Why is predicting audibility so hard?

Andrew Christian
Structural Acoustics Branch
NASA Langley Research Center

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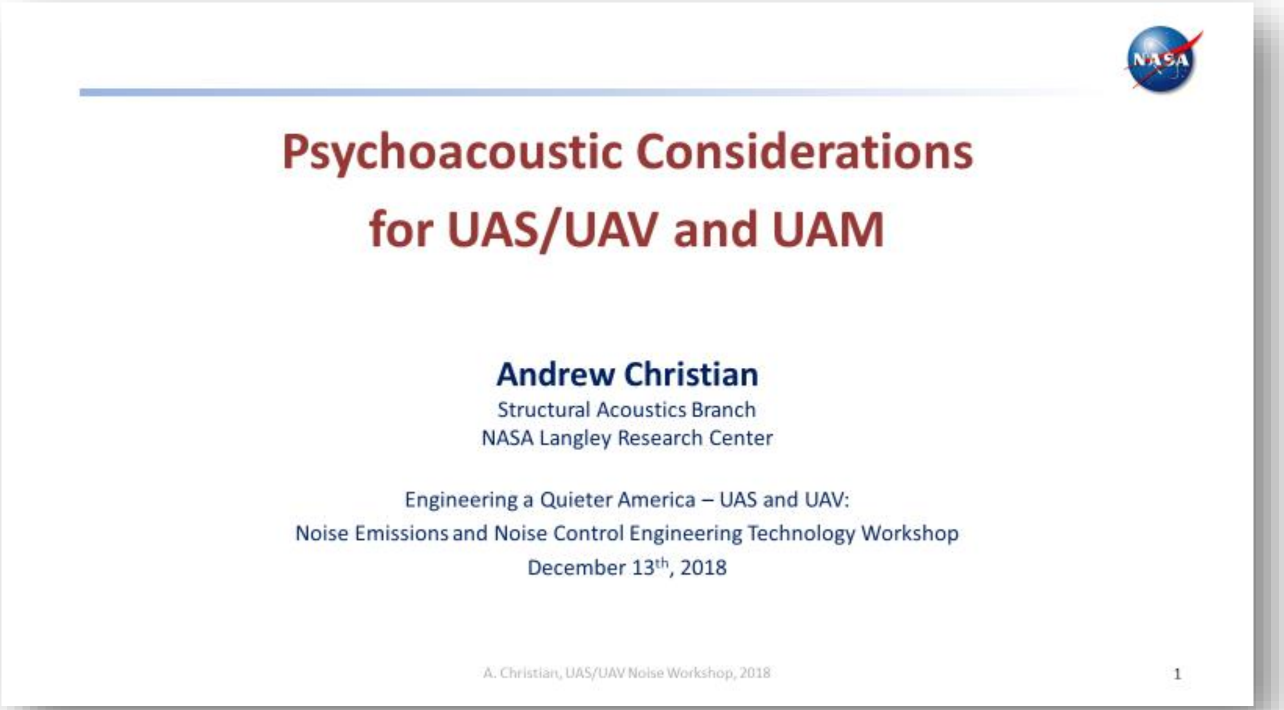
Previously at the NAE

- At the last iteration of this workshop, I presented an overview of how various facets of psychoacoustics might impact the perception of aerial mobility vehicles.
  - This discussed:
    - Loudness metrics
    - Sound Quality metrics
    - Some initial/historical results
  - Full of notes and references

