Calculation of Gen-1 Noise-Power-Distance Data for UAM Vehicles for Community Noise Assessments

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Terminology (simplified)

Acoustics:

Propagation of pressure waves in a medium.
Can be linear or nonlinear; can be subsonic, transonic, or supersonic.
Independent of human presence.

Sound:

Acoustics received by the human ear/brain… so, objective, not subjective.

Noise:

Sound that is unwanted (by a human)… so, subjective, not objective.
“unwanted” is a vague term that depends on human likes and dislikes.
“Noise” is often used as a colloquial term, not a specific term.

Annoyance:

A vague term (one of many) that can be used to characterize “unwanted”.
Annoyance itself is not a metric.
But, metrics can be developed that can quantify the level of annoyance.

All can be characterized by some form of metrics.

Metrics

Metrics are ways to characterize acoustics, sound, and noise.

Unweighted metrics (acoustics, sound):

- Example: Sound Pressure Level (SPL):

$$\textbf{SPL} = 20\ log_{10}\left(\frac{p_{rms}}{p_{ref}}\right)[dB]$$

- Other examples: unweighted Sound Exposure Level (SEL [dB]).

Loudness based metrics (noise):

- Example: A-weighted Sound Pressure Level (SPL):

$$\textbf{SPL} = 20\ log_{10}\left(\frac{p_{rms}}{p_{ref}}\right)[dBA]$$

Note the addition of "A"

- The p_{rms} has been frequency weighted.
- The frequency weighting is a <u>*specific*</u> curve known as the **A-weighting** curve.
- **A-weighting** is a curve fit to the **40-phon loudness curve** in the Fletcher-Munson curves.
- Developed for <u>*tone*</u> noise, but only for comparing to separate tones.
- Technically, it **only** applies to that loudness level.
- Other examples: A-weighted Sound Exposure Level (SEL [dBA]).

Metrics

Noisiness based metrics (noise):

- Example: Perceived Noise Level ("PNdB").
- Developed to characterize the "noisiness" of jet aircraft ***broadband*** noise.
- A "noy" is an equal noisiness level, similar to how a "phon" is an equal loudness curve.
- A "sone" is the equal noisiness curve at a given "noy" value.

$$\text{PNdB} = 40 + log_2(noy) \approx dBA + 12$$

- Other examples:
  - Tone corrected PNdB (**TPNdB)** is **PNdB** with a single tone correction added.
  - Effective Perceived Noise Level ("EPNL" or "EPNdB"):

$$\text{EPNdB} = PNL_{max} + 10\ log_{10}\left(\frac{t_{10}}{20}\right) + F(dB)$$

Where $F(dB)$ is a "pure tone correction"… normally just applied as $F = 3$.

FAA Noise Certification (Rotorcraft)

Optional for GW < 7000 lb and < 10 passengers: (Part 36, Appendix J)

- SEL at a single microphone for level flyover.
- Weight dependent limit on **SEL [dBA]**.
- Limits are at “Stage 3”.

GW > 7000 lb: (Part 36, Appendix H)

- **EPNL** averaged separately at 3 microphone locations for each of these:
    - Takeoff, flyover, and approach.
    - Speed, climb angle, etc. are dependent on the vehicle capabilities.
- Weight dependent limits for each flight condition.
- Can exceed limits at some flight conditions, but offsets must be negated by others, etc.
- Limits are at “Stage 3”.

Tiltrotors: (Part 36, Appendix K)

- Essentially, same as the “Stage 2” version of Appendix H.

FAA Community Impact

Previous slide discussed ***FAA Certification*** of rotorcraft.

However, for ***community impact*** studies related to ***noise,*** fuel burn, or emissions analysis, the FAA uses the software:

- Aviation Environmental Design Tool (AEDT).
- For noise, AEDT:
  - Takes user defined or internally stored "Noise-Power-Distance" curves and
  - Combines
    - many flight operations
    - of many different vehicles
    - over many different flight trajectories
    - to compute integrated noise metrics on the ground (e.g., L_{dn}).

For existing vehicles, there is a database of NPD curves available for AEDT.
For nonexistent vehicles, the **user must supply** NPD curves.

