Modeling Noise and Acceptability of eVTOL Operations

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Outline

- Acoustic modeling of eVTOLs
- Source characteristics and metric calculations
- Illustration via acoustic animations
- Including background when modeling operations
- Expanding upon the foundation of US National Parks research
- Future modeling plans

The U.S. Department of Transportation does not implicitly endorse the Uber Elevate Project. Research conducted by the Volpe Center is to gain better insight of potential future Urban VTOL transportation modes.

Acoustic Modeling of eVTOLs

Research Goal: Help develop the science and modeling tools that will allow Uber to predict community **acceptability** for an urban VTOL ecosystem.

- How do we define community noise acceptability?
  - Large body of dose-response testing led to today's regulations, standards and metrics
  - Regulations and Guidelines limit percent "Highly Annoyed", which is not the same thing as maximizing community "Acceptability"
  - Need to move from annoyance to acceptability
- A modular toolset is needed for acceptability analysis and decision making for eVTOL acoustic design requirements and Uber Elevate Operations\

  Where, when, how many and how frequent?

Audibility and Detection

Audibility refers to the potential for a human to detect the presence of a sound source.

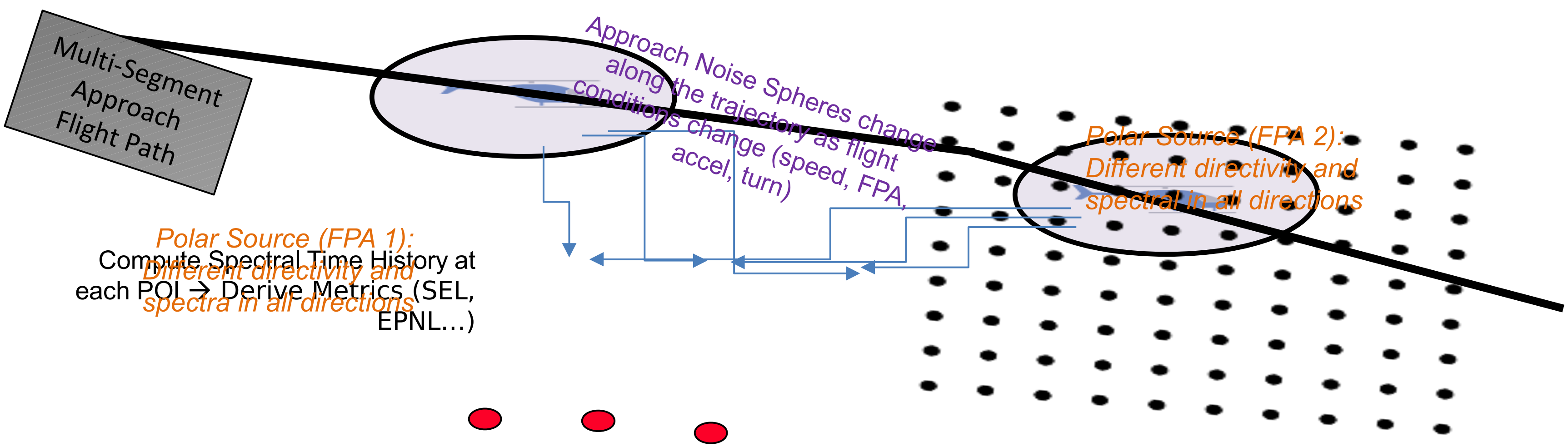
- Many methods for quantifying "Loudness"; fewer for quantifying "audibility" or "human detection"
- Loudness modeling often used to derive audibility and masking effects
- Human hearing system is able to discriminate/resolve noise components in different frequencies

Models needed to predict these characteristics for new designs

The uniqueness of a vehicle's sound character can increase detection and identification. Conversely, ubiquitous sound quality can aid in signal masking.

