A psychoacoustic test for urban air mobility vehicle sound quality

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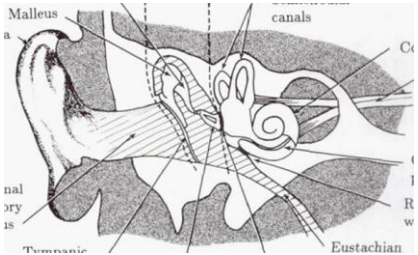
Motivation: A psychoacoustic test for urban air mobility vehicle sound quality

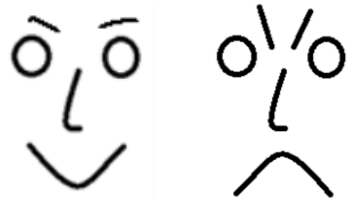
- NASA Urban Air Mobility (UAM) Reference Vehicles

https://sacd.larc.nasa.gov/uam-refs/

Outline

- UAM noise stimuli
  - Auralizations
  - Modifications
- Auditory System
  - Sound quality metrics
  - Lab test
- Outputs
  - Annoyance responses
  - Data analysis





Research questions:

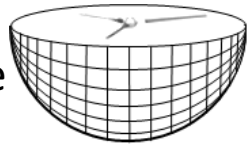
- Is loudness all that matters?
- Do other sound quality metrics affect annoyance?

UAM noise stimuli generation: Start with predictions

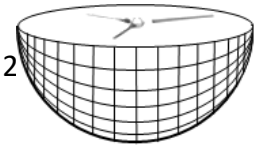
Blade geometry, blade passage frequency, flight condition

Blade loading, motion, inflow velocity, effective angle of attack [1]

Loading & thickness noise prediction[2]



Selfnoise prediction[2]



Generate auralization [3]

8 baseline stimuli

	Level cruise	5 degree descent
Blade passage frequency (Hz)	**20***	**20***
	15^	15^
	40^	40^
	80^	80^
*: original auralizations		
^: modified auralizations		

Tools:

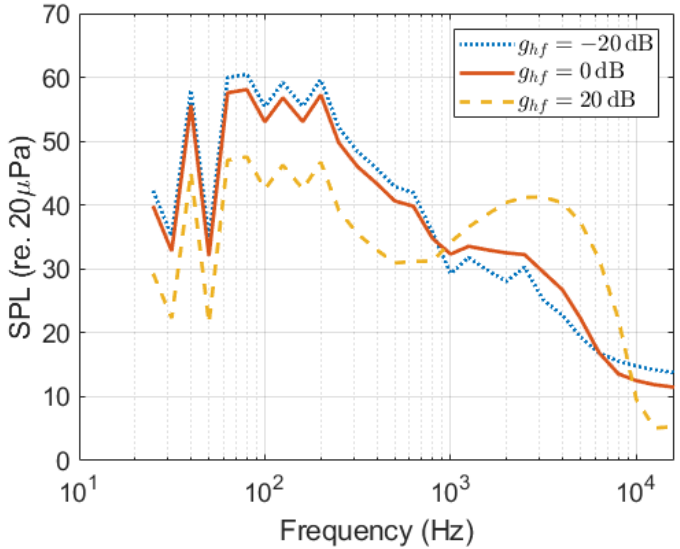
[1] CAMRAD II

[2] ANOPP2 (Formulation 1A and Self Noise)

[3] NASA Auralization Framework

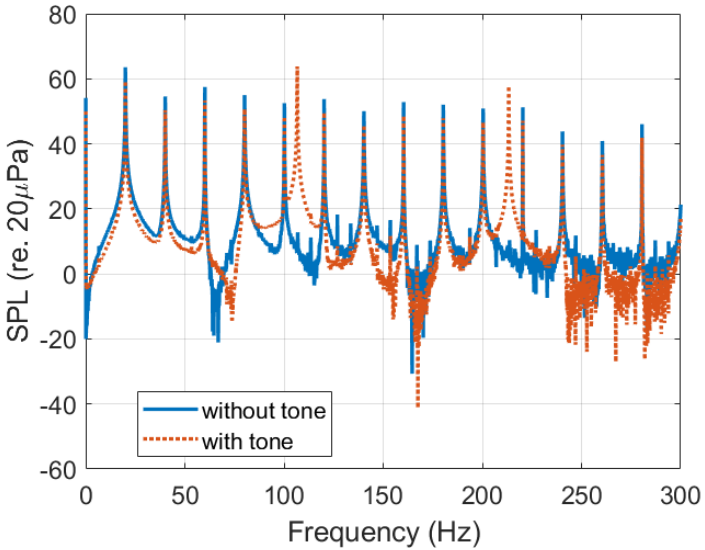
UAM noise stimuli: modifications of baselines

