Overview of NASA Psychoacoustic Activities for UAM

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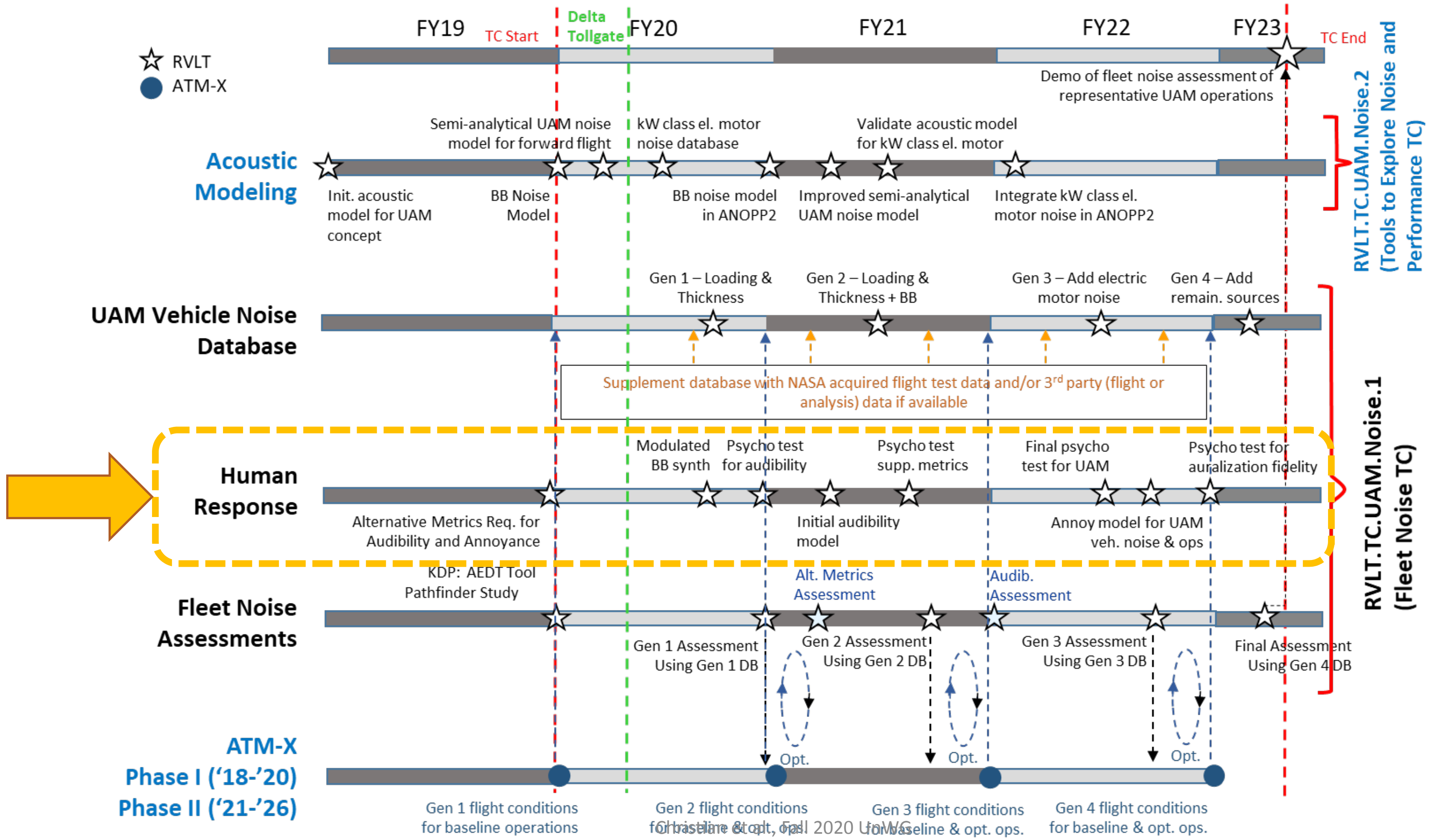
Introduction

- Why are we concerned with human response?
  - Although the starting point for UAM noise assessment will be rooted in results from other vehicle types, there is decent indication that the UAM space might be very wide in terms of types of noise, where/when the noise is heard, and the context in which it is heard.
  - Researchers, regulators, OEMs, and operators may benefit from having a large slate of psychoacoustic knowledge to draw from when wrestling with this breadth.

