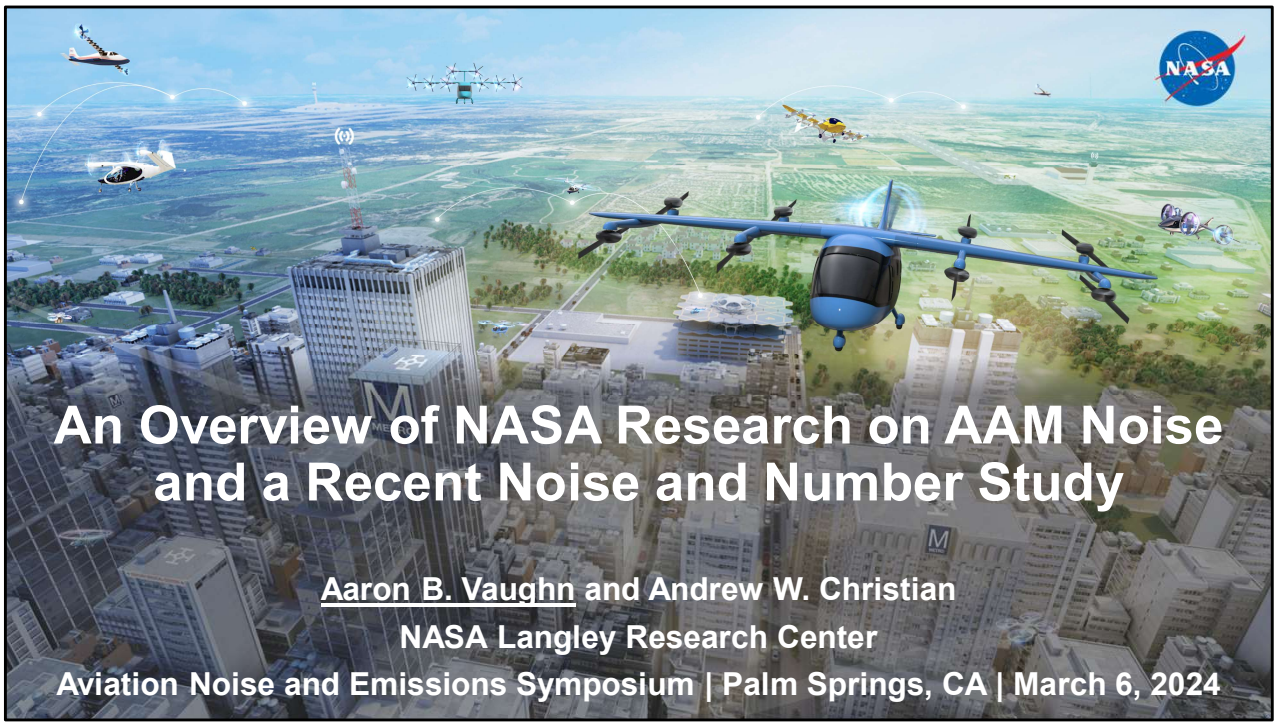

An Overview of NASA Research on AAM Noise and a Recent Noise and Number Study

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NASA conducts psychoacoustic research to support Advanced Air Mobility (AAM)



