A Psychoacoustic Test on the Effect of Masking on Annoyance to Urban Air Mobility Vehicle Noise

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Outline

- Background
- Audibility and Annoyance
- Psychoacoustic Testing Approach
- Results

Urban Air Mobility and Noise

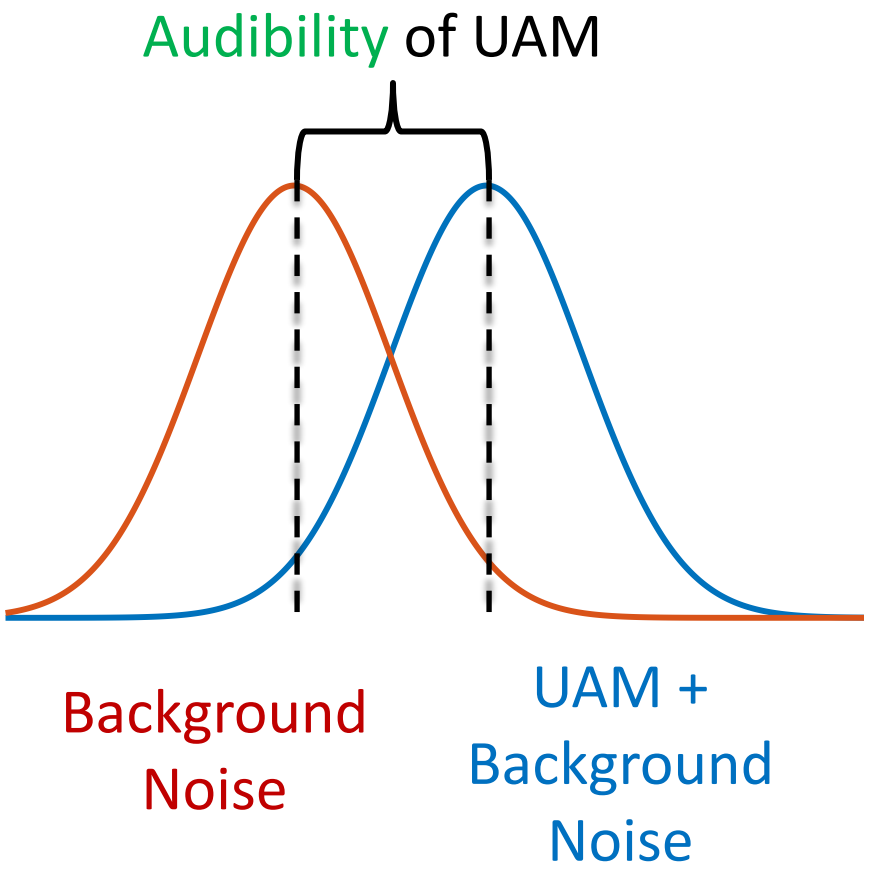
- Safe, efficient and accessible transportation for passengers and cargo [1]
- Noise concerns must be mitigated in communities where UAM operations take place [2]
- Models of annoyance to UAM noise are needed [3]

[1] Thipphavong et al., "Urban Air Mobility Integration Concepts and Considerations," 2018 Aviation Tech., Int., and Operations Conf., (2018)
[2] Hill et al., "UAM Vision Concept of Operations (ConOps) UAM Maturity Level (UML) 4'', NASA (2020)
[3] Rizzi et al., "Urban Air Mobility Noise: Current Practice, Gaps, and Recommendations," NASA/TP-2020-5007433 (2020).