Advanced Acoustic Model (AAM)

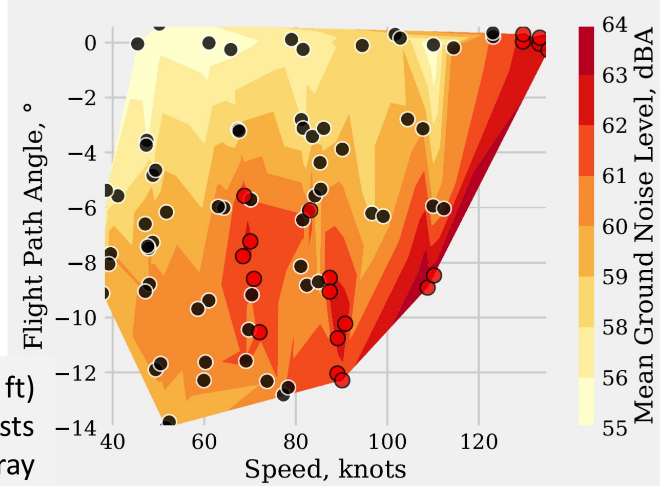
- Noise data comes from *modeling or measurement* and includes 3D spectral directivity and is provided as a function of speed, FPA, acceleration, turn etc…
- AAM propagates each direction separately for each frequency of interest accounting for environmental factors such as meteorology and terrain and stores the time history at each receiver
- Audibility metrics are then computed at each receiver accounting for background noise.



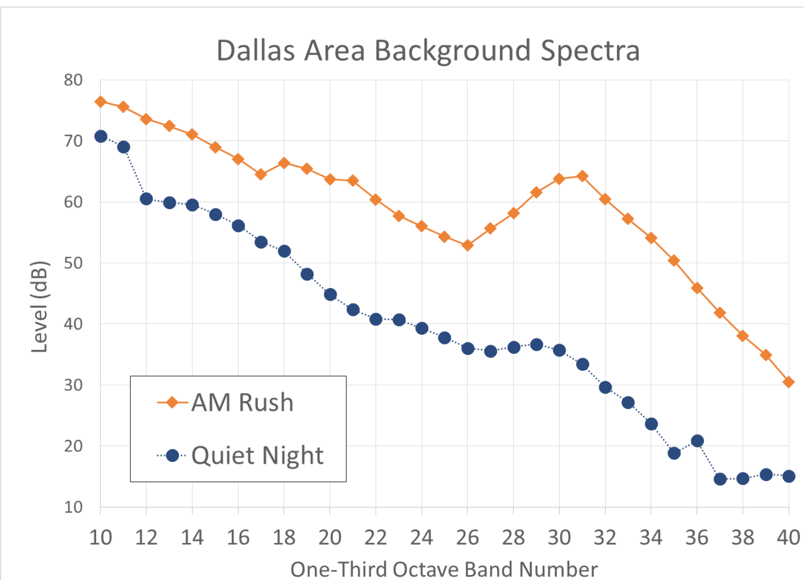
Acoustic Animation

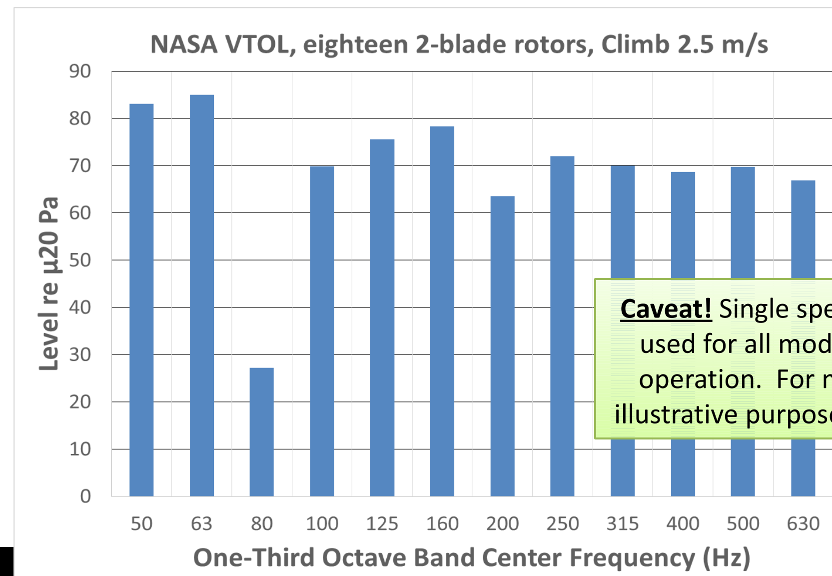
- Two vehicles: Conventional light helicopter (Bell 206 *approx.*) and notional NASA eVTOL
  - Input data limitations: notional eVTOL → simple monopole
    Helicopter → complex set of frequency / directivity characteristics
- Defined using 1/3 octave bands
- Notional Elevate operation in the Dallas area
- Background environments: AM rush & quiet night