NPD curves for conventional vehicles

For conventional fixed wing vehicles, NPD curves consist of these integrated metrics:

- SEL [dBA] — Sound Exposure Level
- L_{Amax} [dBA] — maximum Sound Pressure Level (SPL) over a given time period
- EPNL [EPNdB] — Effective Perceived Noise Level
- PNLTM [TPNdB] — maximum tone corrected Perceived Noise Level

Computed for:

- Approach, Takeoff, Flyover.
- For various engine states.
- For distances of: 200, 400, 630, 1000, 2000, 4000, 6000, 10000, 16000, 25000 feet above a centerline microphone; however, altitude effects are not included (… those are accounted for inside AEDT).

AEDT internally computes the flight state for a given vehicle based an internal “performance model” for conventional aircraft.

NPD curves for helicopters vehicles

For helicopters, NPD curves consist of the same metrics as conventional vehicles.

Computed for:

- A number of “operational modes” (“operating condition”)… hover, taxi, flyover, etc.
- For distances of: 200, 400, 630, 1000, 2000, 4000, 6000, 10000, 16000, 25000 feet above a centerline microphone; however, altitude effects are not included (… those are accounted for inside AEDT).
- Also, microphones at $\pm 45°$ laterally under vehicle.
- NPD curve to use is chosen in AEDT based on operational mode specified by the user.

“NPD” curves for unconventional vehicles

For our purposes, the Noise-Operating Condition-Distance method is used; however, it is still called an NPD curve.

- Same integrated metrics as before are required.
- However:
  - Instead of AEDT internally determining flight condition based on a Power setting,
  - We directly provide the operation condition to AEDT:
    - A unique integer identifier assigned to each condition as a surrogate for thrust.
    - Fixed point flight profile used in AEDT.
  - “Flight Condition” defined by combinations of indicated airspeed and climb angle.

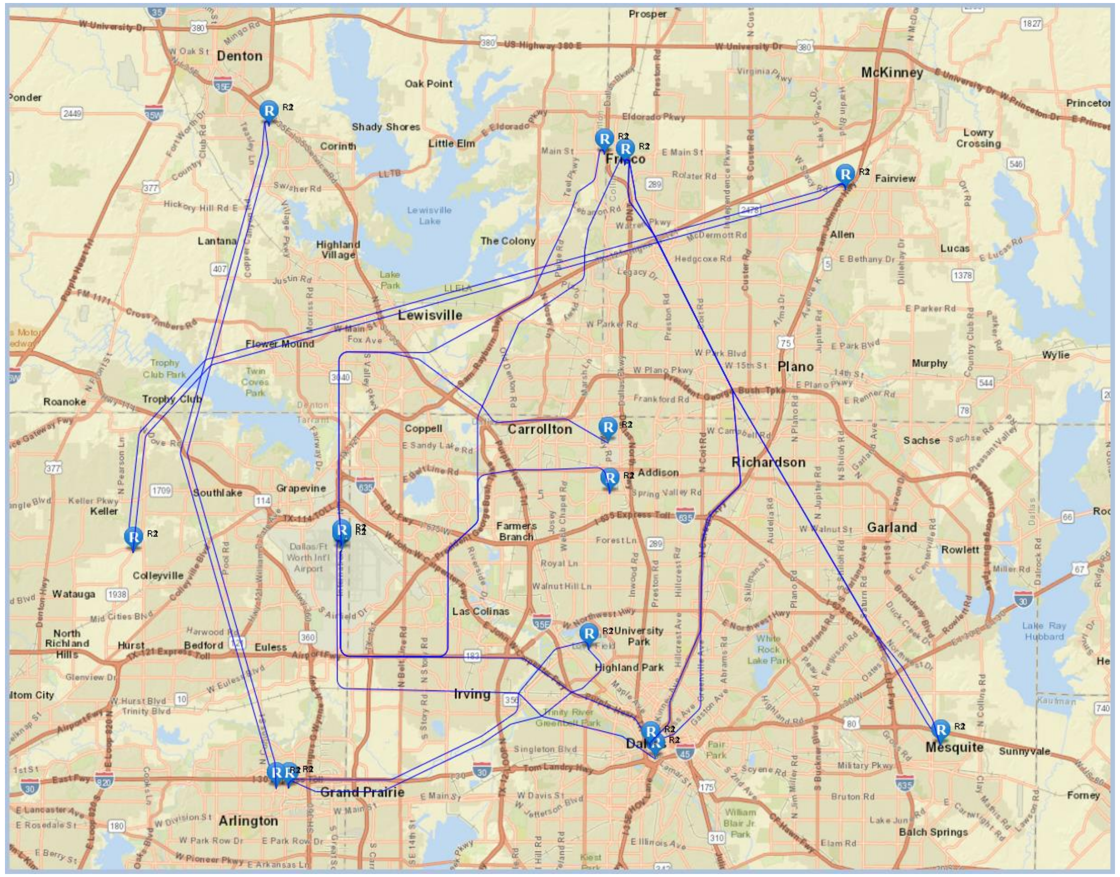
Computed for:

- Every flight condition (function of indicated airspeed and climb angle).
- For distances of: 200, 400, 630, 1000, 2000, 4000, 6000, 10000, 16000, 25000 feet above a centerline microphone; however, altitude effects are not included (… those are accounted for inside AEDT).

Question: Where do we get the flight conditions to analyze?

Where do we get flight conditions?

Dallas Ft. Worth (DFW) Airport



- Routes provided by NASA ATM-X UAM X2 team.
- 16 routes around Dallas Ft. Worth (DFW).
- Two vehicles (from NASA Conceptual Design):
  - Quadrotor: 6 passenger, 3 bladed rotors.
  - Lift+Cruise: 6 passenger, 8 rotors plus pusher.

Quadrotor Vehicle Trim

Rotors have:

- Constant RPM.
- Collective pitch, θ.
- Blade passage frequency = 20 Hz.

Trim targets:

- 6 DOF (F_x, F_y, F_z, M_x, M_y, M_z) trim targets.

Trim variables:

- Pilot controls combine blade θ combinations rotor pairs.
  - Fore-to-aft pairing for longitudinal control,
  - Side-to-side pairing for lateral control,
  - Diagonal pairing for yaw control.
- Vehicle pitch, roll, yaw orientation angles.

Lift+Cruise Vehicle Trim

Rotors (and pusher propeller) have:
- Constant RPM.
- Collective pitch, θ.
- Blade passage frequencies:
  - 35 Hz (main rotors).
  - 105 Hz (pusher propeller).

Low Speed configuration trim:
- Trim targets: 3 DOF longitudinal trim (F_x, F_z, M_y).
- Trim variables: Pilot controls combine rotor θ; vehicle pitch.
- Pusher prop not used; wing-body provides lift, drag, etc.

Moderate Speed configuration trim:
- Trim targets: 3 DOF longitudinal trim (F_x, F_z, M_y).
- Trim variables: Pilot controls combine rotor θ; pusher θ.