Urban Air Mobility and Noise

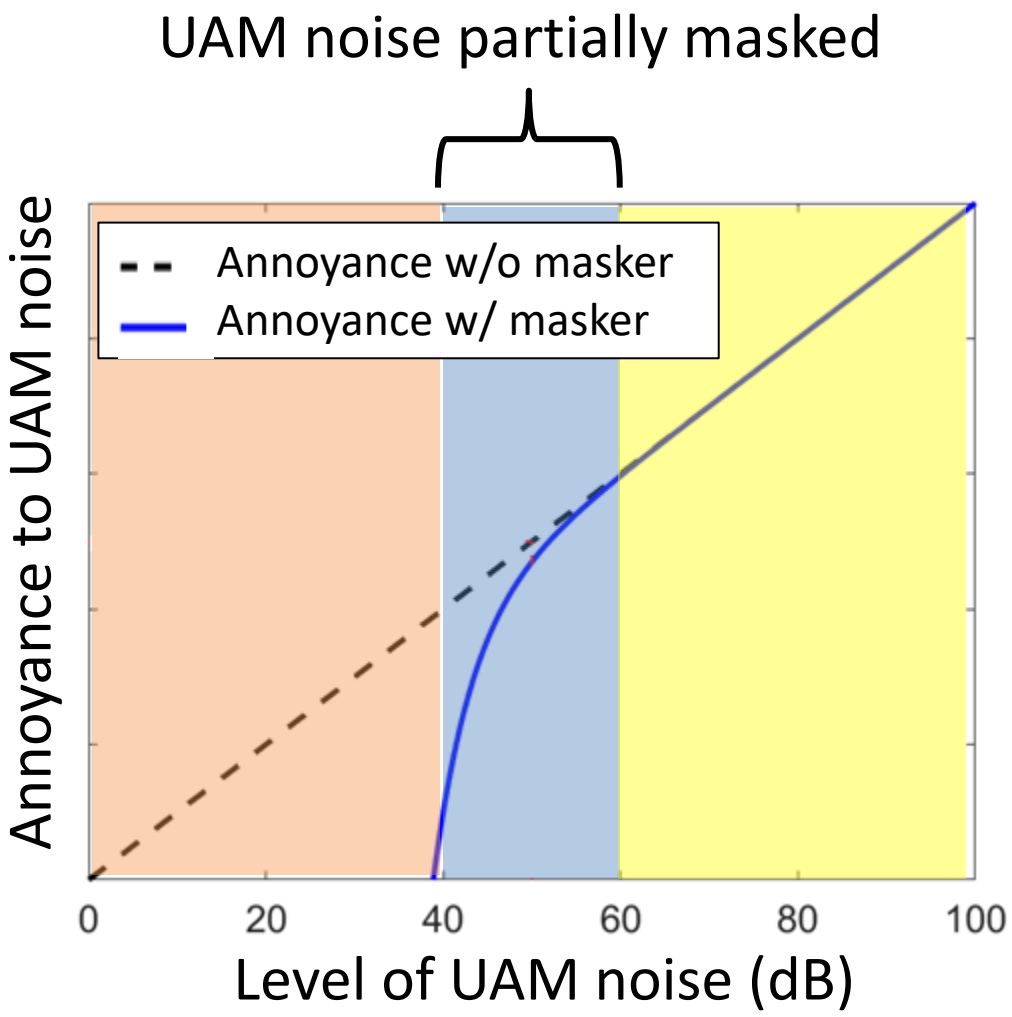
- Gap: Human response to UAM vehicle noise in the presence of background noise
  - Noisy city environment
  - Near existing transportation routes

- How does **audibility** affect annoyance?
  - Masking a UAM-like sound with background noise should reduce its annoyance



Hypothesis: Masking Reduces Annoyance [4]

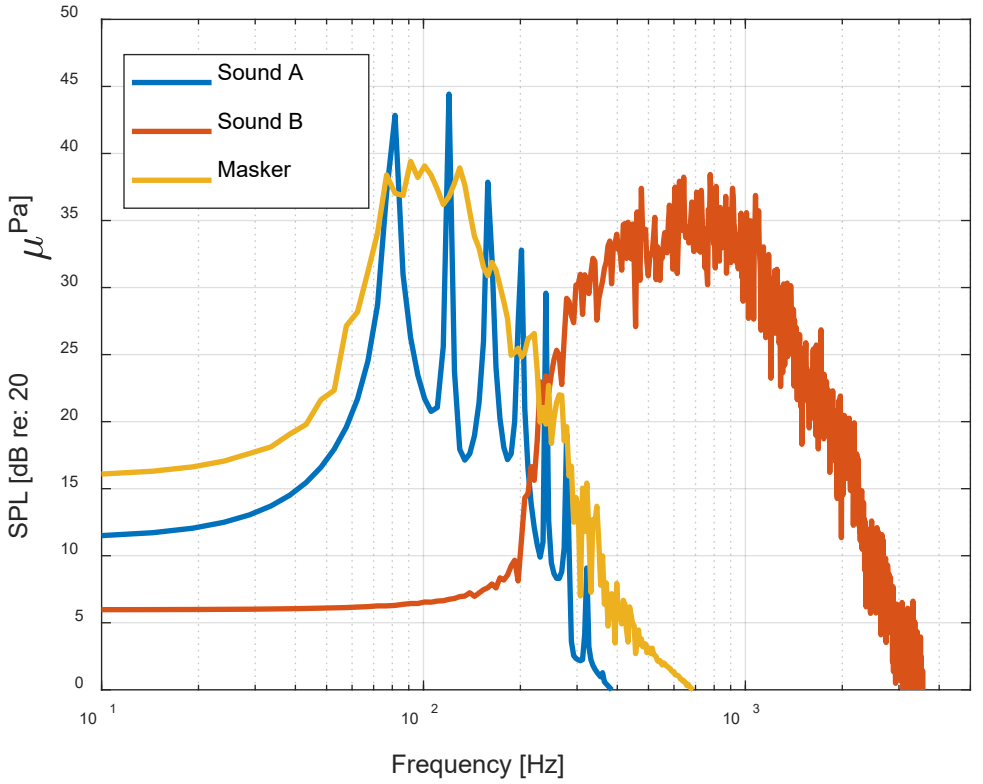
- High UAM noise level (rel. background):
  - Annoyance to UAM noise is predicted by UAM noise level
- Low UAM noise level (rel. background):
  - No annoyance to UAM noise
- UAM noise and background levels are similar:
  - Annoyance to UAM noise is lower than predicted by UAM noise level alone
  - Masking reduces annoyance



[4] Christian, "The effect of background noise on human response," NATO/STO-TR-AVT-314.