Helicopter source noise emissions vary with flight condition



Looking at the **overall footprint** (appx. 3000 x 5000 ft)
Bell 407 empirical data from 2017 NASA-FAA flight tests
Arithmetic mean dBA value, 52 microphone dynamic array

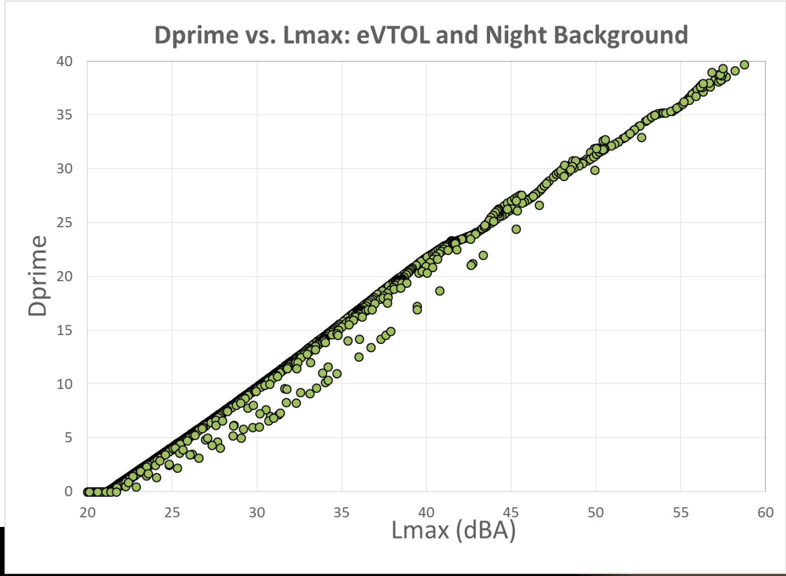


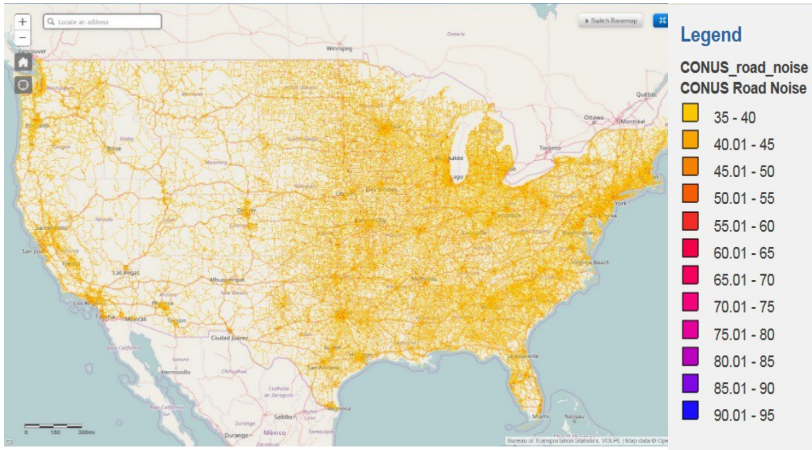


Caveat! Single spectrum used for all modes of operation. For model illustrative purposes only!