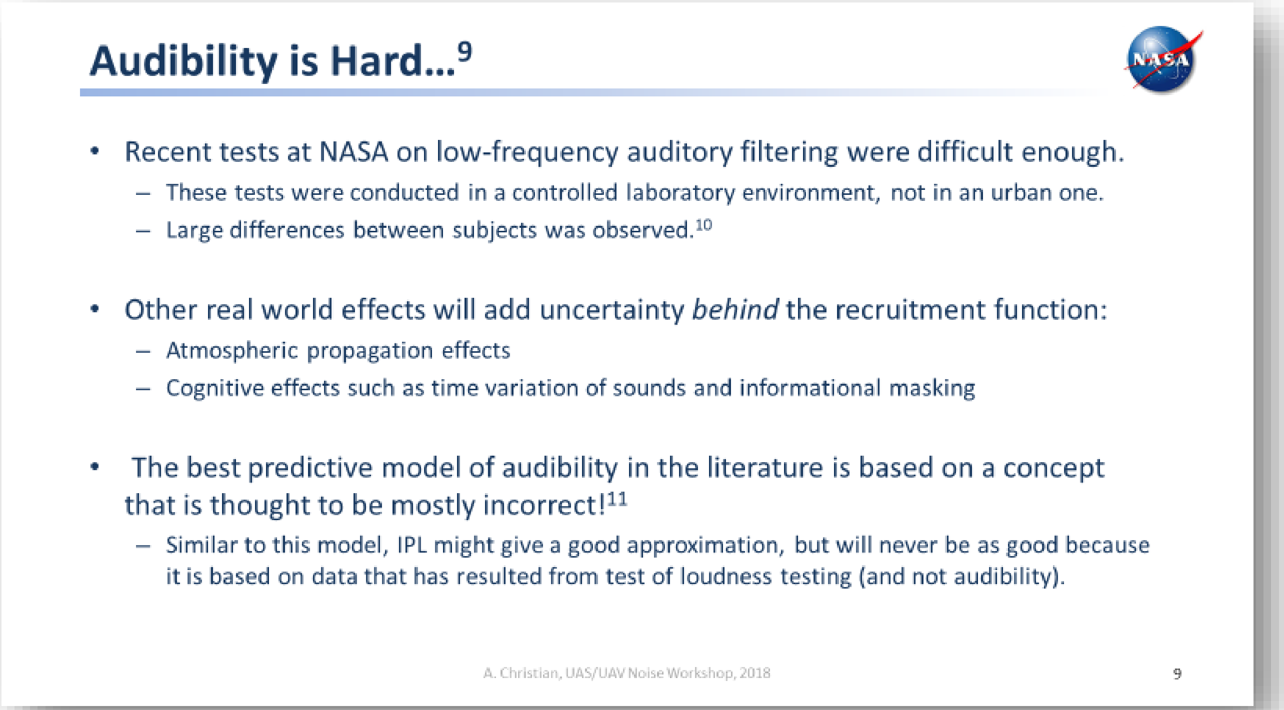


- Available via the [NASA Technical Reports Server]

Previously at the NAE

- Regarding audibility, the conclusion was that its prediction was difficult, but would be necessary to understand community response.

- Much of the work that has been going on at NASA wrt. aerial mobility in the intervening time has been focused on creating models of audibility to aid in the prediction of annoyance.
- This presentation will dig a bit deeper into the difficulties we've been running into.



Audibility is Hard…[9]

- Recent tests at NASA on low-frequency auditory filtering were difficult enough.
  - These tests were conducted in a controlled laboratory environment, not in an urban one.
  - Large differences between subjects was observed.[10]

- Other real world effects will add uncertainty *behind* the recruitment function:
  - Atmospheric propagation effects
  - Cognitive effects such as time variation of sounds and informational masking

- The best predictive model of audibility in the literature is based on a concept that is thought to be mostly incorrect![11]
  - Similar to this model, IPL might give a good approximation, but will never be as good because it is based on data that has resulted from test of loudness testing (and not audibility).

A. Christian, UAS/UAV Noise Workshop, 2018 9

Why is predicting audibility necessary?

- Starting with two rules of thumb from the literature regarding the link between annoyance and audibility:
  - When sources of noise are sufficiently prominent over the ambient, there is no strong effect of the ambient level on annoyance.
  - When sources of noise get close to the ambient, annoyance is impacted.

- For urban air mobility (UAM) situations, there could be a double benefit of reducing the level of noise into the existing soundscape.
  - Some seem to think that this effect will be essential to predicting community reaction to UAM (whether there is acceptance or not).

The Problem of Audibility

- Generally, what we want to do is predict how likely it was that a listener heard a ***signal*** in the presence of a ***masker***.
  - If the signal is inaudible, we say that it was ***masked***.