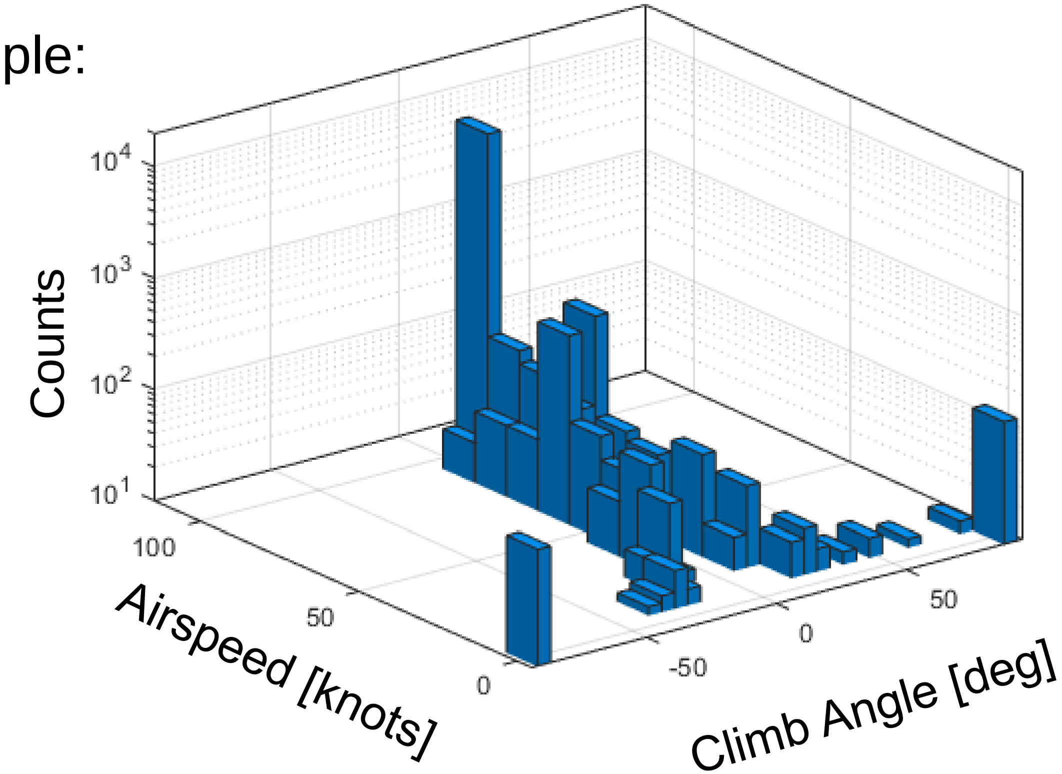
High Speed (cruise) configuration trim:
- Trim targets: 2 DOF longitudinal trim (F_x, F_z).
- Trim variables: Vehicle pitch and pusher θ.
- No rotors; wing-body provides lift, drag, etc.

Flight conditions determination

The routes provided consist of 1000s of points along each flight track.

- This is an unmanageable number of points to analyze individually.
- The subsequent talk will discuss the analysis of these routes to be examined.

Example:



Result: Flight conditions binned into:

- 42 flight conditions for Quadrotor.
- 44 flight conditions for Lift+Cruise.

Computation of individual NPD curves

Now, have:

- Individual flight conditions (indicated airspeed and climb angle combinations).
- A comprehensive analytical model for each vehicle.

Need to:

- Compute acoustics for each flight condition.
- Propagate that information to a location that matches the distances previously discussed.

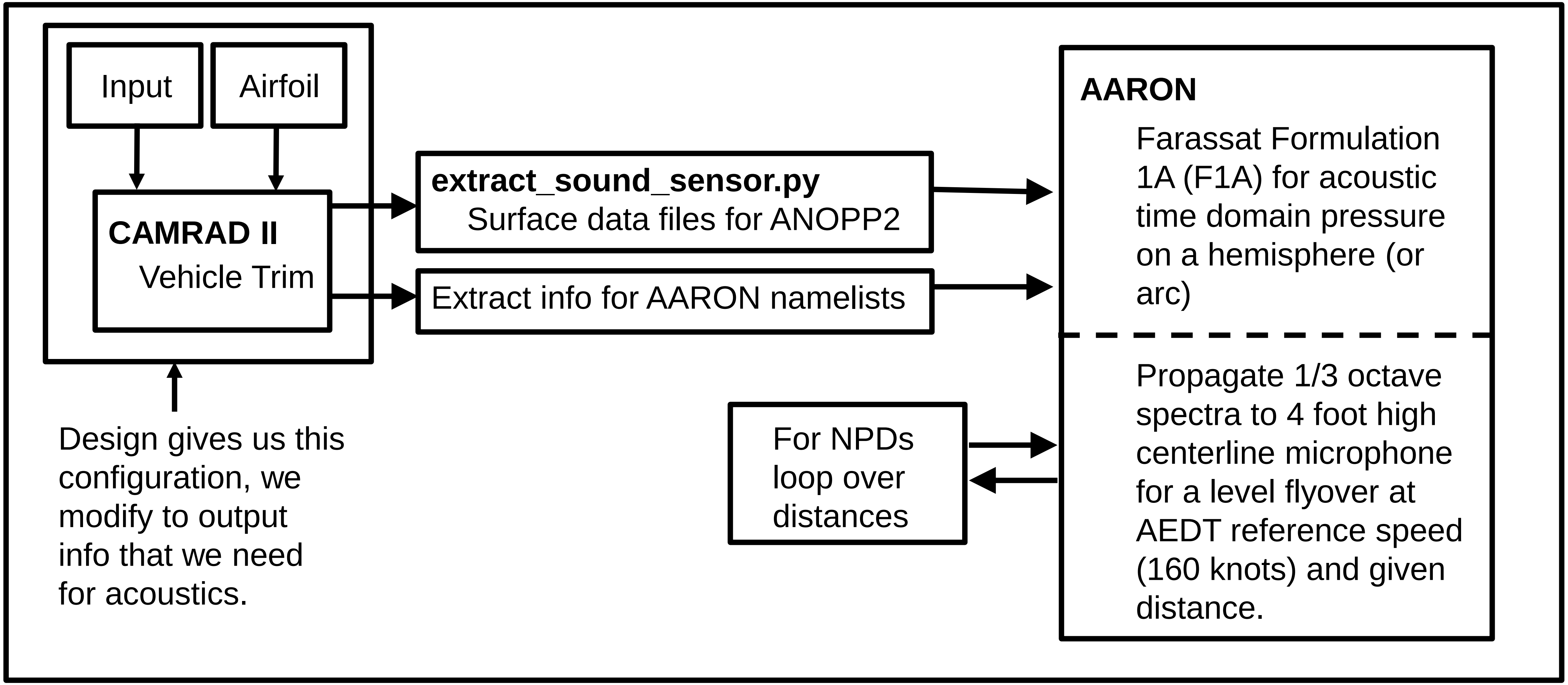
Generation 1 (“Gen-1”) data:

- For NASA purposes, “Gen-1” data only include:
  - Thickness and loading noise from rotors.

- Subsequent “Generations” of data will include more and more components and noise sources.

NASA Computation of individual NPD curves

pyaaron



Sample Hemisphere Created for Flyover

AARON results:

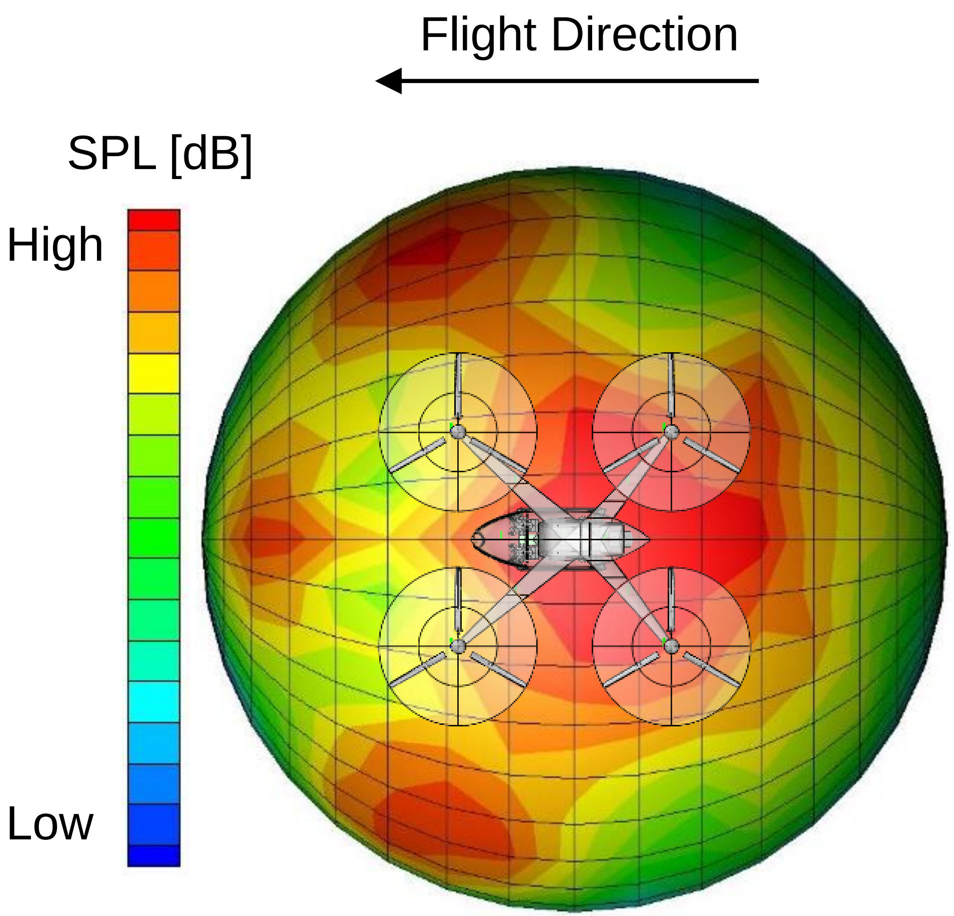
- The F1A analysis described on previous slide results in a hemisphere underneath the rotor similar to the figure.

