



A perceptual evaluation of the efficacy of Sound Exposure Level in the rating of annoyance to helicopter noise

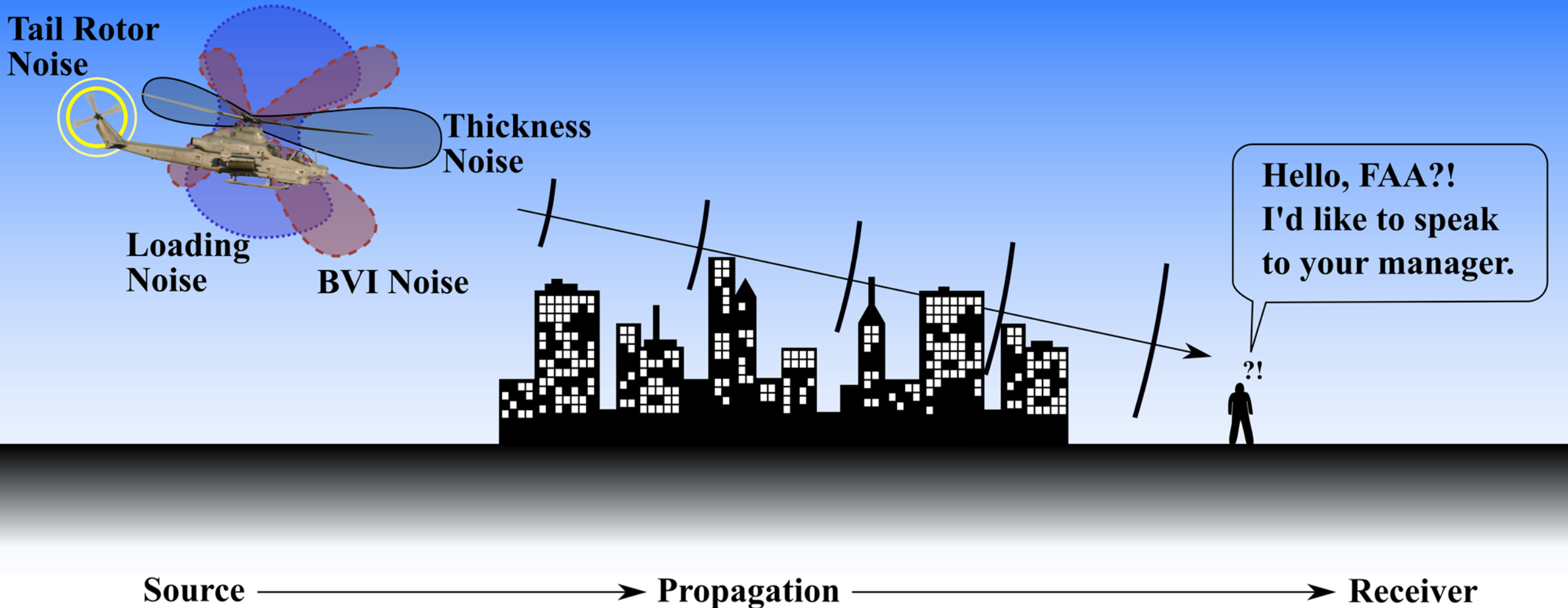
Matthew Boucher, NASA Langley Research Center, Structural Acoustics Branch

Andrew Christian, NASA Langley Research Center, Structural Acoustics Branch

Siddhartha Krishnamurthy, NASA Langley Research Center, Structural Acoustics Branch




