7 (west, x=100 kft)

Lateral Attenuation On
Single/Many Segments



Track Point Determination

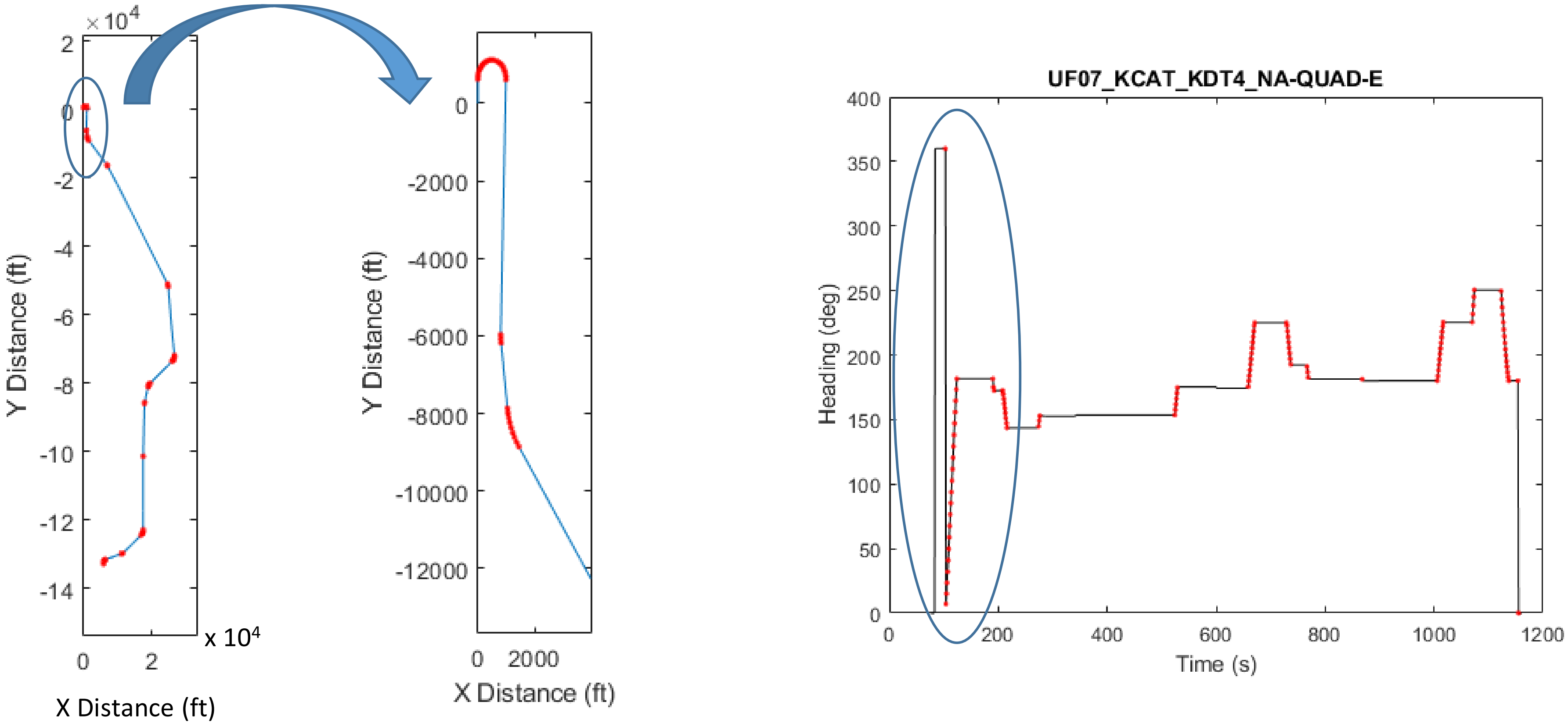
1) Define a user-specified delta heading increment. Used 2 deg for Gen-1 assessment.
2) When heading change from one point to the next is greater than or equal to user-specified heading increment, store that point as a track point.
3) Assemble ordered list of all track points consisting of:
   - First point in original data (take-off)
   - All points from sequential heading changes
   - Last point in original data (landing)



Notes

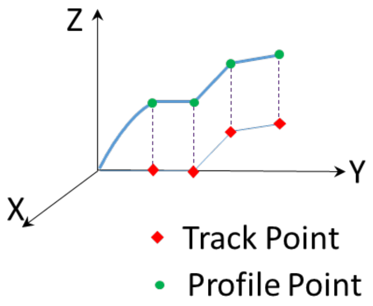
- It is possible to use all the 1 Hz data to define the set of track points (lat/long), but that is not efficient. A subset is sufficient to define heading changes.
- Track points are different for each route and each vehicle.