- Spectral weighting parameter, g_{hf}, to adjust sharpness



- Changes sharpness

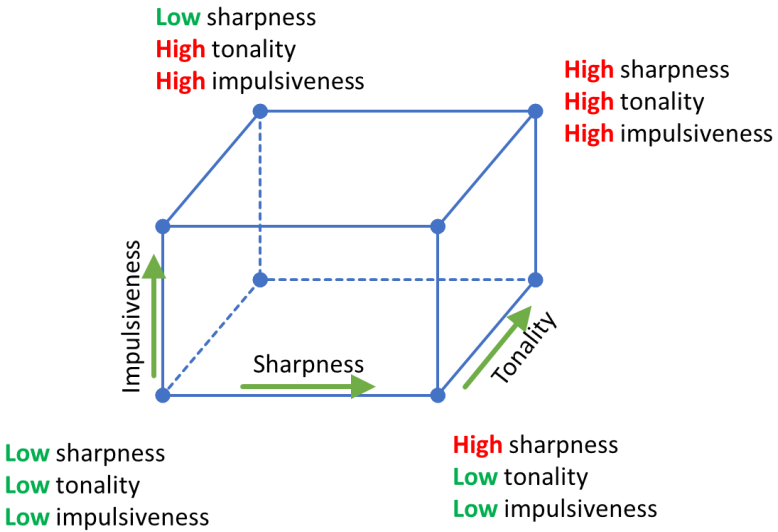
- Add a tone to increase tonality metric

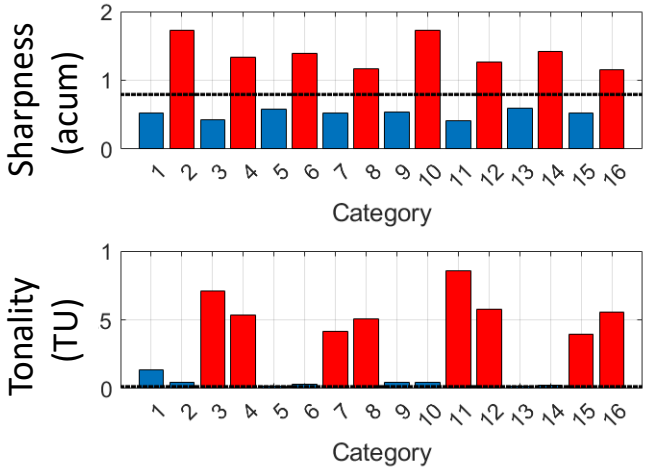


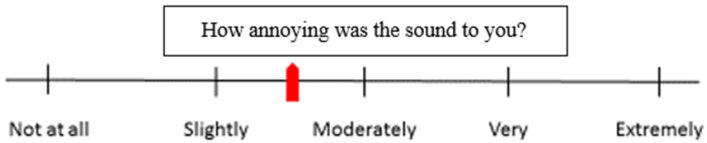
- Changes tonality

Psychoacoustic test: task 1

$$Annoyance = Loudness + f(S, T, I, FS, \ldots)$$







8 baselines x (1+16) = 136 UAM noise stimuli

Psychoacoustic test: task 2

$$Annoyance = Loudness + f(S, T, I, FS, \dots)$$

How does annoyance change with loudness?

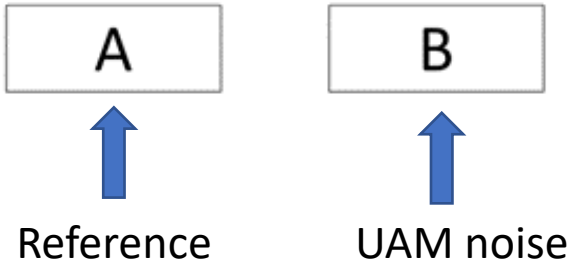
- 26 sounds UAM noise stimuli
- Vary loudness of reference sound

Reference sound

- Broadband selfnoise component of level cruise auralization (no impulsive/tonal loading & thickness noise)
- Then removed modulation from broadband

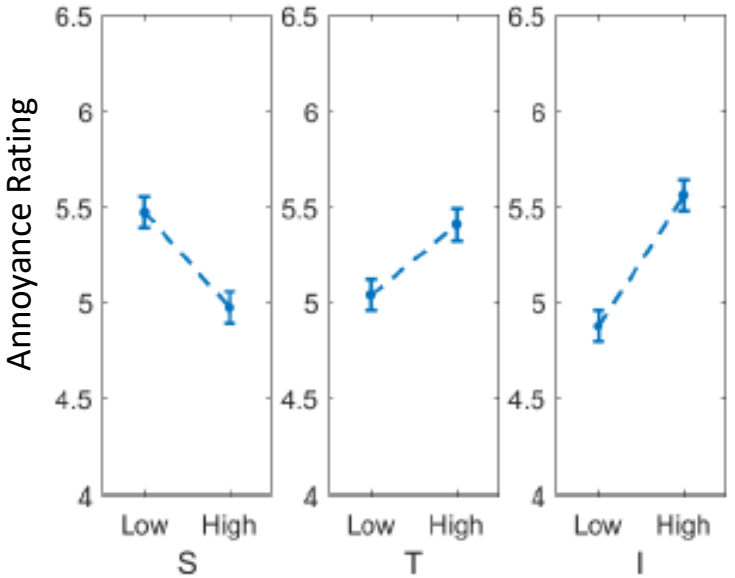
Paired comparisons:

Which sound was more annoying?