- This hemisphere (1/3 octave band version of this hemisphere) is then “flown” at the AEDT reference speed.

- The above step is repeated for the AEDT distances described previous.

- The four metrics (listed below) are computed at the centerline microphone location.

  - SEL [dBA]
  - L_{Amax} [dBA]
  - EPNL [EPNdB]
  - PNLTM [TPNdB]



This analysis method is not just to NPDs… It is also being used in conjunction with auralization, acoustically aware vehicle research, CFD/CSD coupling, conceptual design, noise reduction methods, Advanced Acoustic Model, etc.

What does an NPD curve look like?

Example:

- SEL curve as function of distance for several flight conditions.

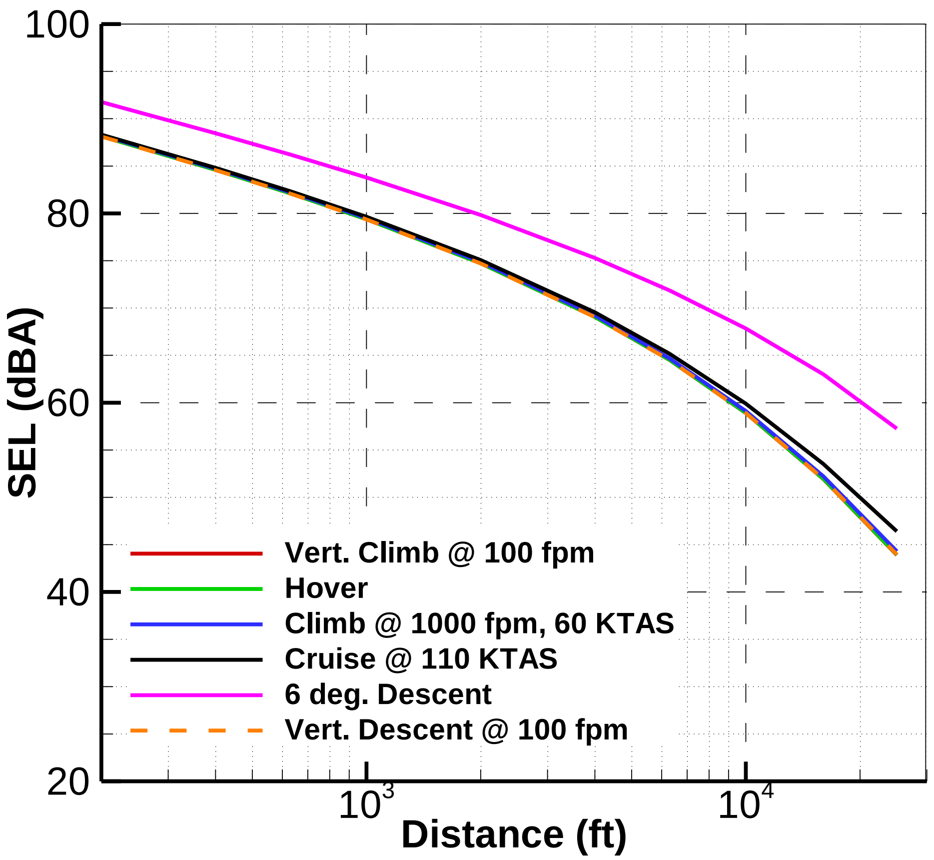
Similar curves for:

- L_{Amax} [dBA]
- EPNL [EPNdB]
- PNLTM [TPNdB]

Each curve for a given vehicle for a given flight condition is provided to AEDT.