Track Point Example



Profile Point Determination

1) Determine 1st pass profile points.
   i. Define a user-specified IAS increment. This selection same as used in calculation of NPD data.
      Discretize IAS into bins, then select changes in bin index.
   ii. Define a user-specified CA increment. This selection same as used in calculation of NPD data.
      Discretize CA into bins, then select changes in bin index.
   iii. Remove repeated indices of IAS and CA bin changes.
      Include first and last points.



<u>Notes</u>

- Determination of profile points is on basis of changes in operational states (defined by IAS, CA) = changes in noise.
- Profile points are different for each route and each vehicle.

Profile Point Determination

2) Assign operating states to profile points.
   - By discretizing IAS and CA into bins, most profile points will correspond to a previously defined operating state.

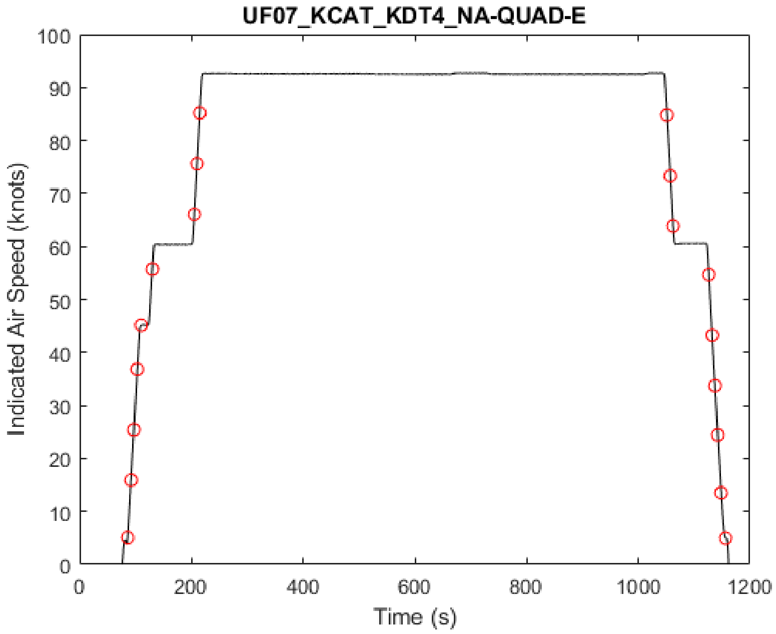
3) Add guard points to force each segment to be at a constant operating condition.

4) Reconcile accumulated distance of each profile point with accumulated distance along the track.

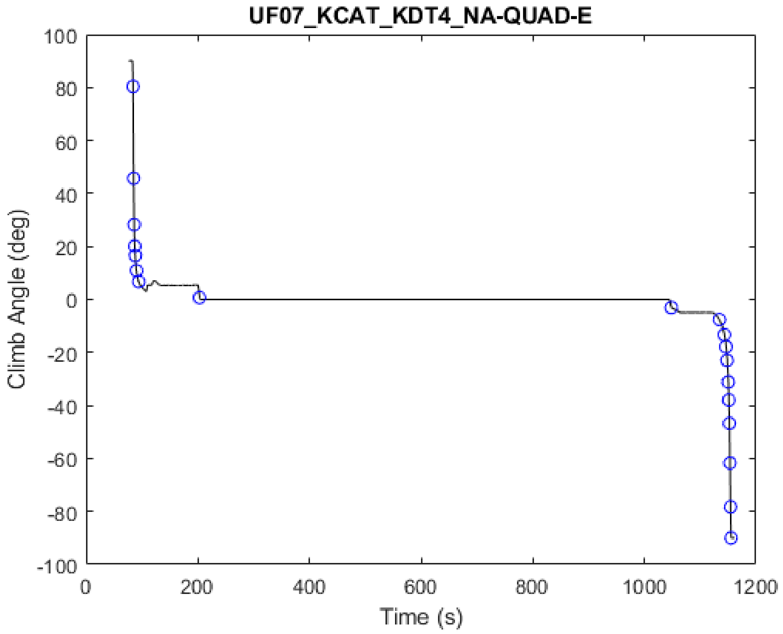
4) Assemble fixed-point profile from profile points, including segment number, cumulative distance along the ground track, altitude, average segment velocity, NPD state ID, and operation mode (always departure).