UAM-like sounds used in psychoacoustic test

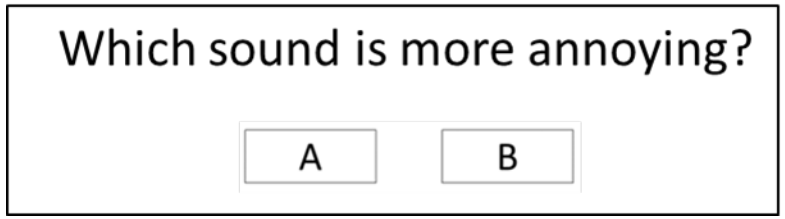
- Sound A
  - Harmonic tone complex (80-320 Hz)
  - Similar to rotor loading and thickness noise
- Sound B
  - Shaped broadband noise (300-2000 Hz)
  - Similar to rotor self noise
- Masker
  - Designed to mask Sound A
  - Equal amount of masking in 1/3 octave bands [5]

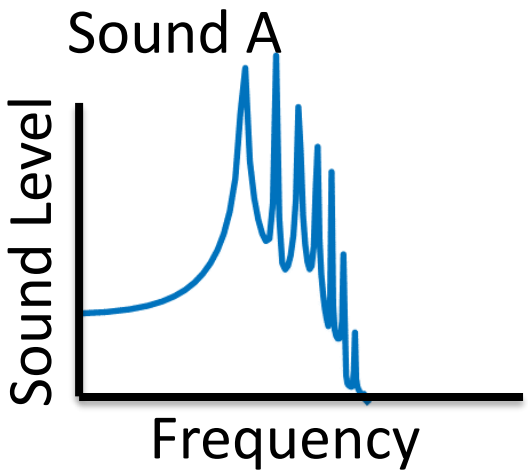


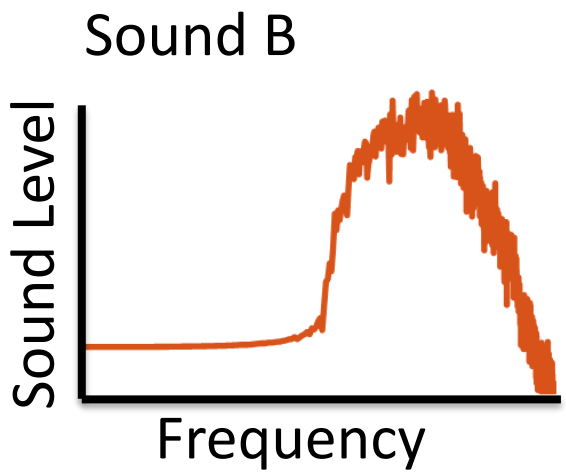
How is annoyance to Sound A reduced by masking?

[5] Sneddon et al., "Laboratory study of the noticeability and annoyance of low signal-to-noise ratios sounds" NCEJ, 51 (5), 2003.

At what levels are Sound A and B equally annoying?

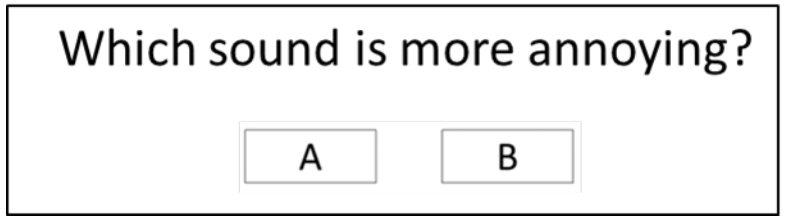


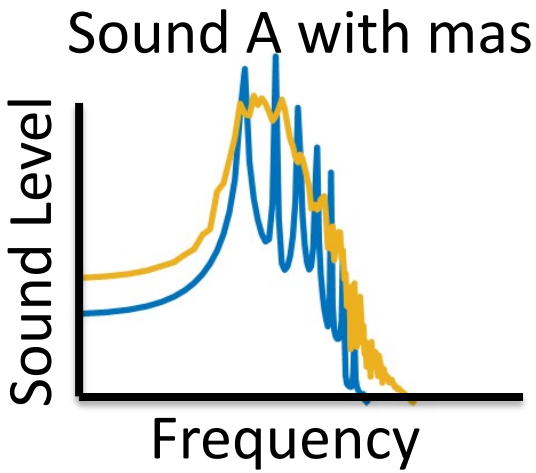


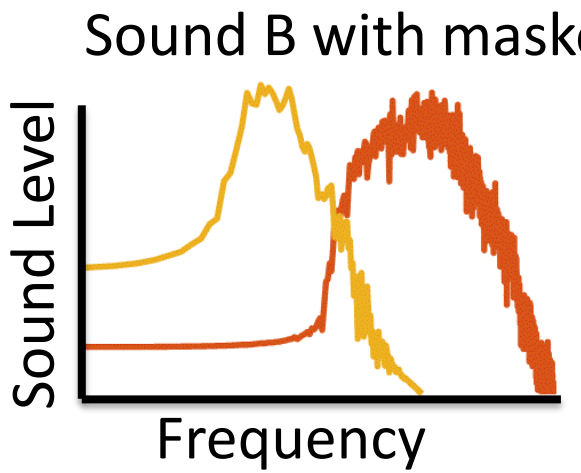


- At what relative level is Sound A equally annoying to Sound B without the masker?
- This gives an unmasked Equal Annoyance Point
  - Relative difference in level where Sounds A and B are equally annoying

At what levels are Sound A and B equally annoying?