Adaptation of Background Data

- U.S. Bureau of Transportation Statistics (BTS)
  https://www.rita.dot.gov/bts/press_releases/bts015_17
  - U.S. Roadway Noise & Airport Noise and combined databases
  - A-weighted 24-hour LAEQ (dBA) *(24-hour equivalent sound level (LAEQ) is (logarithmic) average of sound energy over a 24 hour period)*
- Data “Transformed” into D-Prime Equivalent for illustrative purposes
  - Linear d-Prime dBA relationship established based on simulation over 8 mi x 8 mi area
  - Empirical Dallas Data AM rush vs. Quiet Night used to determine offset (~28 Dprime dB)
  - Better time-based spectral background data is needed!





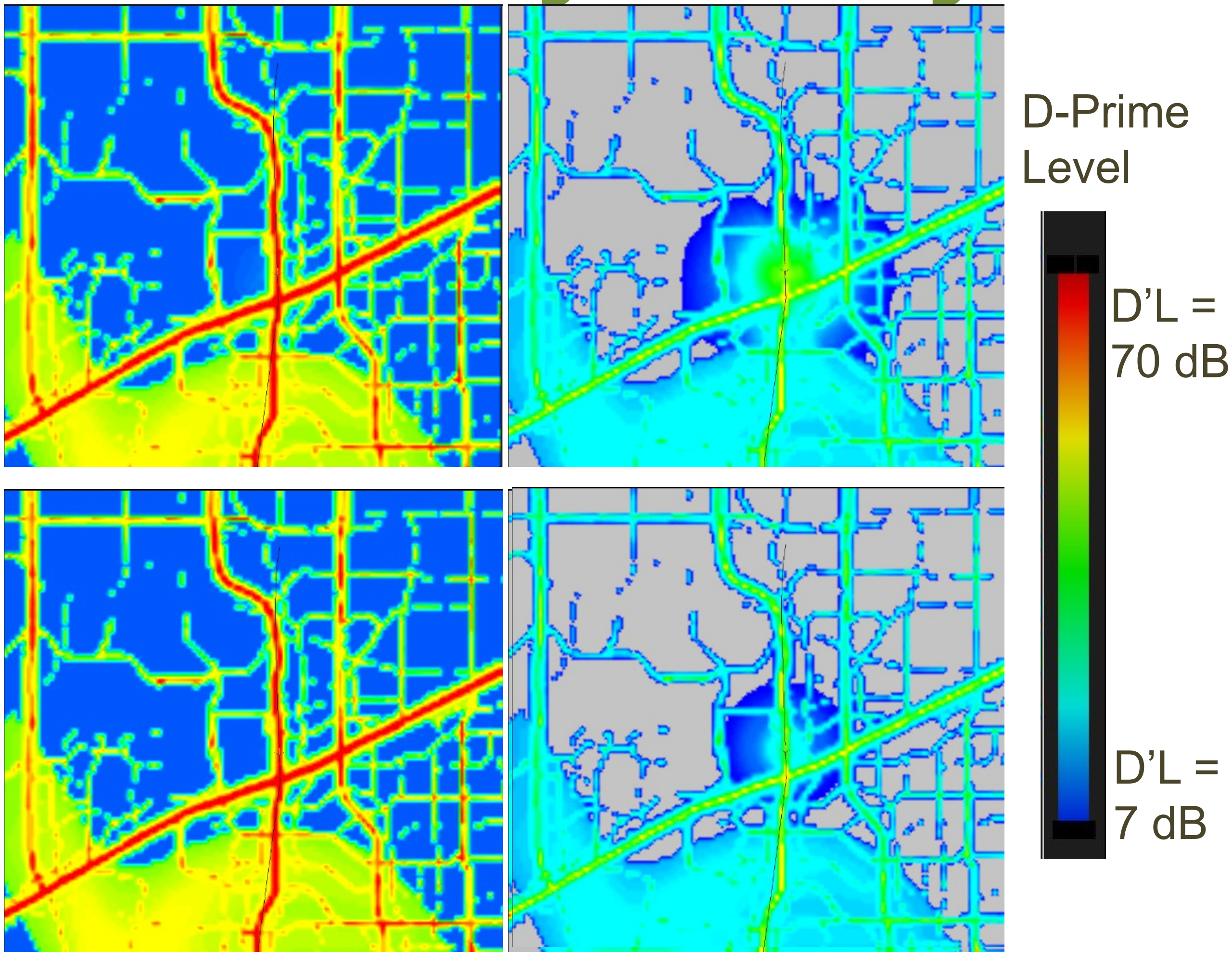
BTS

Vehicles Top: Bell 206 Bottom: Notional eVTOL
Background Left: AM Rush Right: Quiet Night

NPS Findings:
Attentive listeners heard tour aircraft when average 'Audibility threshold'