Profile Point Determination

1st Pass Profile Points Based on IAS Increment



1st Pass Profile Points Based on CA Increment



Gen-1 Assessment

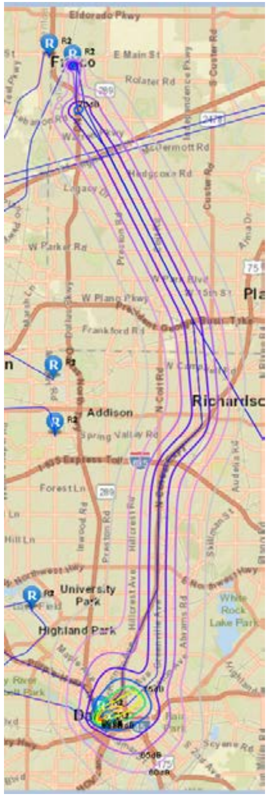
- Uses RVLT Quadrotor NPD data only.
  - Recently found trim error in Gen-1 NPD database for Lift+Cruise (regenerating NPDs as part of Gen-2 database).

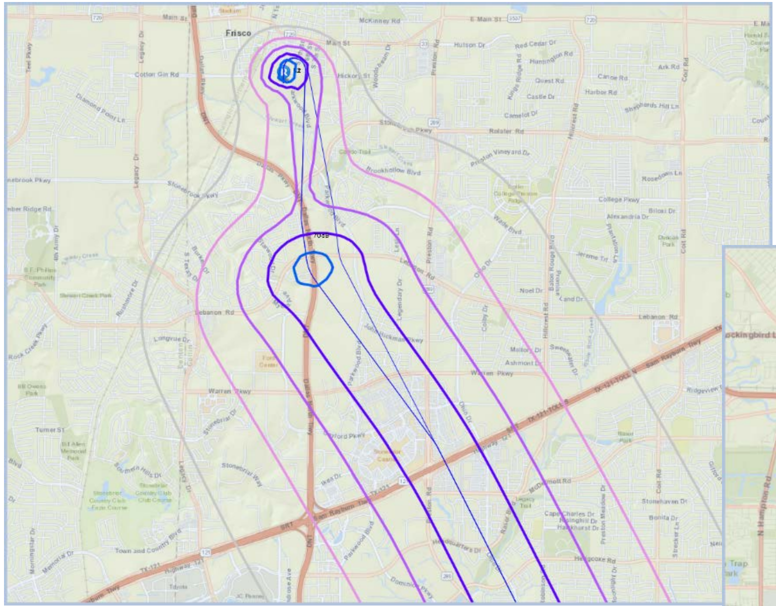
- Selected 100 (takeoff and landing) operations per hour over 12-hour daytime period as baseline (based on communication with Uber in absence of other demand data).
  - No nighttime penalty in DNL calculation.
  - 1200 operations / 2 = 600 departures for each route.

- Computed:
  - Sound Exposure Level (SEL) – single operations from each departure vertiport
  - Day-Night-Level (DNL) – 600 operations from each departure vertiport

Gen-1 Assessment (Example SEL Results)