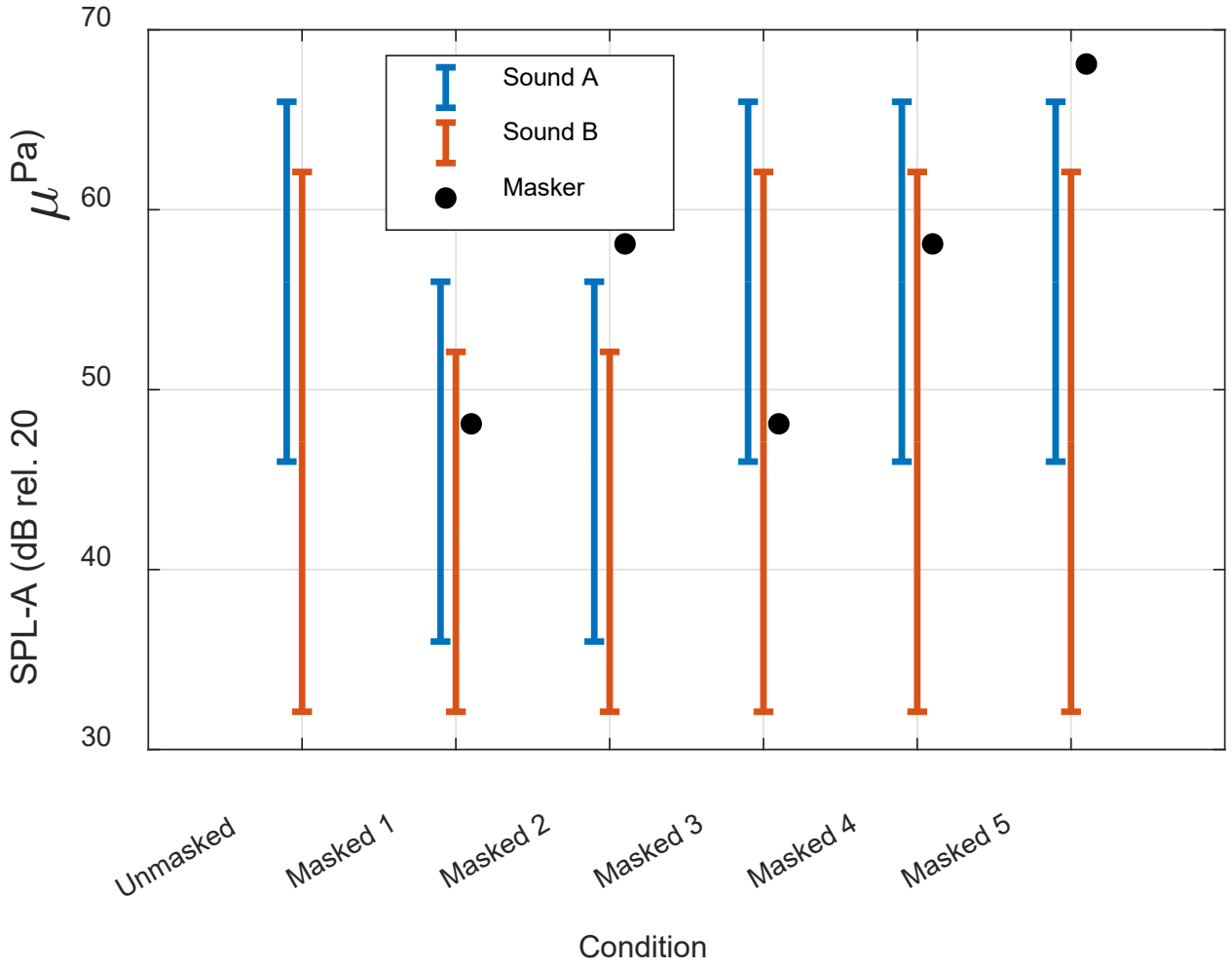






- At what relative level is Sound A equally annoying to Sound B with the masker?
- This gives a masked Equal Annoyance Point
- Two possible results:
  1. Unmasked EAP = Masked EAP (masking does not affect annoyance)
  2. Unmasked EAP ≠ Masked EAP (masking affects annoyance)