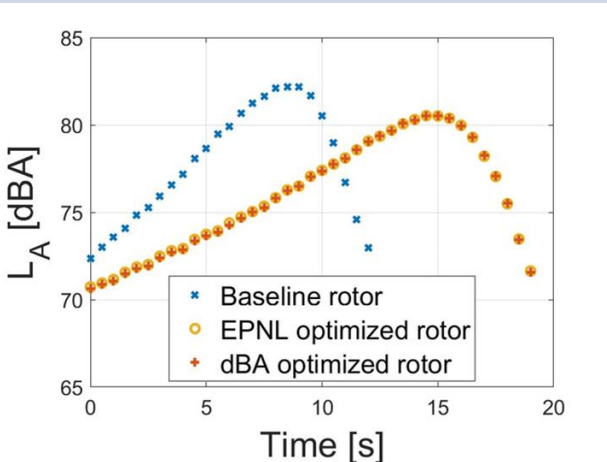



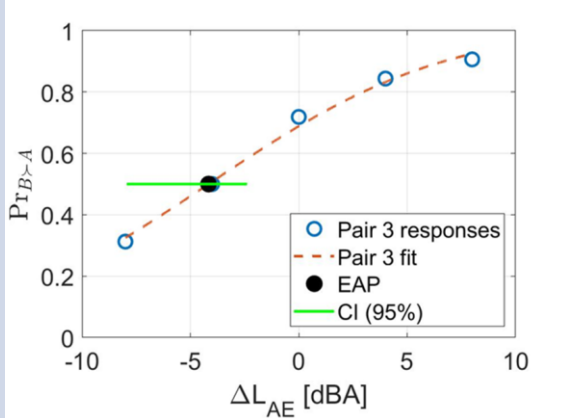
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A perceptual evaluation of the efficacy of Sound Exposure Level in the rating of annoyance to helicopter noise



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Sound stimuli	Adjust stimuli to have equal SEL	Playback in Exterior Effects Room (NASA LaRC)	Gather annoyance responses	Analyze efficacy of SEL
  	<p>Portion of A-weighted SPL within 10dB of peak used for certification</p> 	<p>31 loudspeakers in a quiet room Included flight paths</p>  <p>Paired comparisons Adjust relative SEL</p>	 	 <p> <input checked="" type="checkbox"/> Binomial test passes <input checked="" type="checkbox"/> CI (95%) contains 0dB relative level </p>



Pair	Type	Sound A	Sound B
1	Auralization	AS350 baseline MR	AS350 SEL-optimized MR
2	Auralization	AS350 baseline MR	AS350 EPNL-optimized MR
3	Recording	AS350 low-noise approach	EC130 low-noise approach
4	Recording	AS350 mostly constant sound character	AS350 varying sound character