- We're working on the cutting edge.
  - Our research is not meant to directly suggest that regulations or industry should work a certain way, but to generate knowledge that may be used by anyone when the time comes.



RVLT
ATM-X
FY19
TC Start
Delta Tollgate
FY20
FY21
FY22
FY23
TC End
Demo of fleet noise assessment of representative UAM operations
Acoustic Modeling
Semi-analytical UAM noise model for forward flight
kW class el. motor noise database
Validate acoustic model for kW class el. motor
Init. acoustic model for UAM concept
BB Noise Model
BB noise model in ANOPP2
Improved semi-analytical UAM noise model
Integrate kW class el. motor noise in ANOPP2
RVLT.TC.UAM.Noise.2 (Tools to Explore Noise and Performance TC)
UAM Vehicle Noise Database
Gen 1 – Loading & Thickness
Gen 2 – Loading & Thickness + BB
Gen 3 – Add electric motor noise
Gen 4 – Add remain. sources
Supplement database with NASA acquired flight test data and/or 3rd party (flight or analysis) data if available
Human Response
Modulated BB synth
Psycho test for audibility
Psycho test supp. metrics
Final psycho test for UAM
Psycho test for auralization fidelity
Alternative Metrics Req. for Audibility and Annoyance
Initial audibility model
Annoy model for UAM veh. noise & ops
KDP: AEDT Tool Pathfinder Study
Alt. Metrics Assessment
Audib. Assessment
Fleet Noise Assessments
Gen 1 Assessment Using Gen 1 DB
Gen 2 Assessment Using Gen 2 DB
Gen 3 Assessment Using Gen 3 DB
Final Assessment Using Gen 4 DB
RVLT.TC.UAM.Noise.1 (Fleet Noise TC)
Opt.
Opt.
Opt.
ATM-X Phase I ('18-'20) Phase II ('21-'26)
Gen 1 flight conditions for baseline operations
Gen 2 flight conditions for baseline & opt. ops.
Gen 3 flight conditions for baseline & opt. ops.
Gen 4 flight conditions for baseline & opt. ops.

An equation for "Psychoacoustic Annoyance"

$$PA = N_5\left(1+\sqrt{w_S^2 + w_{FR}^2}\right)$$

Here's a textbook example equation for predicting annoyance due to noise.

This equation suggests a process by which one can take a recording of a sound, compute various "sound quality metrics," and combine them into a prediction of annoyance.

The terms on the RHS come from metrics that capture various auditory sensations such as the "sharpness," "fluctuation strength," and "roughness" of a sound.

An equation for “Psychoacoustic Annoyance”

$$PA = N_5\left(1+\sqrt{w_S^2+w_{FR}^2}\right)$$

This kind of distillation could be used as a factor in an MDAO approach to the design and evaluation of UAM vehicles.

Other methods might predict things like distraction or sleep disturbance.

But how does this actually apply to UAM noise?

3 Facets of this Question

- Checking the applicability of this kind of an approach to UAM vehicles can be roughly broken into 3 parts, corresponding to the 3 years of the TC. In reverse order:

3. Sound Quality

A good UAM [might] not sound like a good lawnmower.

2. Time Integration

UAMs (multiple) will not be a stationary noise source.

1. Audibility

UAMs will operate within an existing urban-sound environment.

3: Sound Quality

- What is the appropriate formula for PA for UAM given a set of sound quality metrics?
- What metrics are *useful* for the evaluation of UAM noise?
  - For instance, a measure of “tonality” is likely to be important.
  - What metrics seem to be the keys to annoyance for UAM-like sounds?
  - Does the metric help to discriminate between UAM vehicles?

2: Time Integration

- How should one adapt a PA-like equation for a situation in which time-variation is a significant aspect of the noise?
  - Sounds will come and go as the vehicles fly by. How do we “cook down” the exposure of a flyover into a single number?
  - What’s the best way to take into account integration across multiple exposures?
  - What about situations where there are so many vehicles that there is a relatively constant sound perceived?