These data are being used to assess community impact for the NASA Fleet Noise Technical Challenge.

SEL [dBA] vs. distance for several flight conditions



What does an NPD curve look like (alternative view)?

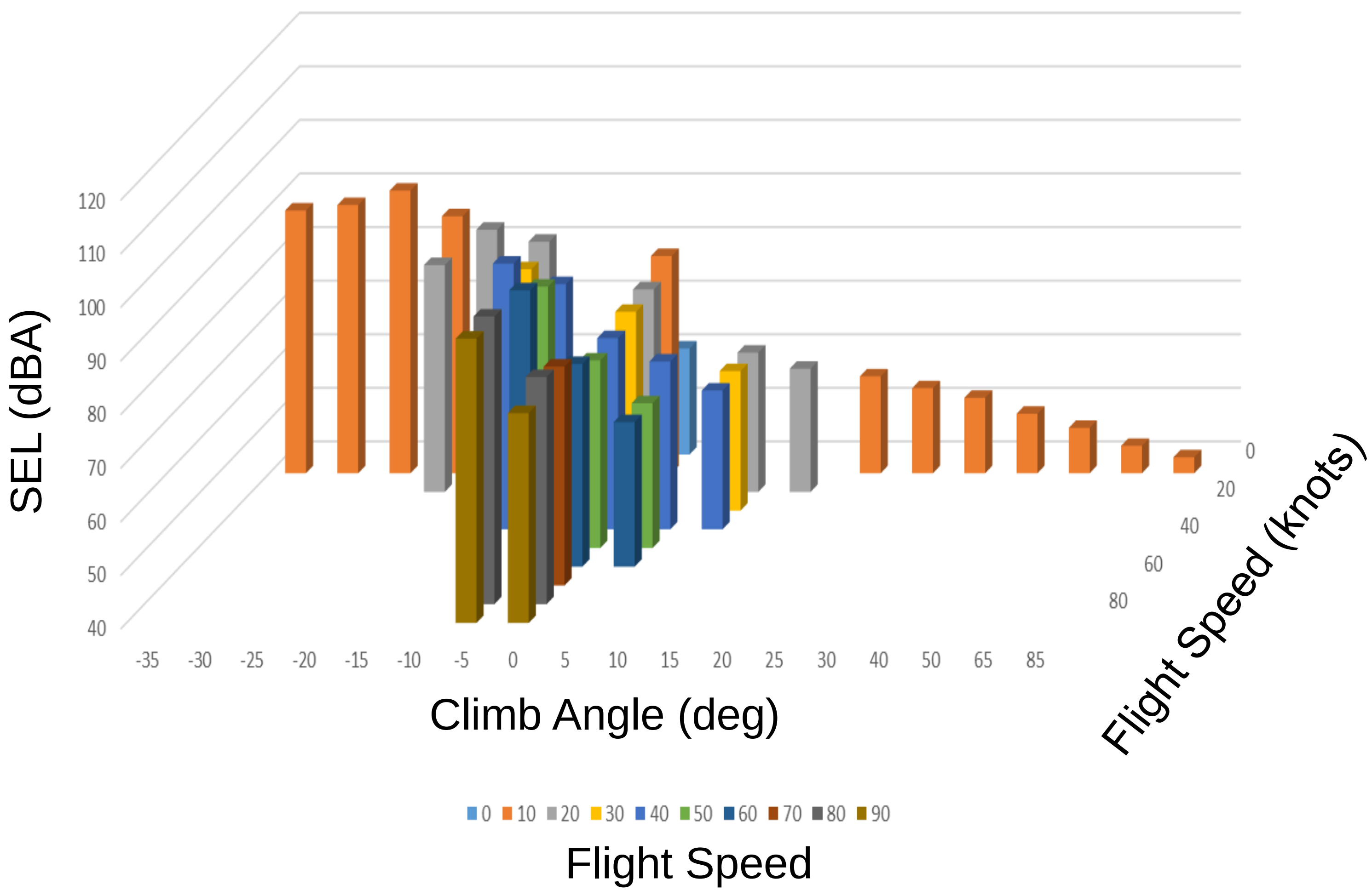
Example:

- Bar chart of SEL [dBA] at a given distance, for all flight conditions.