Conditions Tested

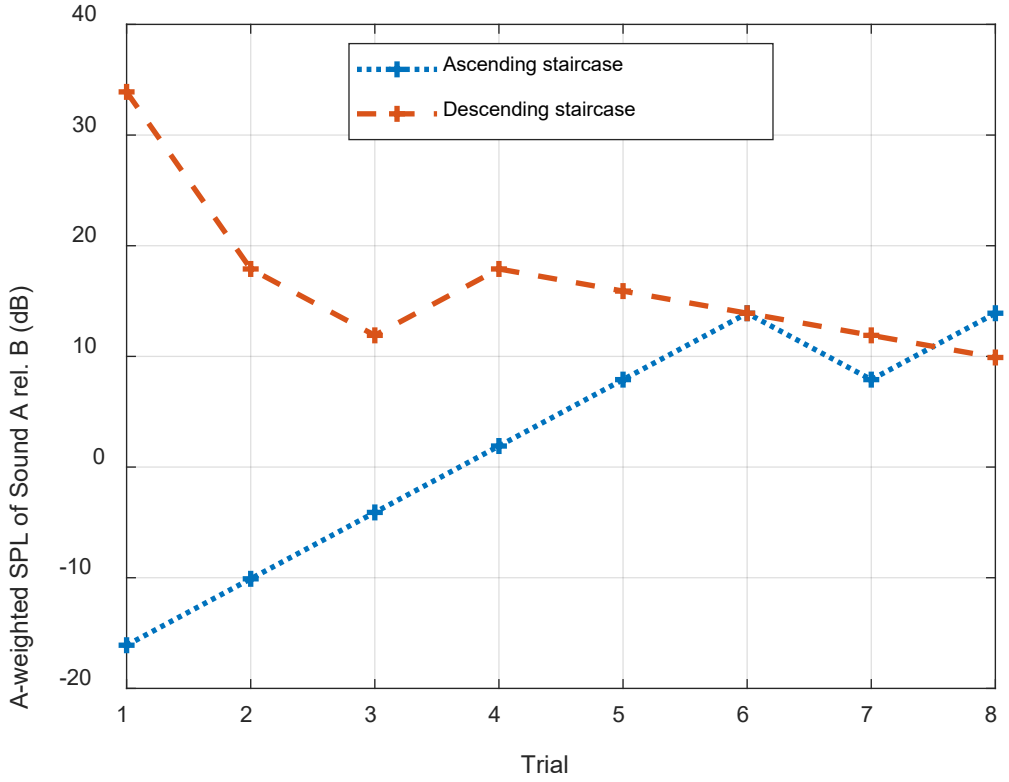


- Unmasked : Compare Sound A to Sound B
- Masked 1-5: Compare Sound A to Sound B

- Two ranges of Sound A and B: low and high
- Three levels of Masker: low, medium and high