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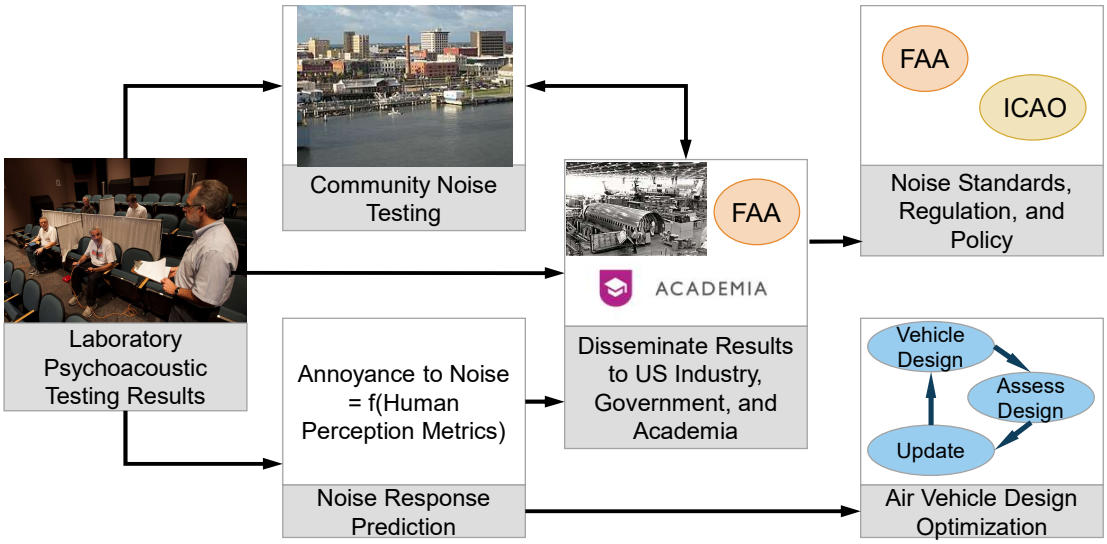
- For AAM, NASA is a technical partner to industry and communities
    - NASA is not a regulator nor manufacturer
- AAM includes both “rural” and “urban” applications
    - Point-to-point transportation of cargo and people
- Urban Air Mobility (UAM) is a challenging use-case with high benefit
    - Enabled by electrification and automation
- Where I fit into this picture is on characterizing the human response to the noise of these vehicles

Psychoacoustic testing results can be applied to vehicle design and noise regulation/policy



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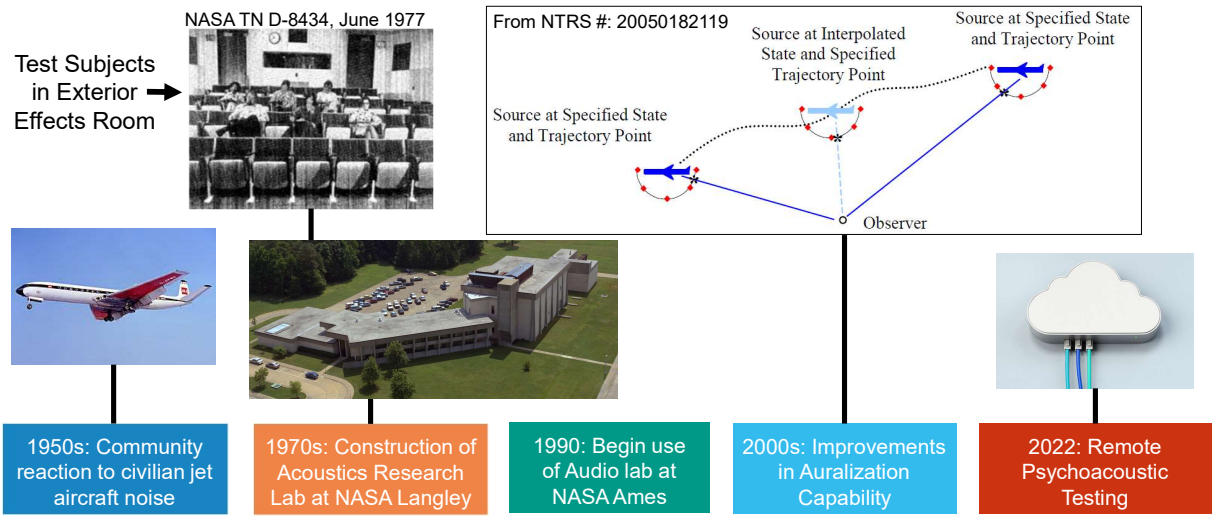
- Through dissemination of our research results, NASA:
  - supports and guides community noise testing in collaboration with industry, government, and academia
  - informs regulators and policy makers in their efforts
  - develops and updates noise response predictions, or annoyance models, that are factored into the vehicle design process by manufacturers