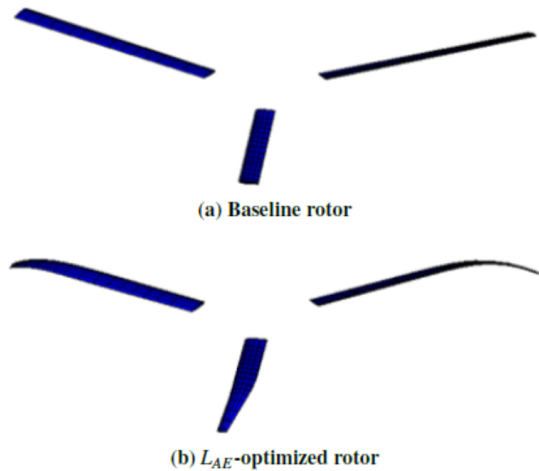
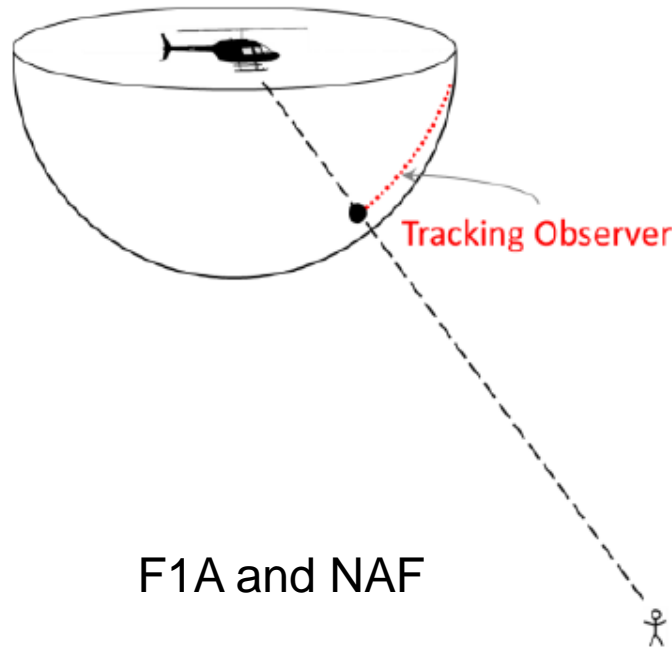
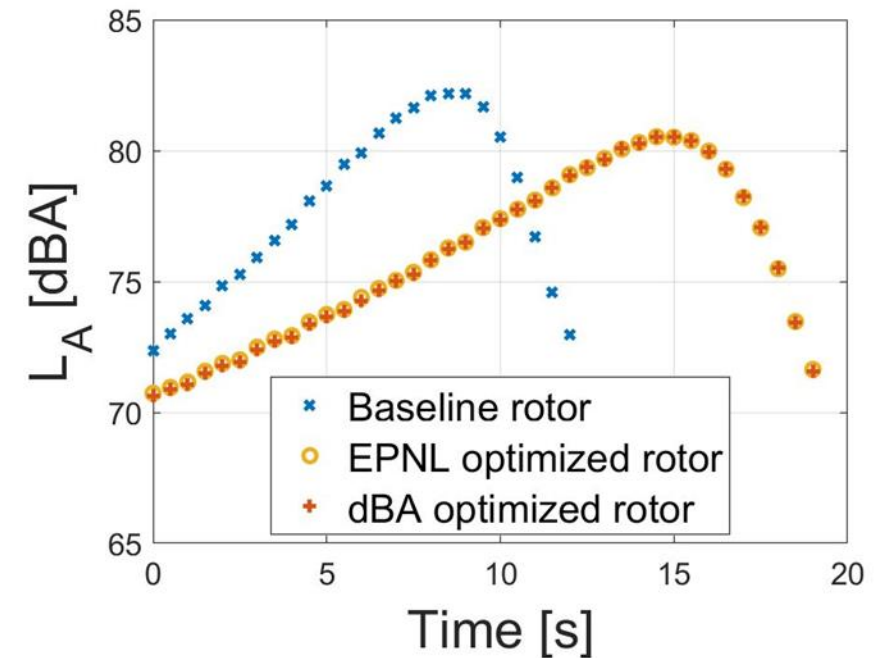


Figure 1: Main rotor geometries used for auralizations (EPNL-optimized rotor not shown).

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F1A and NAF





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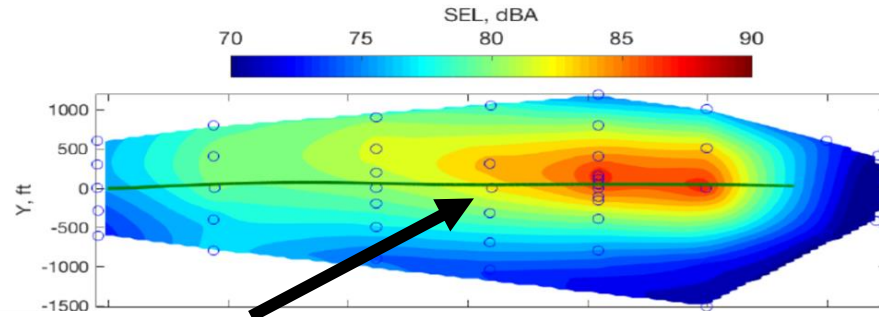


Figure 971: AS350B3, A45, run 291294 A-Weighted SEL contour.