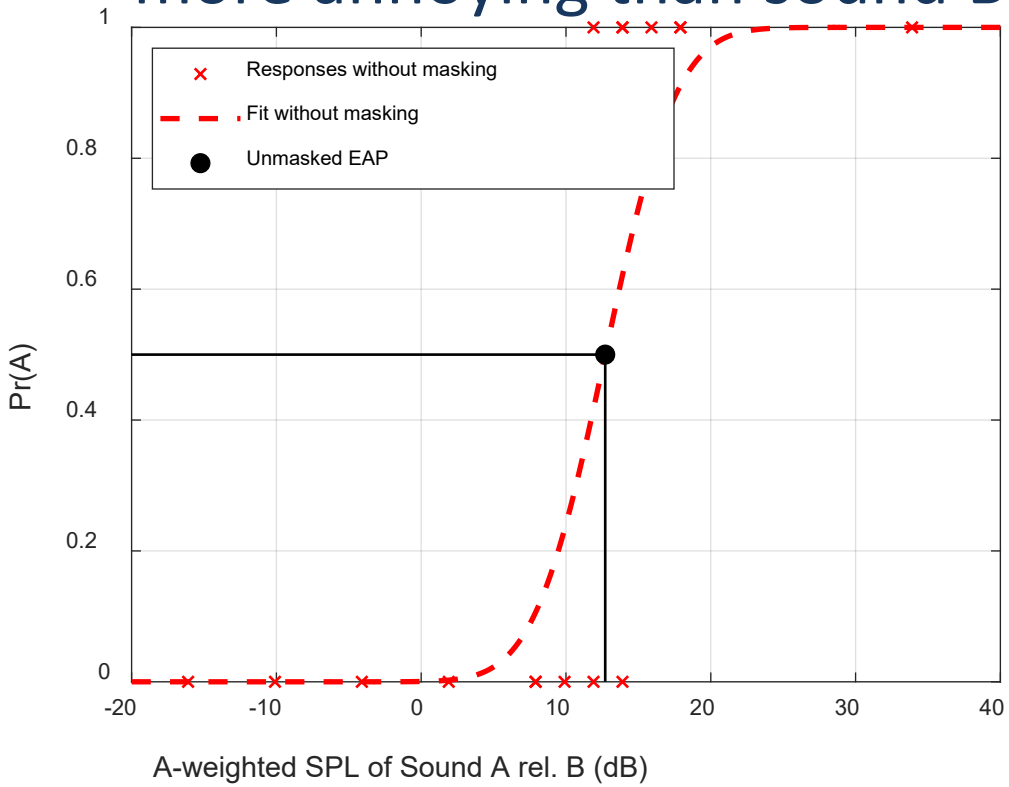
Finding Equal Annoyance Point

Unmasked



Unmasked Equal Annoyance Point
≈ 10-15 dB

Pr(A): probability sound A is more annoying than sound B



Logistic regression is more accurate:
Unmasked Equal Annoyance Point = 12.7 dB

Shift in EAP with Masker at 48.1 dB

- Shift in EAP =

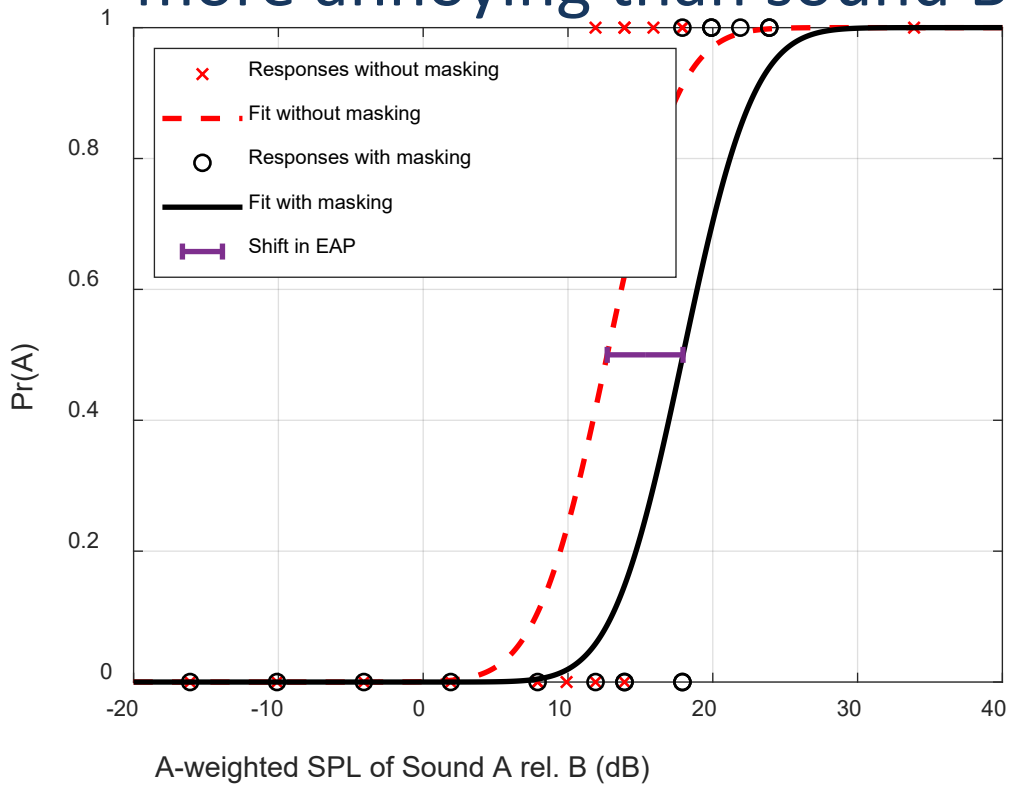
Masked EAP – Unmasked EAP = 5.2 dB

- Meaning: level of Sound A should be increased by 5.2dB (rel. to unmasked case) to remain equally annoying to Sound B

Shift in EAP > 0 ➡ Masking reduces annoyance

- Indication: Some masking reduces annoyance to Sound A

Pr(A): probability sound A is more annoying than sound B



Unmasked Equal Annoyance Point = 12.7 dB

Masked Equal Annoyance Point = 17.9 dB

Shift in EAP with Masker at 58.1 dB

- Shift in EAP =

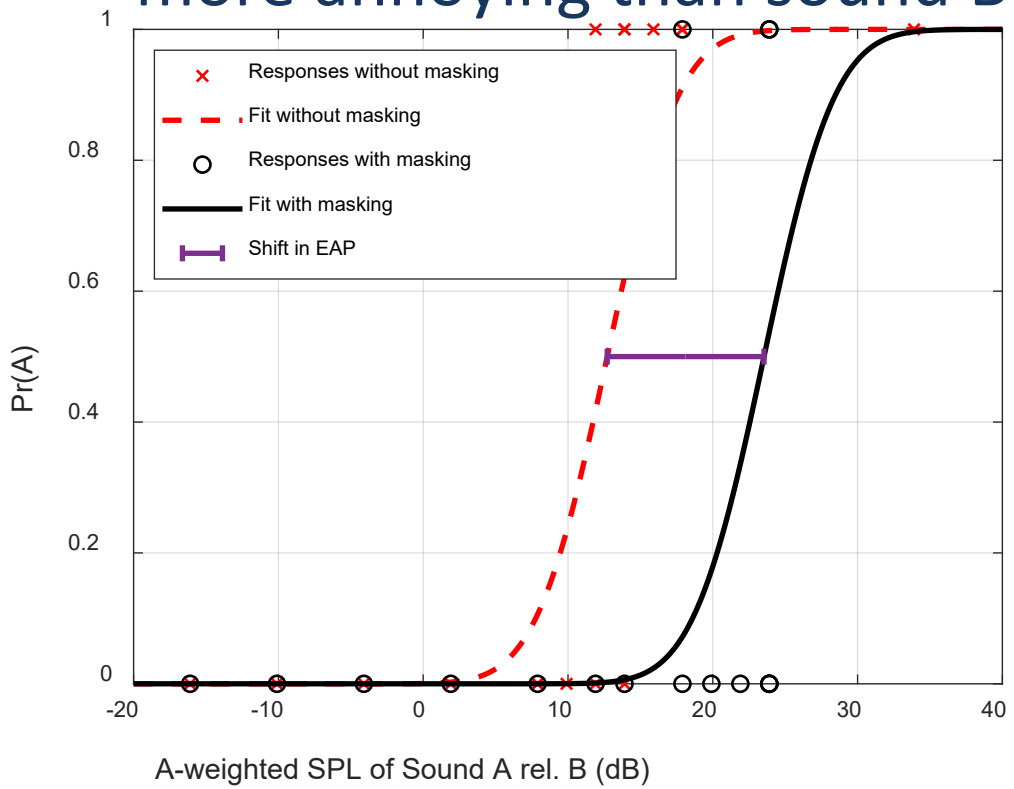
Masked EAP – Unmasked EAP = 10.8 dB

- Meaning: level of Sound A should be increased by 10.8 dB (rel. to unmasked case) to remain equally annoying to Sound B