NASA has decades-long experience with psychoacoustic testing



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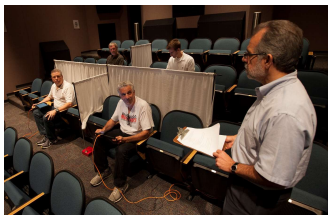
- NASA has been in the psychoacoustics business for over half a century
  - From the 1950s with civilian jet aircraft noise
  - To the 1970s with the construction of the Acoustics Research Lab that houses our psychoacoustic testing facilities
  - In the 1990s, NASA Ames Research Center began use of their Audio Lab
  - In the 2000s, we made improvements in our auralization capability, or the ability to simulate the noise of an aircraft in flight based on the physics of their design
  - And out of the pandemic we extended our capabilities to include remote psychoacoustic testing
- Nearly all our work is driven by community reaction to aviation noise sources, as opposed to acoustic issues of spaceflight vehicles or space habitats

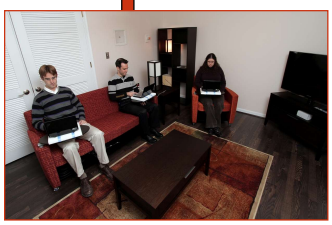
NASA has in-person psychoacoustic testing facilities





Exterior Effects Room
(aircraft, rotorcraft, etc.)





Interior Effects Room
(sonic boom)

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- We conduct our psychoacoustic studies with support across multiple NASA centers
- Some capabilities at NASA Langley Research Center include in-person psychoacoustic testing facilities
    - The Exterior Effects Room has auditorium-like seating and loudspeakers mounted all around the room.
        - This configuration allows participants to hear recorded or synthesized sounds of vehicles in motion, such as a UAM vehicle flyover
    - The Interior Effects Room is setup like a small living room and has 52 subwoofers mounted on the outside wall.
        - This allows us to simulate sonic booms, particularly quiet supersonic noise signatures in preparation for the Quesst mission with the quiet supersonic X-59 aircraft for the commercial supersonic technology project

The “noise and number” problem:
How do people respond to a frequent sound? What metric to use?



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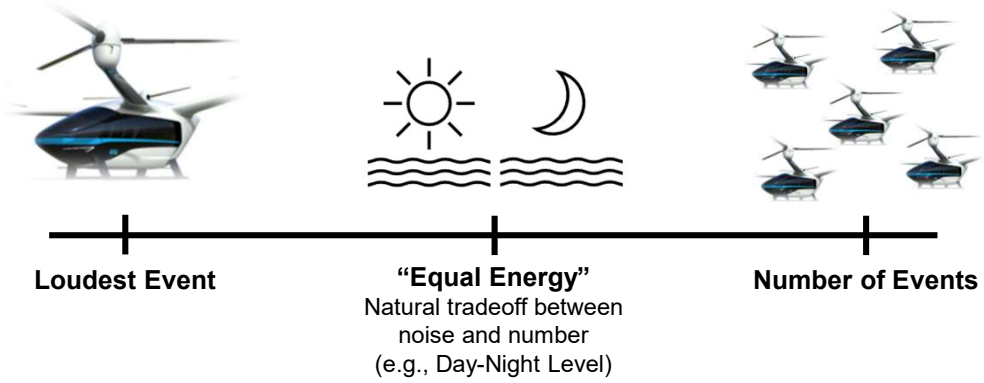
- Recently, we’ve applied our expertise to the noise and number problem
- This is motivated by the anticipated high frequency of events
- People have been working on the noise and number problem for several decades
- The noise and number problem refers to how people respond when a sound is frequent
- Frequent is in contrast to rare sounds (once a day, once a month, etc.) and continuous sounds, such as a busy freeway
- UAM vehicles naturally going to exist in this frequently occurring domain
- What is the right metric to predict human response for a frequent sound?