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Audibility Prediction

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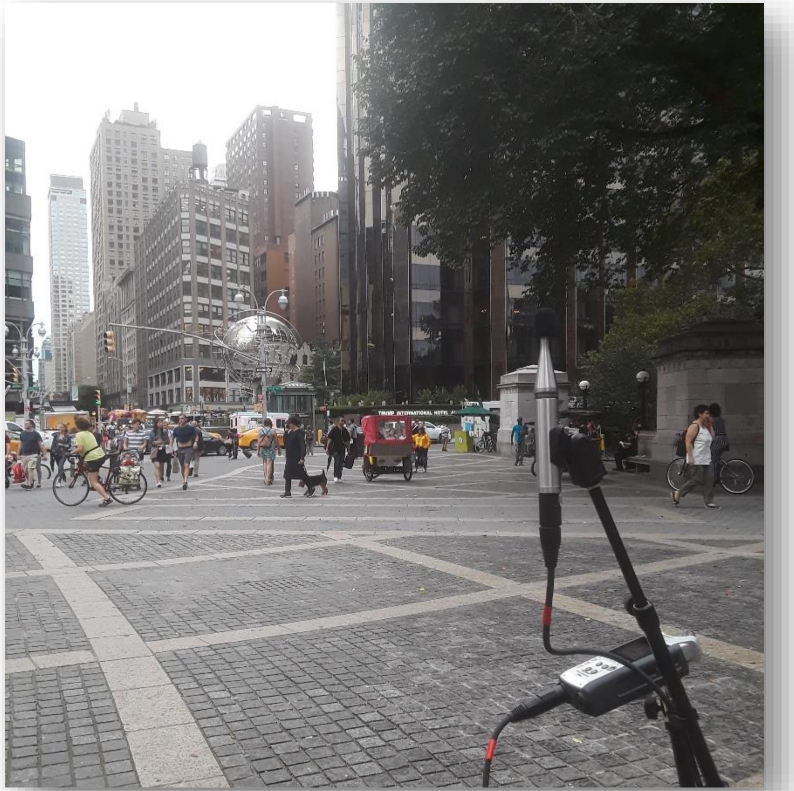
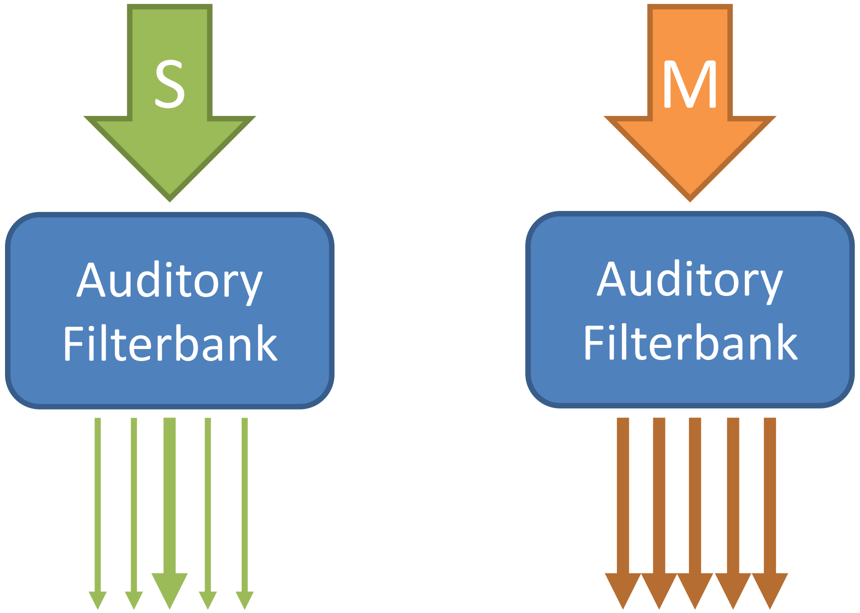


Statistical Measure of Audibility (d’)