Results: ANOVA (sharpness, tonality, impulsiveness and fluctuation strength)

- Fluctuation strength was not a significant contributor
- Higher sharpness leads to lower annoyance (max sharpness was 1.8 acum)
- Higher tonality or impulsiveness leads to higher annoyance



Significant main effects contributing to annoyance, considering sharpness (S), tonality (T), impulsiveness (I) and fluctuation strength (F)

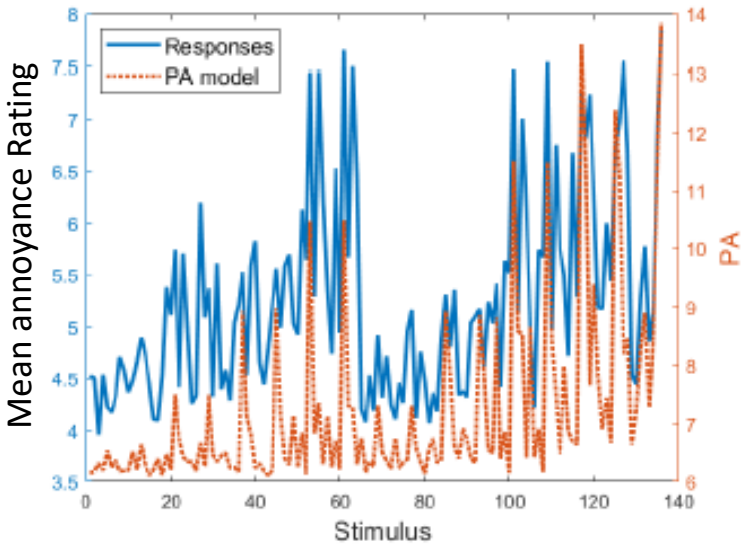
Results: Effect of roughness using Psychoacoustic Annoyance (PA)

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

- Annoyance responses correlate with Psychoacoustic Annoyance (Zwicker)

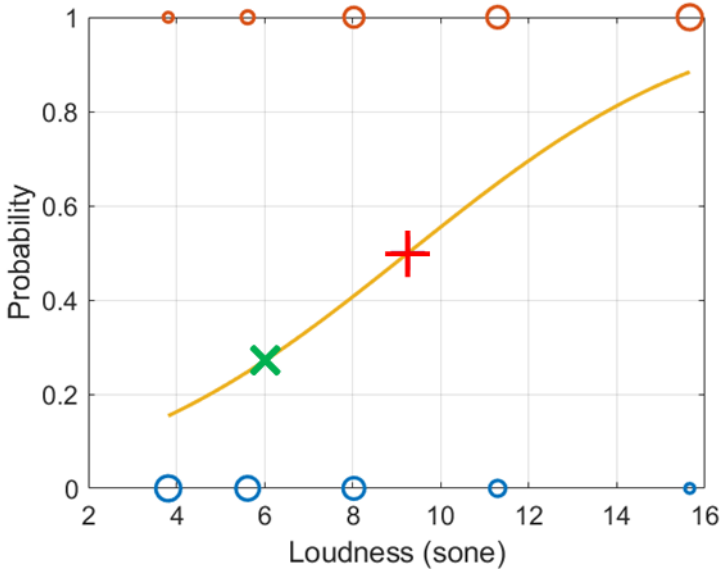
Loudness was 6 sones for all stimuli	N_5 not the cause
Sharpness < 1.8 acum	w_s not the cause
Fluctuation strength not significant	F not the cause

- Roughness was only contributor to correlation between PA and responses



Comparison between mean annoyance responses and Zwicker PA

Results: Equal annoyance point (EAP) for reference sound



Probability that the reference sound is more annoying than UAM noise stimuli. Larger circles indicate more responses.

×: UAM noise stimuli at 6 sones

+: Reference at 9 sones is equally annoying

- Difference in loudness is 3 sones (≈6dB) for reference to be equally annoying as UAM noise
- Why such a different response to the reference sound?
  - High sharpness
  - Low tonality
  - Low impulsiveness
  - Low roughness
- Annoyance differences due to sound quality can be similar to difference in 6dB

Summary

- Psychoacoustic test for annoyance to UAM vehicle noise
- Stimuli based on predictions, auralizations and modifications
- Annoyance rating and paired comparisons

Conclusions

- Tonality, impulsiveness and roughness: positive correlation with annoyance
- Sharpness: negative correlation with annoyance for S<1.8acum
- Differences in sound quality can have similar effect on annoyance as a change in 6dB

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