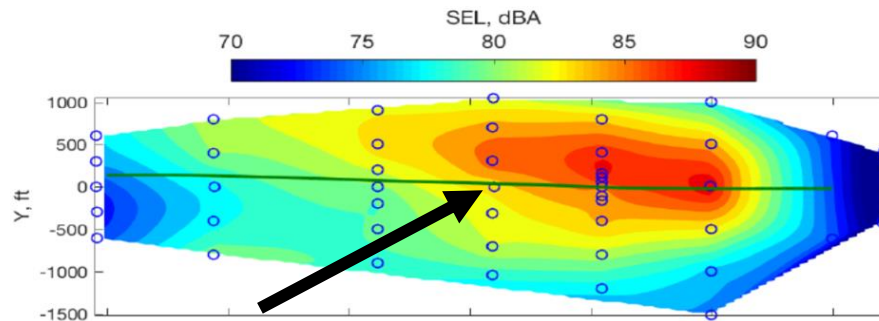
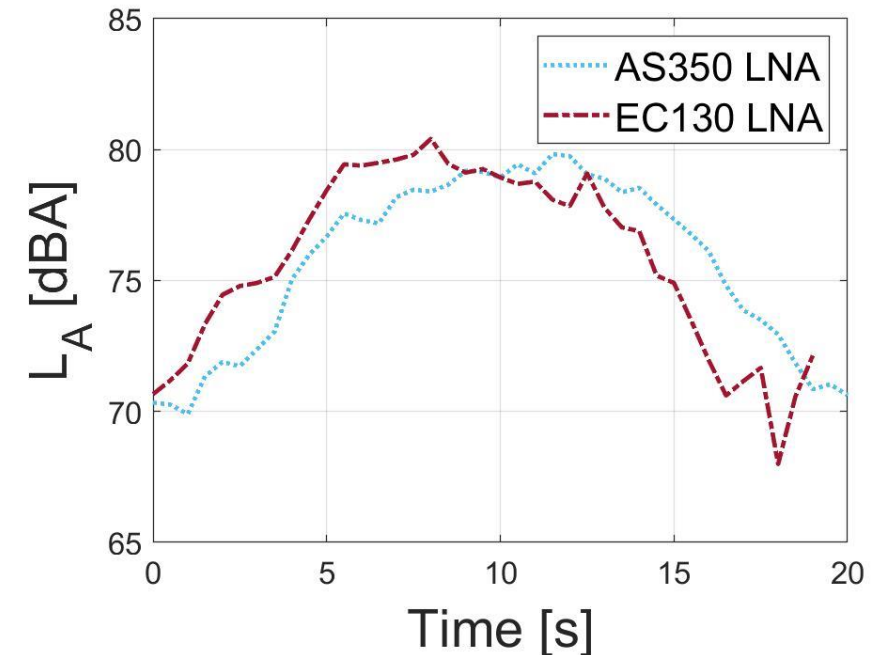


Figure 1181: EC130B4, A45, run 298280 A-Weighted SEL contour.





Pair	Type	Sound A	Sound B
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4	Recording	AS350 mostly constant sound character	AS350 varying sound character

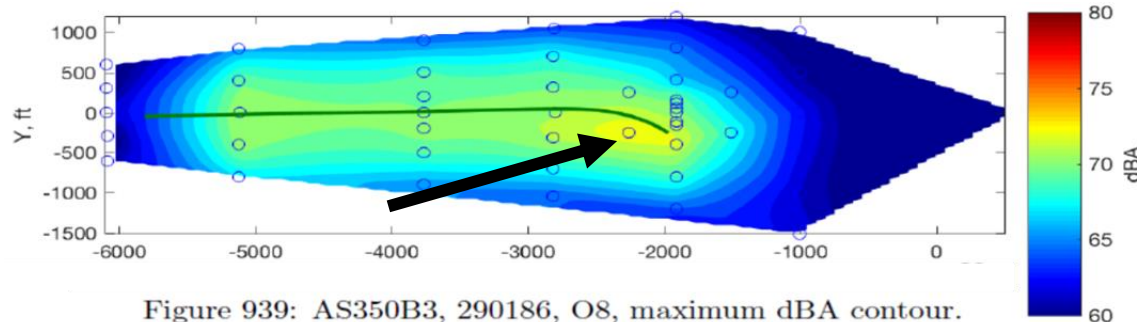


Figure 939: AS350B3, 290186, O8, maximum dBA contour.