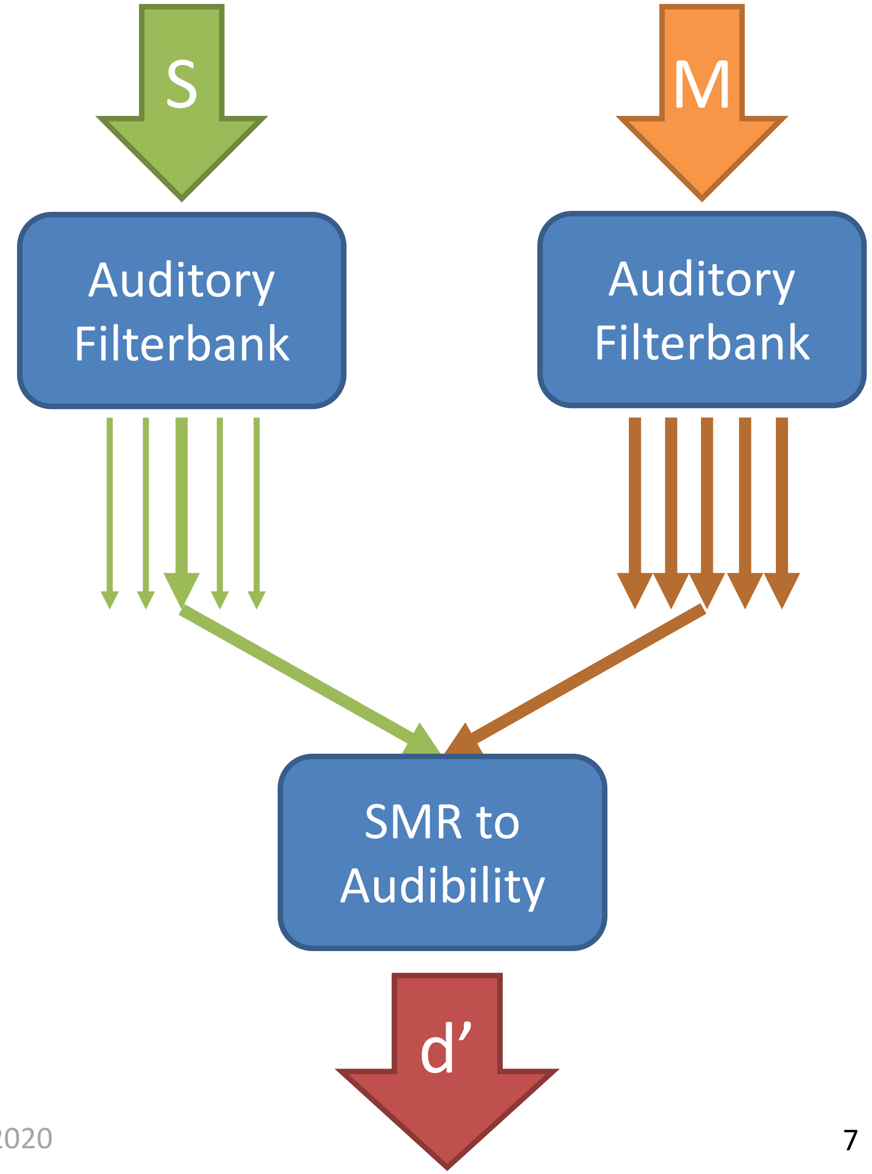
Start with the ear as a transducer

- Based on the mechanisms of the peripheral auditory system, we can formulate a good set of first steps:
  - Consider the ear as a bank of bandpass “auditory filters” (AFs).
  - The signal and noise are filtered by this bank separately.
- There are a number of issues already:
  - The AFs have a complicated shapes.
  - These shapes change with frequency and absolute level (nonlinearities).