Developing a single (continuous) scale with several common possible responses



Loudest Event

"Equal Energy"
Natural tradeoff between noise and number (e.g., Day-Night Level)

Number of Events

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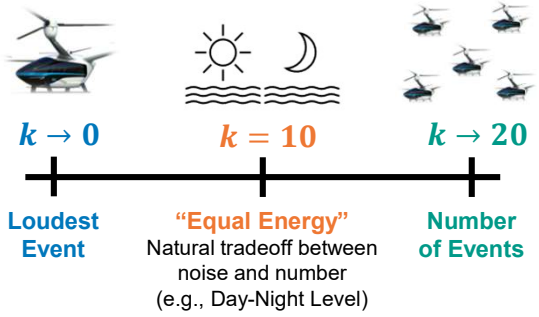
- What drives annoyance response?
- Here's a scale with common possible responses
- Consider people responding over a period of time, such as a day
    - On one end, you have the loudest event
    - On the other end, you have the number of events
    - In the middle, we have "equal energy," which refers to a natural tradeoff between noise and number that is commonly used in many noise metrics, such as Day-Night Level
- Where do people respond on this scale? At one of the three distinct points or somewhere in-between?

A notable approach to investigate noise and number is with the "decibel equivalent number" k



	Loudest Event	"Equal Energy"	Number of Events
	$k = 5$	$k = 10$	$k = 15$
+0 dB	$N = 1$	$N = 1$	$N = 1$
+10 dB	$N = 100$	$N = 10$	$N = 5$
+20 dB	$N = 10,000$	$N = 100$	$N = 22$

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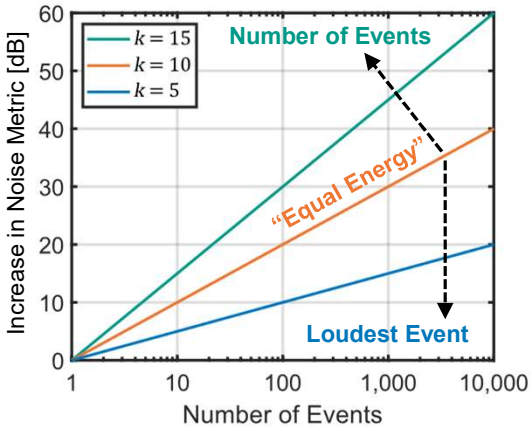
- One way people have looked at noise and number is with the "decibel equivalent number" k
- This formulation comes from work at NASA by James Fields in the 1980s
- Think of k as a weighting factor for a cumulative noise metric
- Varying k allows us to consider these annoyance responses on a continuous scale
  - When $k = 10$, the metric gives us "equal energy"
  - As $k \to 0$, the metric gives weight to the loudest or average event level
  - As $k \to 20$, more weight is given to the number of events
- Table on the right provides an example of how increasing the noise metric in 10 dB increments relates to the number of events at different k values
  - How do we add multiple events together?
  - Consider each aircraft event to be the same noise level
  - All start at the same level with 1 aircraft
  - We hear logarithmically (or exponentially)
  - For each 10 dB increase in the metric
    - $k = 10$: has a 10 fold increase ("equal energy" or DNL)
    - $k = 5$: has 100 fold increase (less weight on number)
    - $k = 15$: fewer events (more heavily weights the number)

A notable approach to investigate noise and number is with the "decibel equivalent number" k