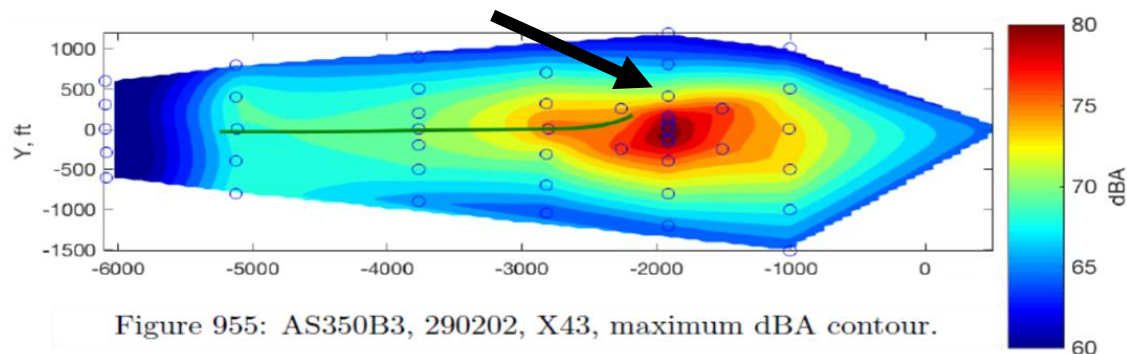
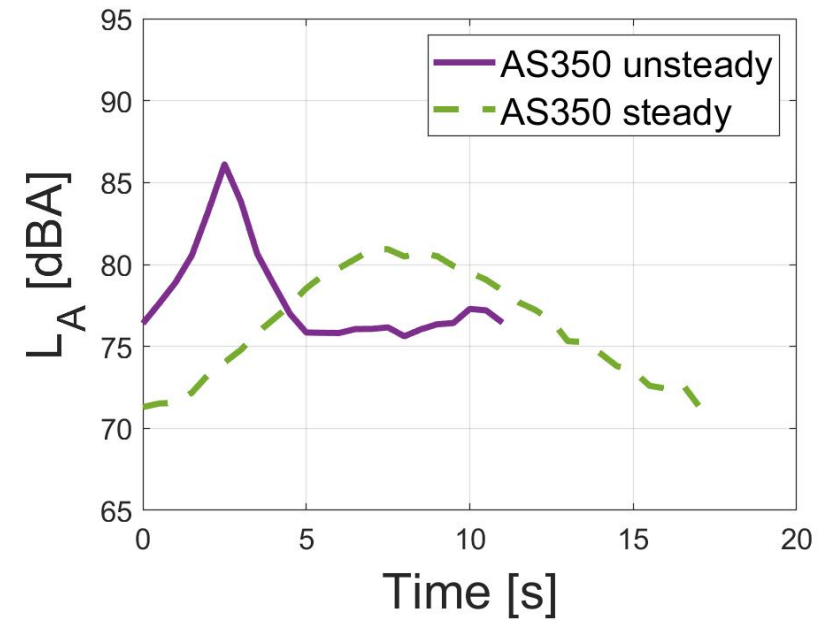
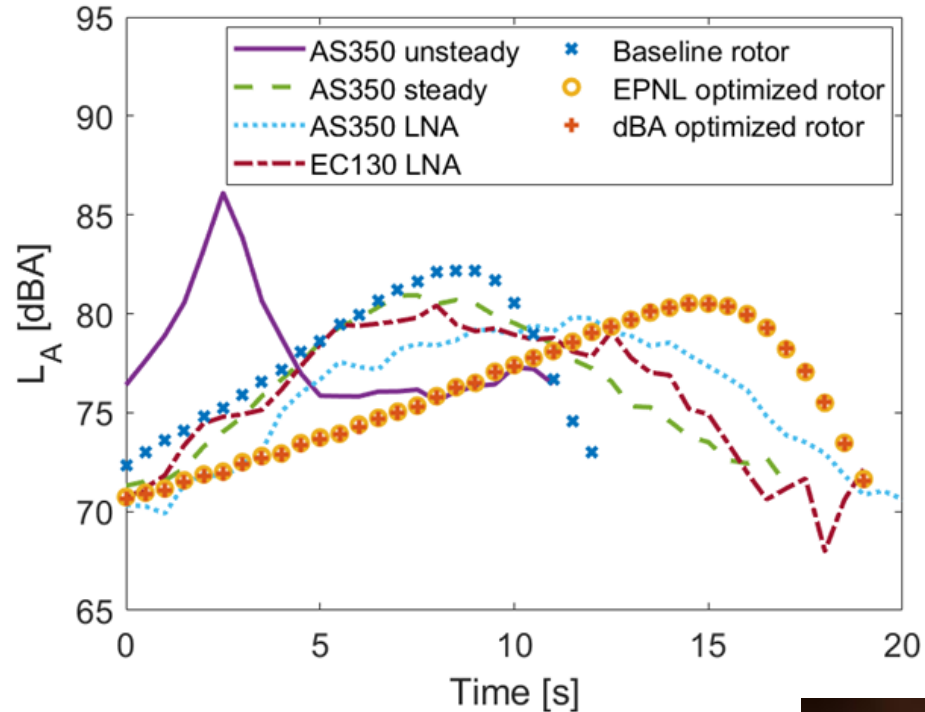