The Power-Spectrum Model

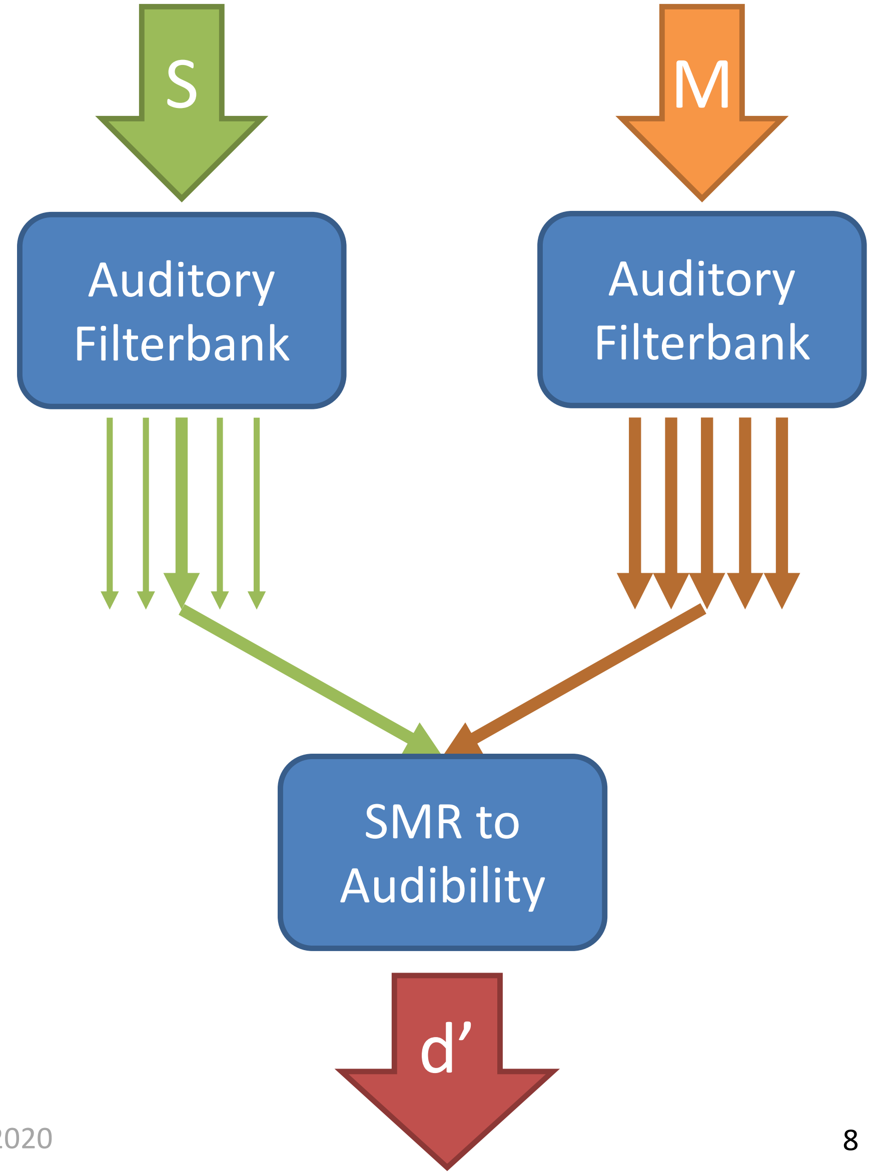
- The simplest model just considers the sound power passing through these bands.
  - Compute the power of the signal and masker in each AF.
  - Select the filter with the highest signal-to-masker ratio.
  - Have some way to relate this ratio to empirical data for audibility.



The Power-Spectrum Model

- There are some problems to solve…
  - What happens when signals occupy more than one filter?
  - Various solutions lead to various “flavors” of this model.

- This model can predict a large amount of empirical data for very fundamental experiments.
  - Up to a few tones of [moderate] frequency and length, in a stationary broadband noise masker.



Complications Arise

- In the late 1980s, researchers started to demonstrate the fragility of the power-spectrum approach.
- The problem is that the AFs in the ear are not attached to power detectors, but rather transduction mechanisms that generate a neural firing code.
- The brain is free to use any information it can gather from the auditory nerve to try to figure out if a sound is there or not.

Complications Arise

Here is a non-exhaustive list of types of information humans have been known to use when doing audibility tasks, that could impact a UAM-like scenario:

Acoustical aspects:

- Temporal envelope
- Spectral envelope
- Spatial cues

Non-acoustical/cognitive aspects:

- Object streaming
- Informational Masking
- Familiarity…

→ *None of these are predicted by the basic power-spectrum model.*

Where does this leave us?

- While there are attempts to generate more complete models of the auditory system, none of them are mature (or accessible) enough to be used for noise assessment.

- Instead, the best course is probably to try and:
  – Bound the set of applicable signals and maskers
  – Calibrate simple models to empirical results to eliminate bias
  – Quantify the remaining uncertainty

→ *This requires data!*

The link back to annoyance

- There is another unknown link in the chain…
  - How does a prediction of audibility impact a prediction of annoyance?
- Is it necessary to just hear a signal, or does it have to be so loud that it draws your attention?
  - Noticeability, intrusiveness, blend, etc.
- My recent thoughts were given at the Quiet Drones conference
  - Slides also available on NTRS.

Summary

- Predicting audibility is hard, but probably will be necessary for the assessment of noise-induced annoyance in UAM situations.

- There are many known complicating effects that may play into the audibility of aerial mobility vehicles operating in already-noisy environments.

- UAM-tuned audibility models have not yet been fielded due to a dearth of data and a lack of ability to perform psychoacoustic tests.