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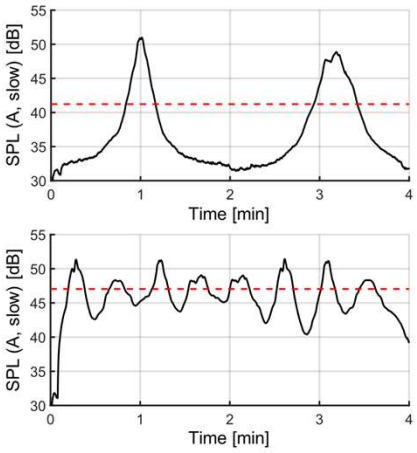
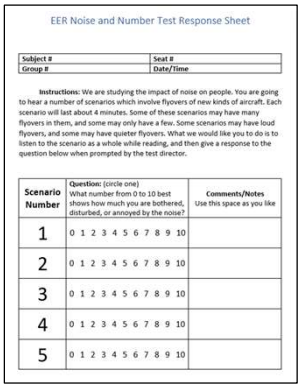
- Figure on left shows how the metric behaves for different values of k as the number of events increases
  - Number of events are on a logarithmic or exponential scale
  - As the lines become shallower with smaller k, there is less of a weighting to the number of events
  - As the lines become steeper with larger k, there is a greater weighting to the number of events
- 50 years ago, many countries used different k
  - The British provide a historic example of this formulation with the Noise and Number Index that used $k = 15$ from 1960s to 1990, where it was replaced by an equal energy metric
  - Nowadays, everyone essentially uses "equal energy" or $k = 10$
    - Simpler to calculate, no need to count number of events
- However, including number of events may improve response predictions.
- We can consider the continuous scale of k from 0 to 20 and test how number of events impacts peoples' response

NASA recently conducted a UAM noise and number study in the Exterior Effects Room







EER Noise and Number Test Response Sheet

Subject #	Seat #
Group #	Date/Time

Instructions: We are studying the impact of noise on people. You are going to hear a number of scenarios which involve flyovers of new kinds of aircraft. Each scenario will last about 4 minutes. Some of these scenarios may have many flyovers in them, and some may only have a few. Some scenarios may have loud flyovers, and some may have quieter flyovers. What we would like you to do is to listen to the scenario as a whole while reading, and then give a response to the question below when prompted by the test director.

Scenario Number	**Question:** (circle one) What number from 0 to 10 best shows how much you are bothered, disturbed, or annoyed by the noise?	Comments/Notes Use this space as you like
1	0 1 2 3 4 5 6 7 8 9 10	
2	0 1 2 3 4 5 6 7 8 9 10	
3	0 1 2 3 4 5 6 7 8 9 10	
4	0 1 2 3 4 5 6 7 8 9 10	
5	0 1 2 3 4 5 6 7 8 9 10	

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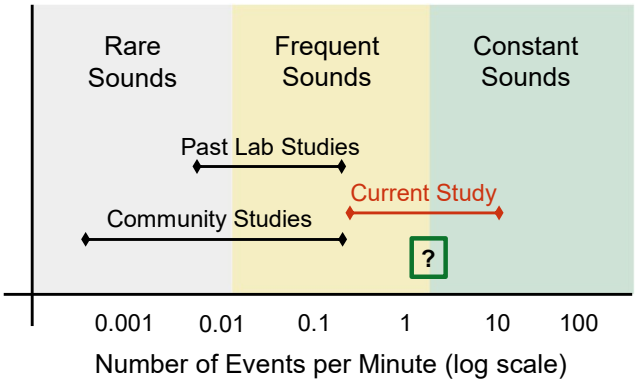
- We recently conducted a noise and number study with UAM vehicle flyover sounds
- We conducted it in the Exterior Effects Room at NASA Langley as shown
- Participants listened to several different 4-min sound stimuli consisting of flyovers of varying frequency – see examples of sound level versus time
- Participants provided their annoyance responses on the scale: 0 to 10

Current UAM noise and number study explores the transition from frequent to constant sound