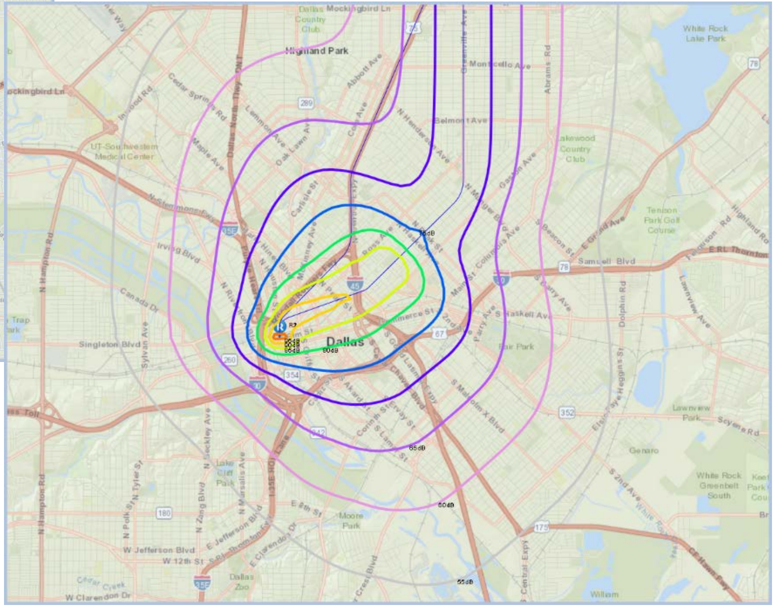
KCAT-KDT4



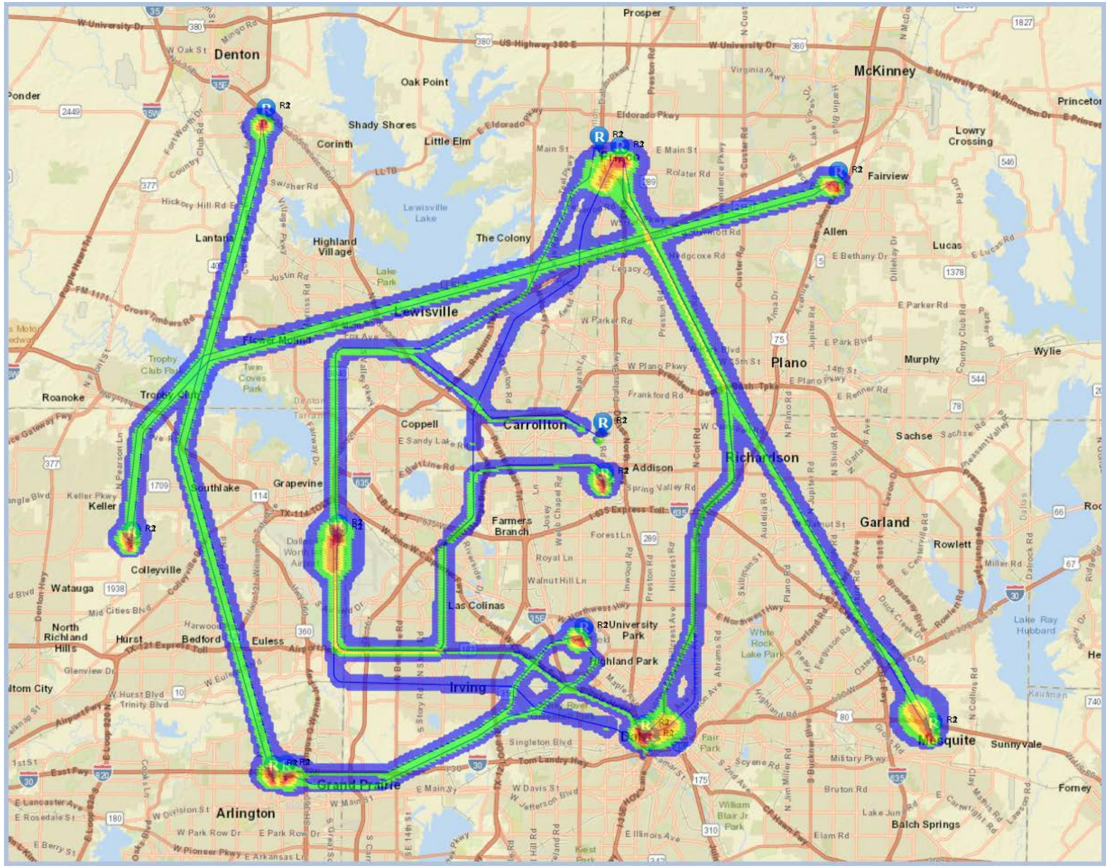


Origin KCAT

Destination KDT4



Gen-1 Assessment (DNL for 600 operations)



Ldn (dB)

- 50-55
- 55-60
- 60-65
- 65-70
- Above 70

Concluding Remarks

What Have We Done –

- Developed a means of performing UAM community noise assessments using AEDT fixed-point flight profiles
  - Some limitations were identified that we will continue to work as part of the Gen-2 assessment (see next slide).
  - Automated method for analysis of routes and development of track and profile data guided by series of mini-studies.
  - Automated methods for generating large and scalable AEDT inputs, e.g., studies and vehicle data.