- The hurdle is that there is no “default” way of doing this – there is no equal-energy principle as there is for simpler metrics.
  - Percentile values have been used in the past, but how does that apply to the above situations?

And then, it was 2020…

- This was already an ambitious schedule.
  - None of these questions are necessarily new, and many researchers have spent entire careers trying to push the state-of-the-art forward.

- Much of the answers to these questions (notionally) depended upon an ability to perform human-subject tests – a capability which is sidelined for the moment.
  - Tests at both LaRC and ARC were shelved.
  - Work is continuing based on available data/literature.
  - This is distinct from the UnWG human response study.

1: Audibility

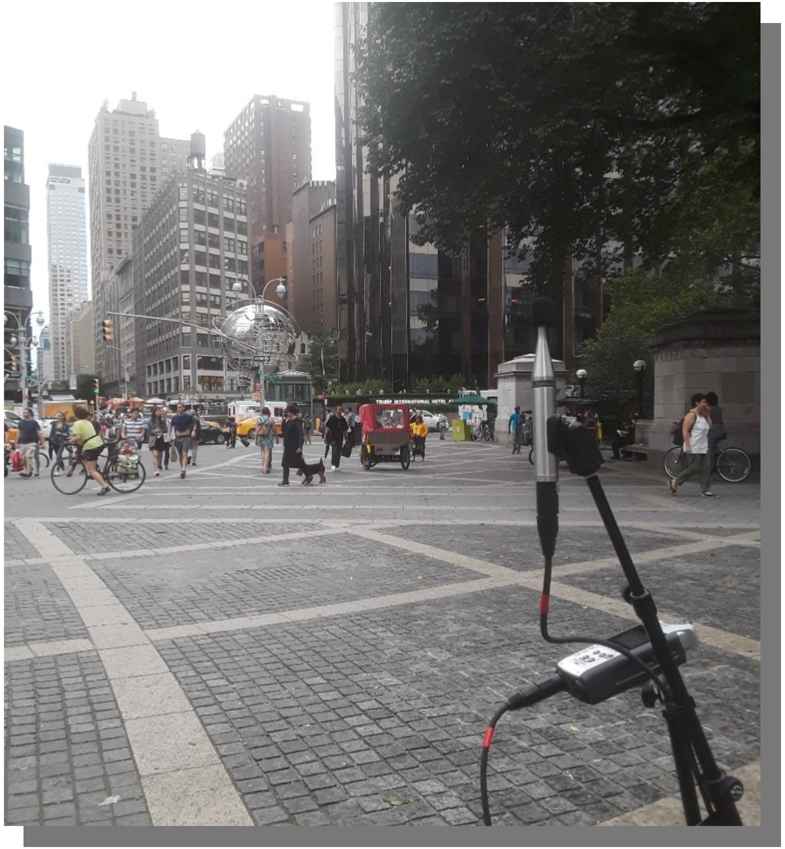
- It's well-known that background sounds can "mask" the perception of individual noise sources, and that this can lead to a reduction of annoyance.
  - Higher background levels lead to lower annoyance when all other things are kept equal, but what does this mean for a *novel* noise source?

- Can we formulate a *predictive* method to assess the impact of background sounds on UAM operations?

Characterizing the Background

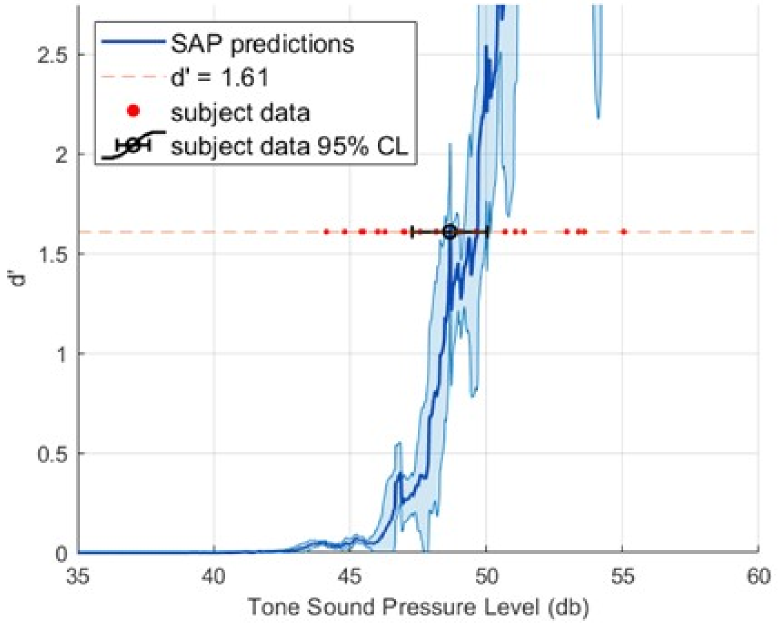
- The first job is to have confidence in a recording of the existing noise.