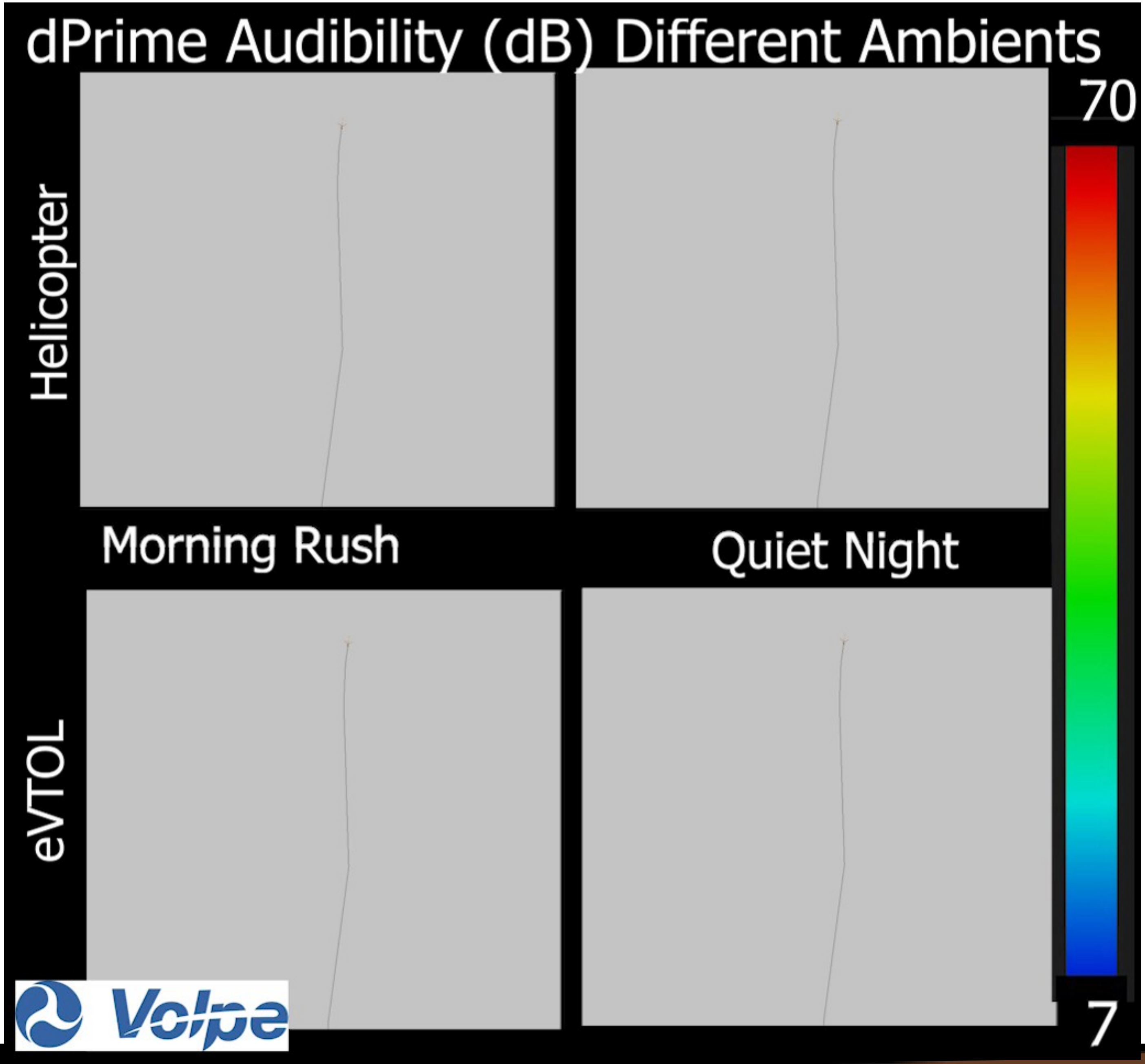
D'L = 7 dB

'Noticeability threshold' of D'L = 17 dB has been used for National Park Visitors engaged in activities



References:

National Park Overflight Decision Support System, 1994


dPrime Audibility (dB) Different Ambients
Helicopter
eVTOL
Morning Rush
Quiet Night
70
7

Research in U.S. National Parks

- Visitor evaluations of acceptability, interference with natural quiet and annoyance *(DOT-VNTSC-FAA-16-01, 2016)*
  - In situ surveys and visitor responses to aircraft overflights
  - Comparisons with prior data for annoyance and interference with natural quiet
  - Multi-level regression analysis: visitor, site, sound energy (helo, props, jets)
  - Developed acceptability questioning format and language
- **Community Engagement techniques to define what is acceptable when and where**

		A. How acceptable or unacceptable were these sounds during your time on this trail?									B. How much did these sounds please or annoy you during your time on this trail?									C. How much did these sounds positively add to or negatively detract from your experience during your time on this trail?								
		--Unacceptable--					--Acceptable--				--Annoy--					--Please--				Negatively detract					--Positively add -			