Figure 955: AS350B3, 290202, X43, maximum dBA contour.





- Auralizations and flight test recordings
- Portion within 10dB of peak
- Equalized w.r.t SEL
- Gain SEL up or down

Research Questions

Efficacy of SEL

- For main rotor designed for low noise? EAP*?
- For recordings of different helicopters flying similar flight paths? EAP*?
- For the same helicopter flying different maneuvers? EAP*?
- Faster way to perform psychoacoustic test instead of full flyovers? (see paper)

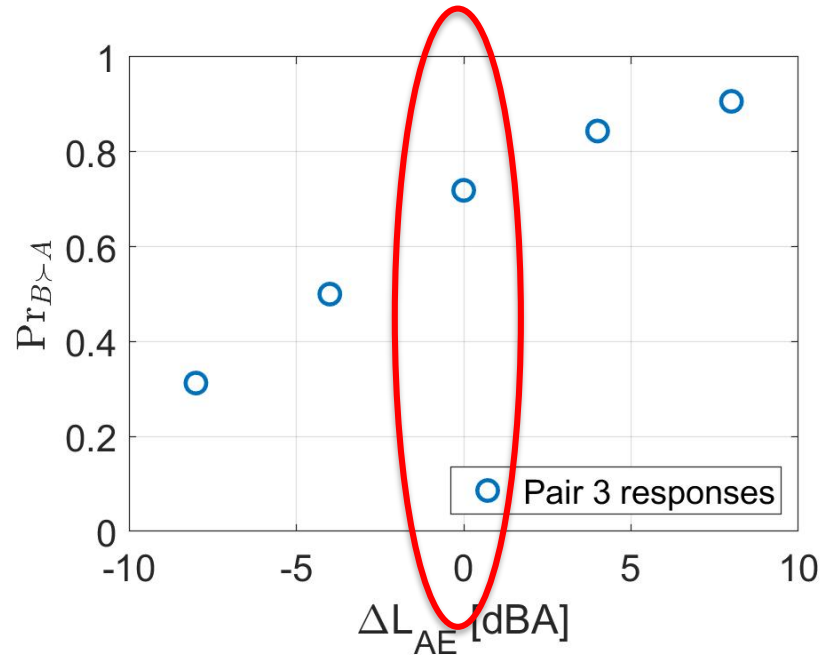
*EAP: Equal Annoyance Point

- Playback in Exterior Effects Room at NASA LaRC
- 16 subjects, 4 at a time
- Paired comparisons
- Sound A or B is more annoying?