- Durand is preparing a NASA TM along these lines.
    - It will bring together best practices from various sources for how to record and document backgrounds.



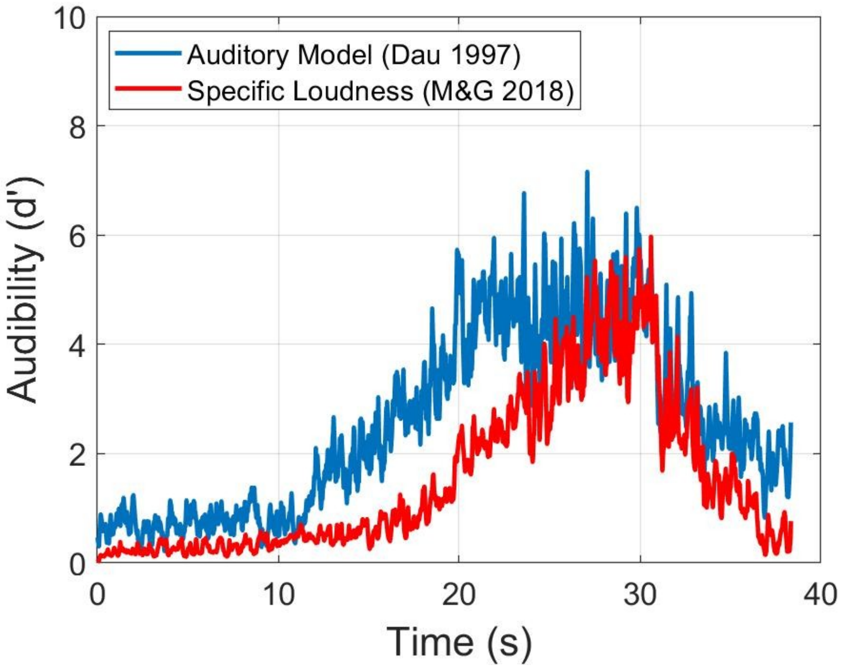
Formulating a New Audibility Algorithm

- A new audibility algorithm is under development based on models of loudness (SAP).
- This work started with Kyle Wendling (NIFS) 2018, and has been carried forward by Menachem Rafaelof.



Comparing Models of Audibility

- There are a number of existing audibility algorithms with various properties:
  - How much information do they need?
  - How hard are they to compute/how complex are they?
  - What data are they based on/where have they been used previously?
- Which audibility algorithm is best suited for use with UAM?
- This effort is being led by Matt.



“Discounting” the Predicted Annoyance

$$PA = N_5\left(1+\sqrt{w_S^2+w_{FR}^2}\right) - f\left(d'\right)$$

- Whatever audibility algorithm is used, the output will likely be a “detectability index” value, usually denoted as d’.
- How does this measure relate to the predicted annoyance?
  - Can we figure out, or at least constrain this relationship with information available in the literature?
- This is what has been keeping me up at night recently.

Final Thoughts

- The Human Response swimlane of the RVLT UAM TC is working to further the understanding of psychoacoustics in ways that will hopefully prove fruitful within the emerging UAM space.

- Although COVID-19 has significantly altered the particular things that were likely to get done, work is still pushing forward.
  - This may be a blessing in disguise: We should not expect to overturn anything found in decades of literature and lifetimes of experience of other researchers with data from 5 (or so) psychoacoustic tests. While we might not wind up with something that is explicitly based on UAM data, it's likely worth our time to build from a more firm foundation on what has already been done.

- We still don't have any (good) recordings of UAM vehicles…

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