SOUNDS	*Did Not hear*	Extremely ▼	Very ▼	Moderately ▼	Slightly ▼	Neutral ▼	Slightly ▼	Moderately ▼	Very ▼	Extremely ▼	Extremely ▼	Very ▼	Moderately ▼	Slightly ▼	Neutral ▼	Slightly ▼	Moderately ▼	Very ▼	Extremely ▼	Extremely ▼	Very ▼	Moderately ▼	Slightly ▼	Neutral ▼	Slightly ▼	Moderately ▼	Very ▼	Extremely ▼
i. Airplanes, jets, helicopters, or other aircraft	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐

*https://www.nps.gov/grca/learn/nature/upload/PL100-91.pdf

NPS metrics

- Preference for time audible comes largely from mandates
  - Public Law 100-91 identifies flight-free zones as large areas where visitors can experience the park essentially free from aircraft sound intrusions, and where the sound from aircraft traveling adjacent to the flight-free zone is not detectable from most locations within the zone; <u>the primary measure of restoration is the percentage of time that aircraft are audible</u>
  - Grand Canyon National Park Policy states that a **substantial restoration requires that 50 percent or more of the park achieve "natural quiet" (i.e.. no aircraft audible for 75-100 percent of the day)**
  - Substantial restoration based on qualitative terms (i.e., large areas)
  - NPS establishes flight-free zones and flight corridors in Grand Canyon
- Strengths: easy to measure, understand, and explain to public