Shift in EAP > 0 ➡ Masking reduces annoyance

- Indication: More masking further reduces annoyance to Sound A

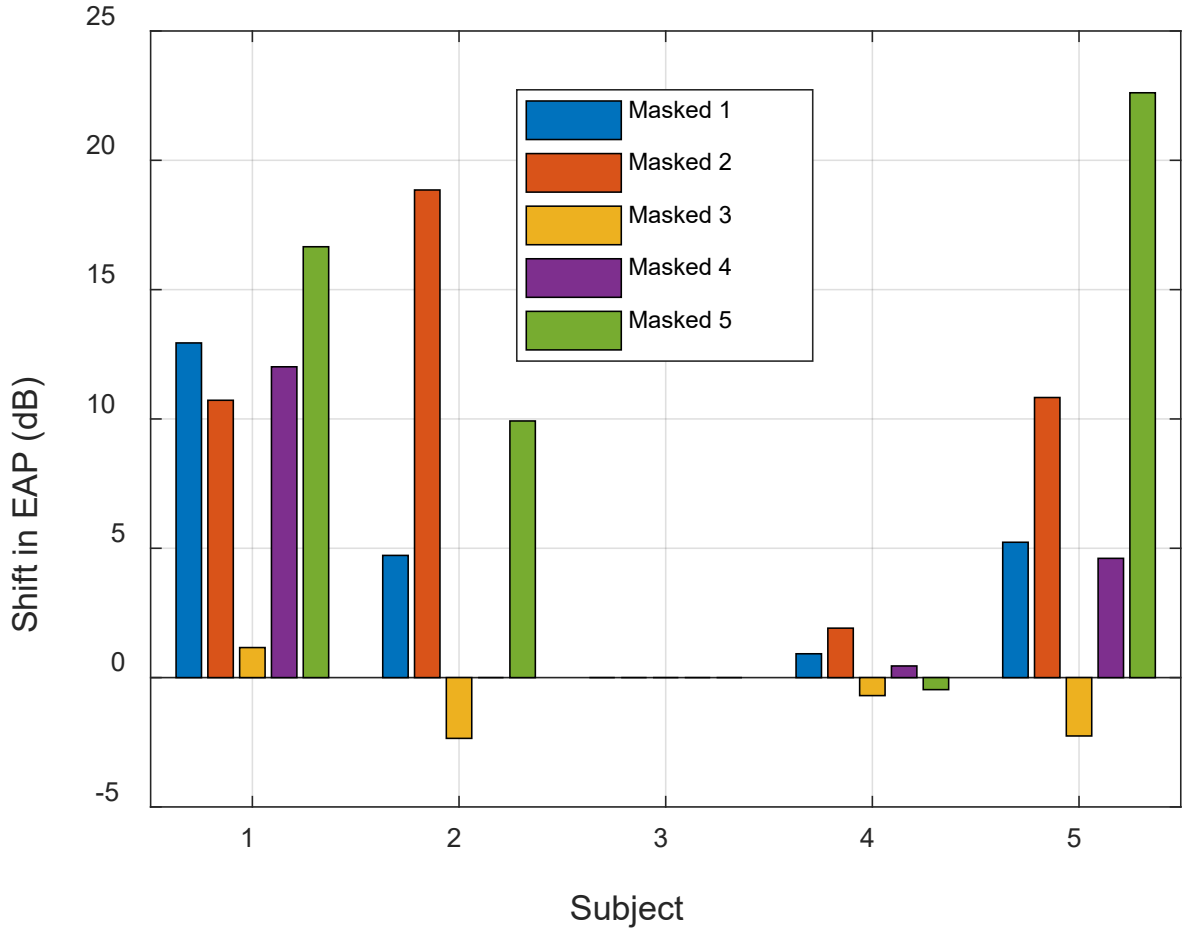
Pr(A): probability sound A is more annoying than sound B