Similar bar charts for:

- L_{Amax} [dBA]
- EPNL [EPNdB]
- PNLTM [TPNdB]

SEL [dBA] at a given distance for all flight conditions



Qualitative Comparison between AEDT and AARON

Example case:

- Single flight operation of Quadrotor on 6-deg descent at 62.3 knots.

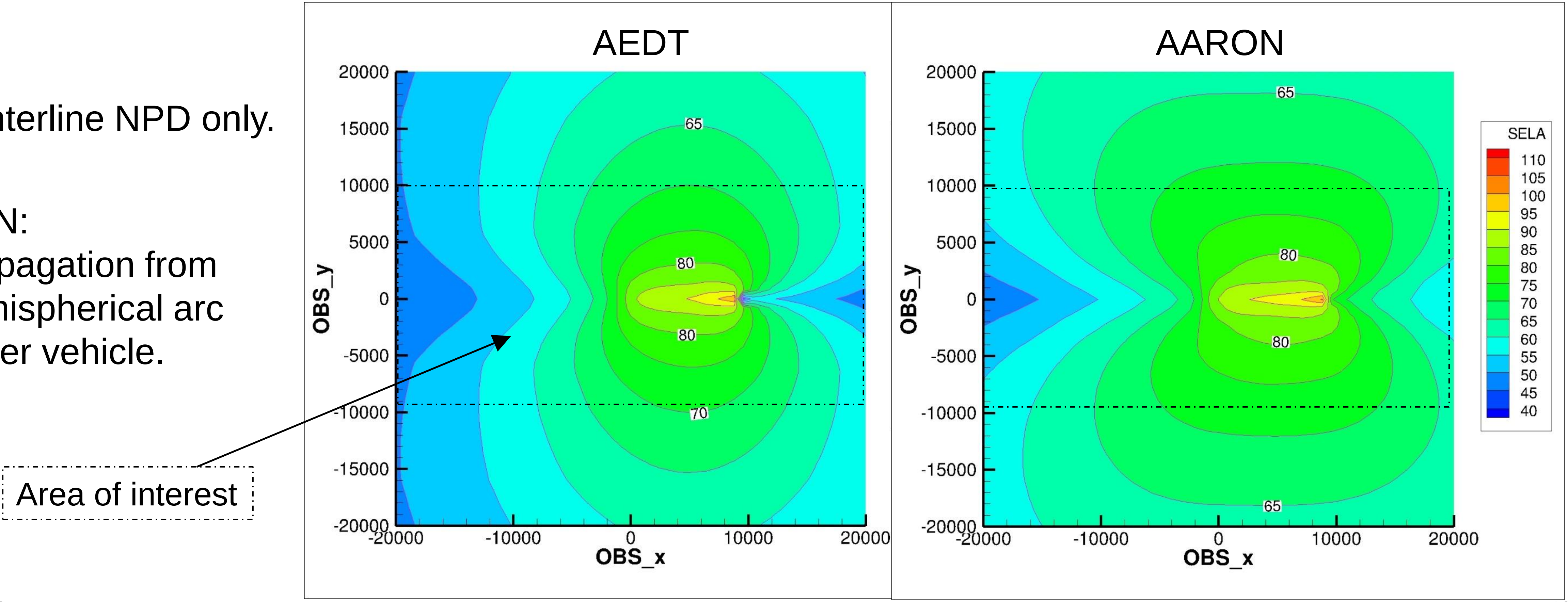
AEDT:

- Centerline NPD only.

AARON:

- Propagation from hemispherical arc under vehicle.

SEL [dBA]
20,000' by 20,000' ground plane



AEDT Usage – Introduction

The NPD example on previous slide was for:

- Single flight operating condition of a single vehicle.

For Fleet Noise:

- NPD curves for multiple flight conditions of multiple vehicles over multiple routes are combined using AEDT to generate ground maps of various metrics.

This is the subject of the following talk.

NASA Fleet Noise POCs for this work:

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