What Have We Not Done –

- Stated that the results shown are what we might expect of UAM operations in the DFW area.
- Drawn conclusions about UAM fleet noise based on the Gen-1 estimates.

Year 2 Work

- Improve analysis fidelity
  - Investigate use of helicopter mode near vertiports to better capture directivity.
    - Quantify differences between fixed-wing (dipole) directivity, helicopter modes, and full hemisphere.
  - Model NPD data to remove restriction of limited number of discrete states.
  - Add terrain modeling.
- Ease of use
  - Input data directly into AEDT database to facilitate study development.
- Investigate alternative metrics as means of communicating impact
  - Time and number above, audibility, etc.

Acknowledgments

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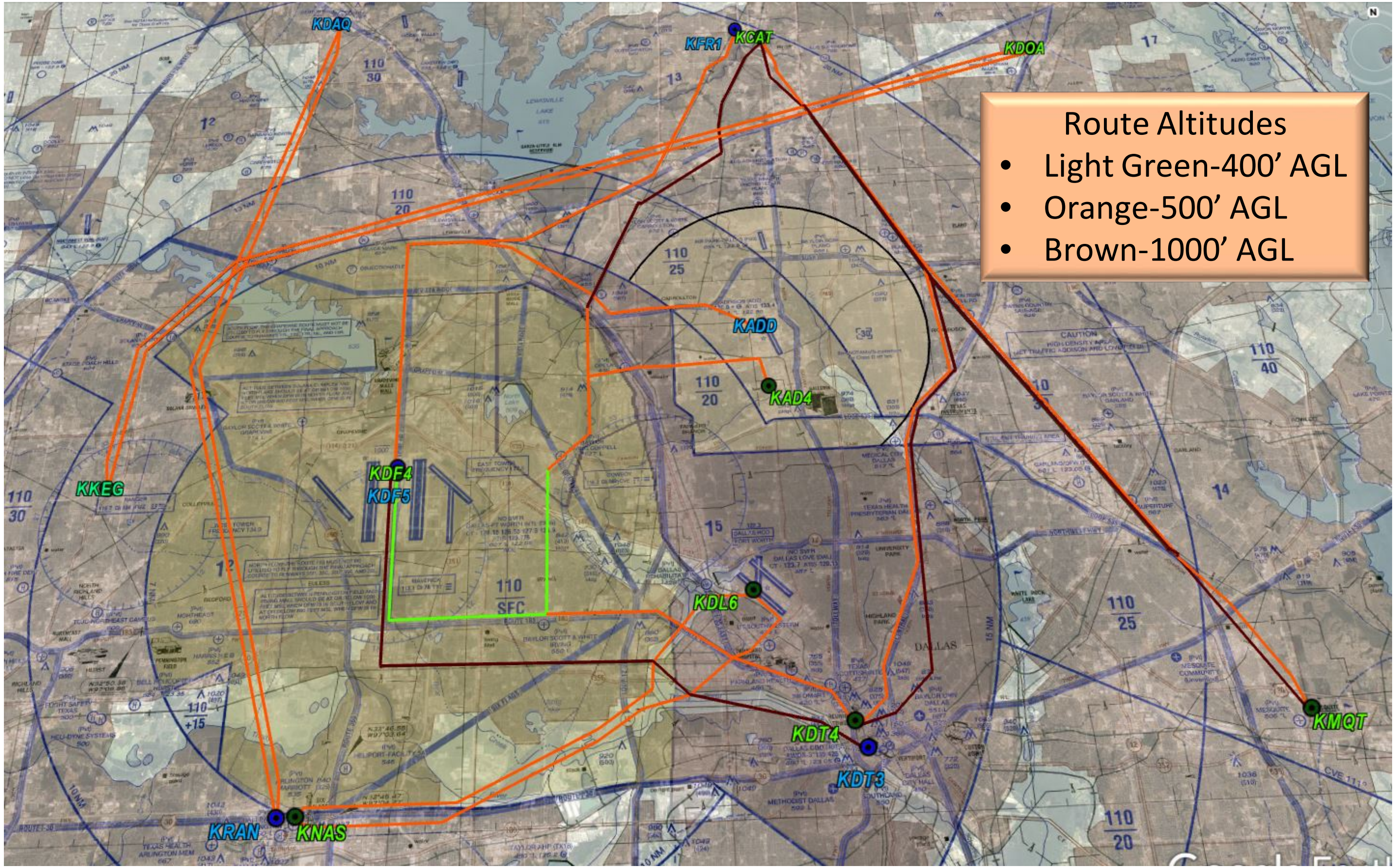
Thanks to Andy Christian (NASA Langley) and Kevin Shepherd (LaRC Distinguished Research Associate), and staff at the FAA Office of Environment and Energy and DOT Volpe Transportation Center for many helpful discussions.