Unmasked Equal Annoyance Point = 12.7 dB

Masked Equal Annoyance Point = 23.5 dB

Summary for 5 test subjects



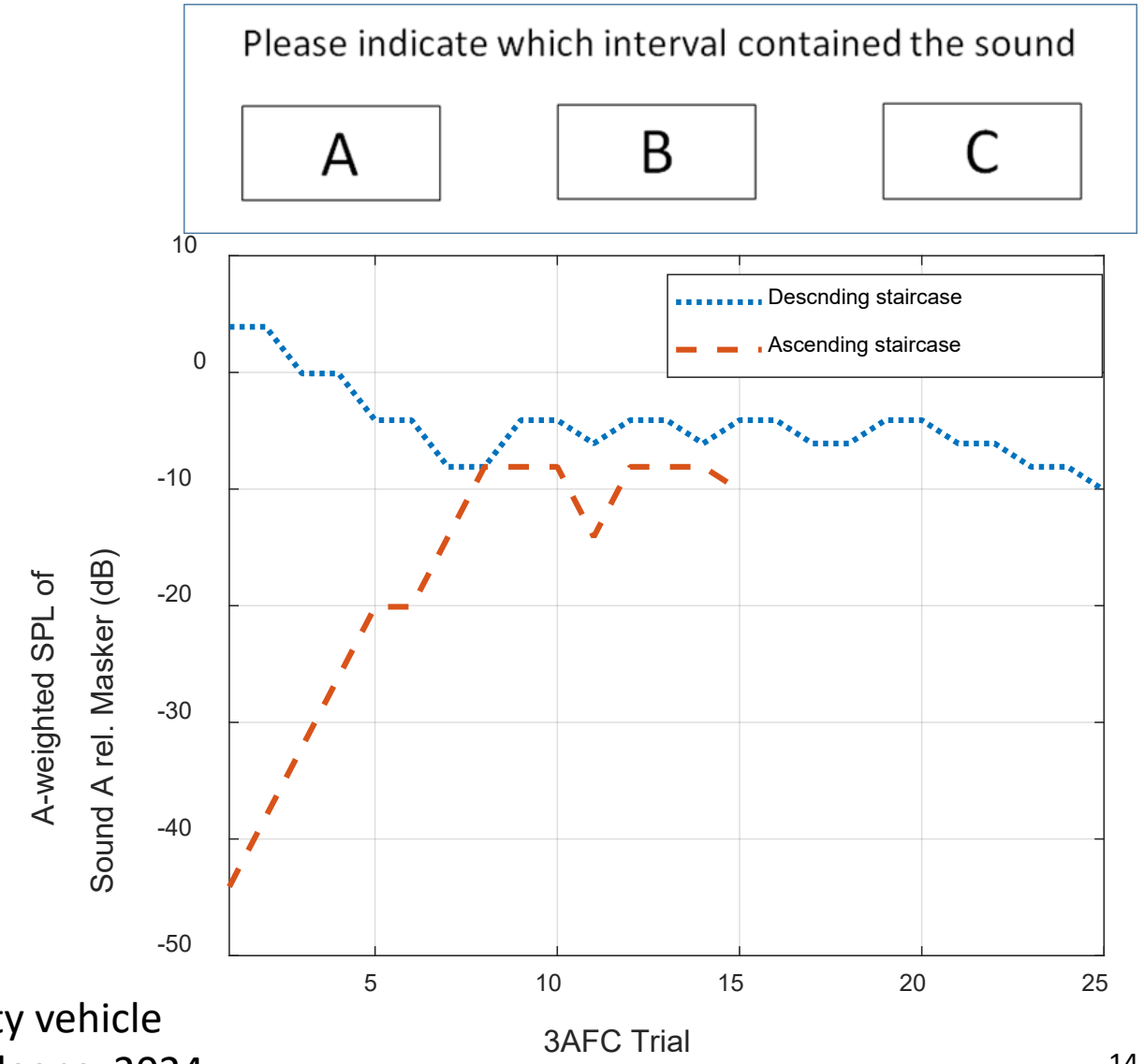
Subject	1	2	3	4	5
Average EAP shift (dB)	10.7	6.2	0.0	0.4	8.2

Shift in EAP > 0 ➡ Masking reduces annoyance

- Masking reduces annoyance for 3 of 5 subjects
- Larger effect when A and B are at low levels
  - More masking in Masked 1 and 2 conditions

Path to model the shift in EAP [6]

- Measured audibility thresholds for each subject (d')
  - 3 Alternative Forced Choice adaptive staircase
- Extrapolate audibility thresholds to determine d' at other relative levels
- Measured other Equal Annoyance Points (A vs. M and B vs. M)
- Modeling the shift is focus of upcoming NoiseCon talk/paper by Tyler Tracy



[6] Tracy, T. et al., "An annoyance model for urban air mobility vehicle noise in the presence of a masker," Noise-Con 2024, New Orleans, 2024.

Conclusions

- Shifts in Equal Annoyance Points (with and without masker) indicate that masking does have an effect on annoyance
- Increase in masking reduces annoyance
- Further psychoacoustic testing is necessary to extrapolate results to wider population
- Other conferences later this year:
  - Functional form of reduction in annoyance due to masking at NoiseCon 2024 (Tyler Tracy)
  - Applications to UAM operations at Aeroacoustics 2024 (Steve Rizzi)

[7] Rizzi, S.A., Christian, A.W., Letica, S.J., and Lympany, S.V., "Annoyance model assessments of urban air mobility operations," 30th AIAA/CEAS Aeroacoustics Conference, AIAA-2024-3018, Rome, Italy, 2024..

Thank You

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Questions?

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- *Advanced Air Mobility Noise: Predictions, Measurements, and Perception*
- Potential topics
  - Theoretical, numerical, or empirical predictions of noise characteristics
  - Measurement of noise sources (components up to full vehicle)
  - Human perception or psychoacoustic testing, Auralization techniques
  - Aspects of noise certification, Passenger comfort **and others**

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