Report of the Effects of Overflights on the National Park System, 1995

Time audible modeling

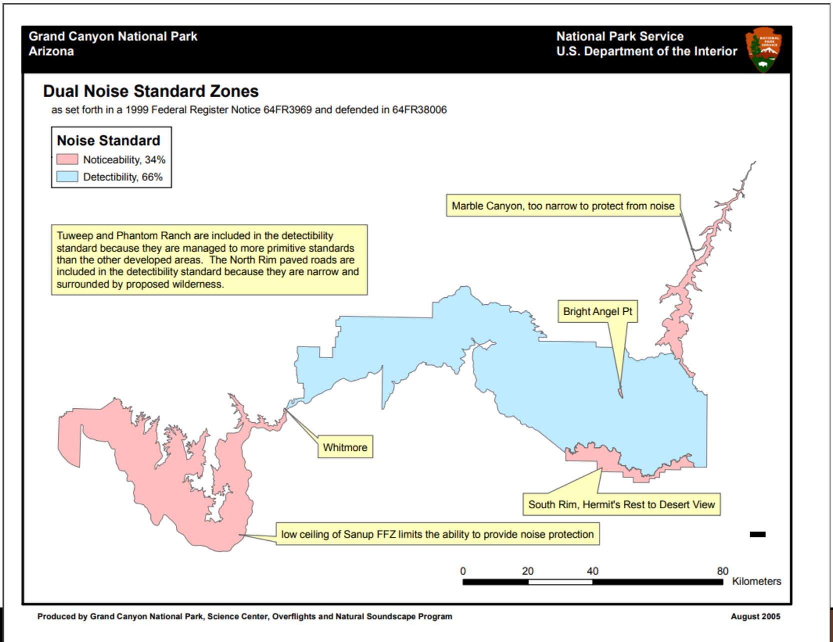
- For modeling, time audible is computed from d' detectability
  - Validation: Audibility threshold validated by listeners in a park setting.
  - D'L values computed from observer logs and aircraft/ambient recordings.
  - ***Attentive listeners*** were hearing tour aircraft when ***D'L = 7 dB*** on average
  - ***A 'Noticeability threshold'*** of ***D'L = 17 dB*** has been used for National Park Visitors engaged in activities

- % Time audible is the cumulative measure
  - In modeling, one must consider the temporal element (overlapping flights), otherwise linear summation often results in percentages >100
  - Methods to account for simultaneously occurring aircraft (time compression) have been developed based on empirical and statistical methods.

References:
Aircraft Noise Model Validation Study, 2003.
Analysis of Modeling Cumulative Noise from Simultaneous Flights, 2012

Noise management by zones

- National Park Service uses management zones to manage different areas of the park with different standards (frontcountry/developed, backcountry, wilderness)
- In Grand Canyon, different thresholds are applied to different zones.
- In conjunction with Community Engagement, Uber Elevate could use this approach to evaluating zone-based audibility and other acceptability metric thresholds



Future AAM Modeling Improvements

- ❑ Implement 1/12 Octave Bands: *Source → Propagation → Receiver*
- ❑ Develop Higher Time-Sampling Capability
- ❑ Integrate Time Varying Loudness (TVL) Metrics

Uber is supporting the enhancement of AAM's solid acoustic foundation from which to analyze unique VTOL designs

- ❑ Vehicle acoustic technologies to foster acceptability
  - Programmed departure, enroute and approach paths for noise abatement
  - Acoustic self-awareness vehicle technologies (route optimizer)
  - Networked route enabled metric non-exceedance technology (noise cost)

Summary

A **holistic approach** to developing models for predicting the community acceptability of potential Urban VTOL ecosystem can be developed by extending the current body of **research and modeling** while proactively engaging the public and extending into temporal and spectral domains **beyond currently employed acoustic metrics**.

- ❑ Modeling capabilities are being enhanced for eVTOL operations
- ❑ Acceptability based noise evaluations must be cognizant of background environment and community expectations
- ❑ Spectral distribution, tonal character, modulations and other sound quality characteristics matter
- ❑ Acceptance predictions must consider operational tempo, individual and overlapping exposures and could possibly be based on zones

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