Backup Slides

Fleet Noise Assessments: Gen. 1 Baseline Ops†



† Provided by ATM-X UAM X2 team

- 16 routes around DFW
- 2 vehicles
  – RVLT Quad
  – RVLT L+C

2019 Recap - AEDT Noise-Power-Distance Data

Fixed Wing

- NPD data are associated with an engine power (thrust) setting.
- NPD data consist of noise curves for each operational mode – approach, level flight, and departure.
- A performance model is used to determine the thrust setting for a specified operation.
- Source directivity applied using a dipole radiation model applied in the noise fraction adjustment for exposure metrics.

Helicopters

- NPD data are associated with an operational mode, i.e., noise-operational mode-distance data.
- NPD data consist of noise curves for each operational mode procedural step
  - Dynamic and static operational modes
- There is no performance model. The operational mode is specified by the procedural step.
- Source directivity
  - Dynamic: 0°, ±45° azimuth
  - Static: Helicopter-specific directivity

2019 Recap – Fixed Point Profile

- We use a 'fixed point' profile in AEDT
  - Fixed wing NPDs that bypass AEDT perf. models

- The database links the noise (L_{AMax}, SEL, $PNLT_{Max}$, EPNL) to the vehicle state and distance to observer
  - Vehicle state is an ID used as a surrogate for thrust and represents a particular operating condition.
  - By specifying piecewise constant flight conditions between waypoints, AEDT will interpolate noise between vehicle states (with short transitions), and distance to observer.

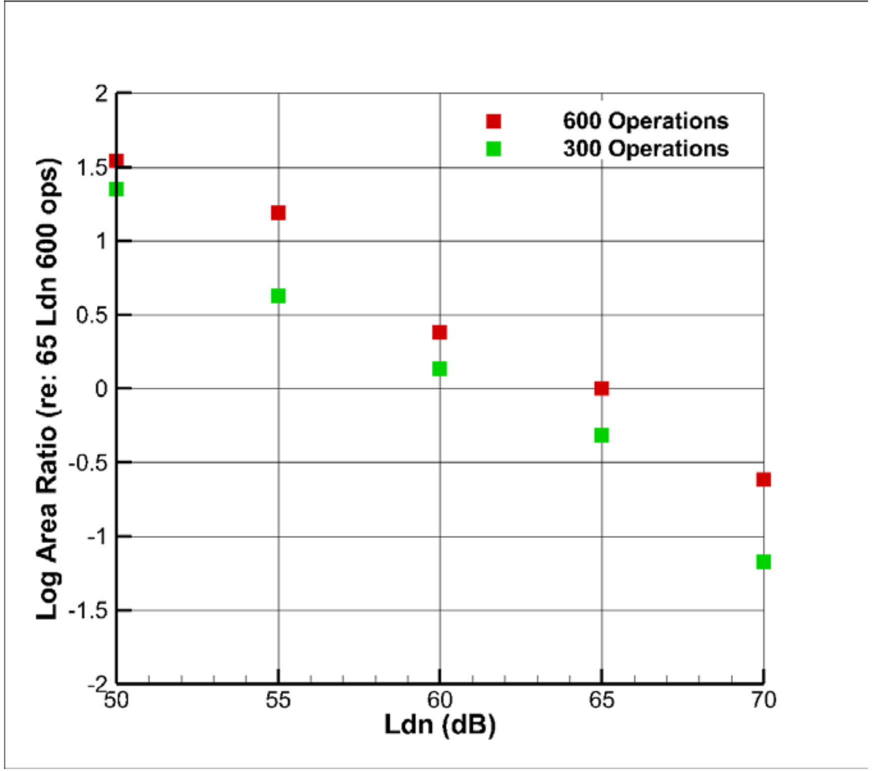
- In this scheme, we are hijacking the fixed wing aircraft type in AEDT.
  - NPDs generated by computing 0° azimuth data (normalized to reference flight speed). Directivity of fixed wing aircraft applied as part of noise fraction adjustment within AEDT.