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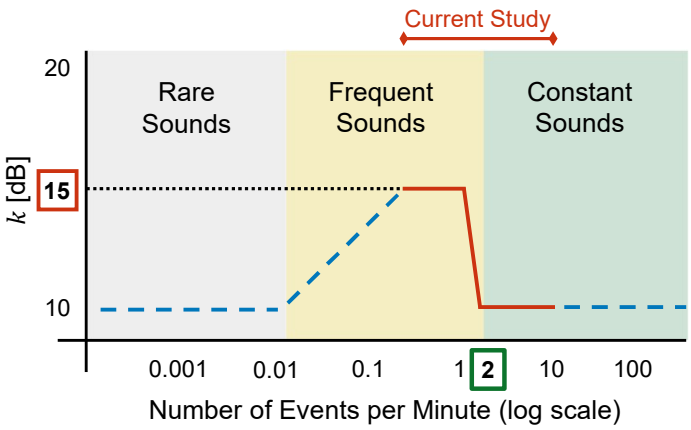
- This figure shows 3 regimes of event occurrence: rare, frequent, and constant
  - X-axis is again logarithmic or exponentially spaced but now is frequency of events instead of number of events
  - Past lab studies have commonly considered single and/or short flyover events (rare or frequent)
  - Community studies limited by airport operations (rare or frequent)
  - Current study extends beyond past work with longer sounds containing multiple flyovers
- One objective of the study was to explore the transition from “frequent” to “constant” sound for UAM vehicles
  - One could hypothesize that for frequent sounds $k > 10$ (more heavily weight for number of events) and for constant sounds $k = 10$ (conventional metric, equally weights number and sound level) as events become indistinguishable

Current UAM noise and number study results suggests greater weighting than suggested by equal energy for frequent events



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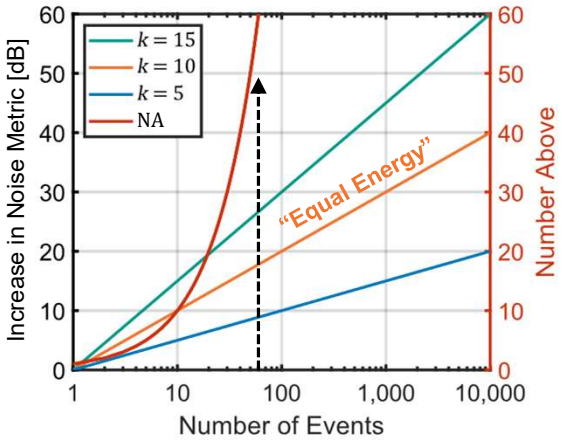
- Results of our study suggest that the transition from “frequent” to “constant” sound occurs at about 2 events per minute for the UAM vehicles in a lab setting
- Y-axis shows k value, where $k > 10$ has greater weighting for number of events
- For less than 2 events per minute, $k = 15$, meaning that there is a greater weighting on the number of events than suggested by equal energy
- For more than 2 events per minute, $k = 10$, meaning that equal energy is a good predictor of the response
- These specific results are not generally applicable to all vehicles and noise sources, but the concept of k to add weight to the number of events for frequent sounds may have relevance elsewhere
- There can even be different regimes within a given test for same group of subjects

How does k relate to Number Above?
Number Above behaves very differently than k-based metrics



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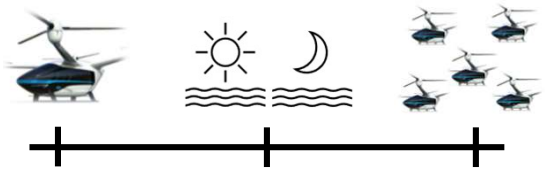
- One unit that is interesting to compare k with is Number Above (NA)
- NA counts the number of events above some noise level threshold
- NA is a linear metric and behaves differently than these k-based metrics
- Consider the trend of NA compared to equal energy ($k = 10$)
  - For few events, NA is lower
  - For many events, NA is higher
  - For even more events, NA becomes significantly greater
- Consider also that NA requires some noise threshold
  - Over time, number of events increases while the levels of individual events decrease with technological advances
  - This scenario highlights the sensitivity of the NA metric to the chosen threshold
  - This can further cause different behavior in NA than k-based metrics

In summary:

- NASA conducts AAM psychoacoustic research that informs regulators and manufacturers
- A single metric with a continuous k-factor can provide insight into human response to noise and number
- Recent UAM noise and number study suggests greater weighting to number of events than prescribed by equal energy for frequent sounds



Loudest Event | **"Equal Energy"** Natural tradeoff between noise and number (e.g., Day-Night Level) | **Number of Events**

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