Track Segmentation Mini-Study

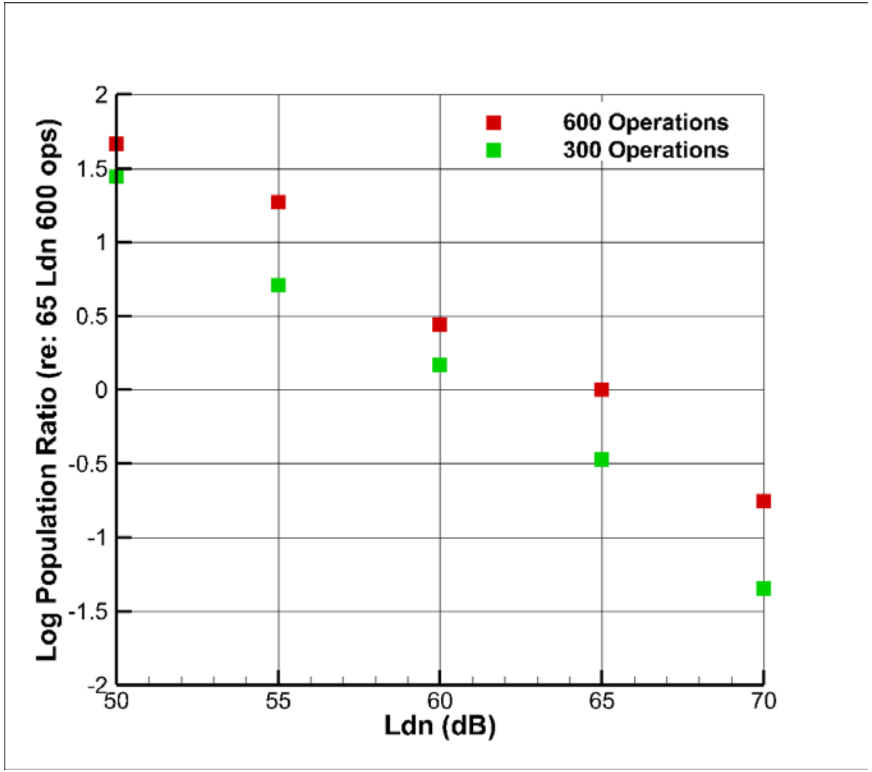
- Single and multi-segment tracks gives same result with lateral attenuation turned off.
- Single and multi-segment tracks differ when lateral attenuation turned on.
  - Receptors under the flight path have nearly the same SEL either way. Laterally offset receptors differ, and the difference increases with increasing lateral distance.
  - This behavior is related to Point of Closest Approach (PCA) used in AEDT.
- Since we will use lateral attenuation in our Gen-1 assessment, we use as few segments as possible (with the assumption that a single segment provides the 'right' answer).
  - This also offers a computational benefit.

Gen-1 Assessment (600 vs 300 operations)

Cumulative DNL Contour Areas



Population within Contours



Concluding Remarks

What Have We Not Done –

- Stated that the results shown are what we might expect of UAM operations in the DFW area. Why?
  - The routes are not representative of expected operations… especially in terminal area.
  - A real demand model is absent. Also, no nighttime operations.
  - The NPDs only reflect isolated loading and thickness noise. We expect the noise to be higher due to broadband and other contributions.
  - Noise estimation in vicinity of vertiport is less certain than enroute (various reasons).
  - Lateral attenuation model in AEDT may or may not be applicable to this class of vehicle. Noise estimation off to side more strongly affected by lateral attenuation.
  - Source directivity not reflected in fixed-wing NPD data.
  - …

Concluding Remarks

What Have We Not Done –

- Drawn conclusions about UAM fleet noise based on the Gen-1 estimates, including
  - Importance of cruise vs near-vertiport exposure.
  - Comparison of UAM noise vs other sources (road or other air traffic).
  - Human response – audibility and acceptability.
  - All is OK since DNL 65 exposure is limited.
  - A relationship between the number of operations and change in contour area.
  - …