Binomial test:

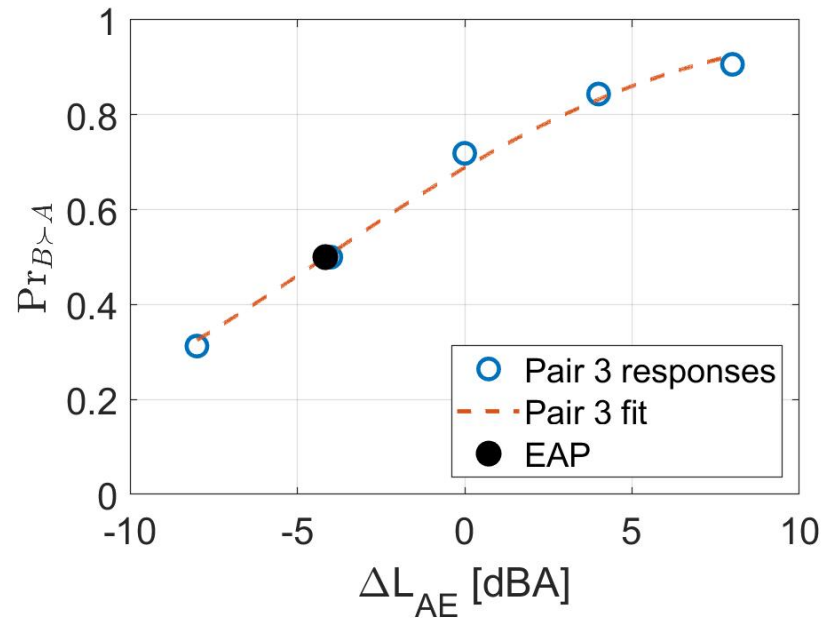
- Raw responses at 0dB rel. level
- Can annoyance responses be explained by a coin flip?



Are responses due to chance or is there something that SEL does not capture?

Logistic regression:

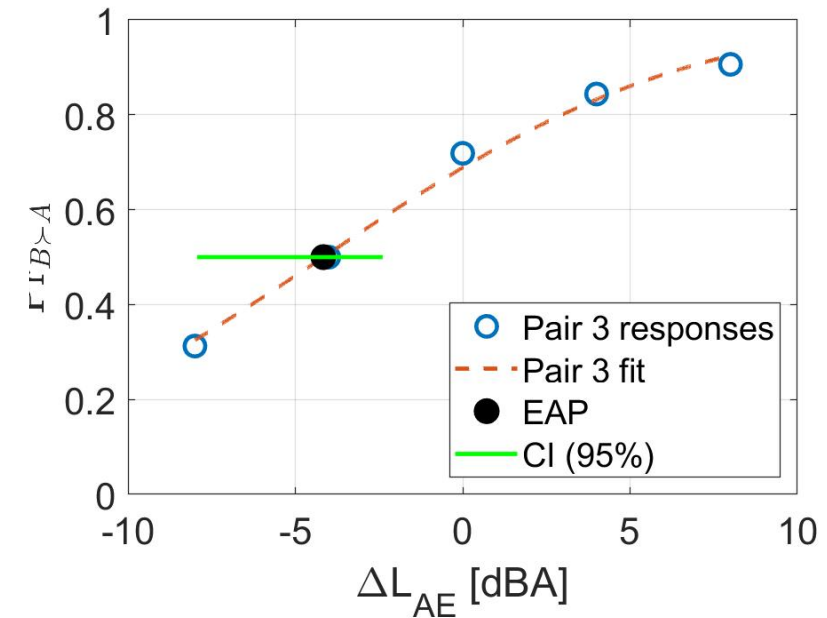
- Fit an S-curve (logit)
- $Pr=0.5$ gives the equal annoyance point (EAP)



What change in level of Sound B w.r.t Sound A makes the sounds equally annoying?

Markov Chain Monte Carlo:

- Most likely values of the EAP
- Gives a confidence interval on the EAP

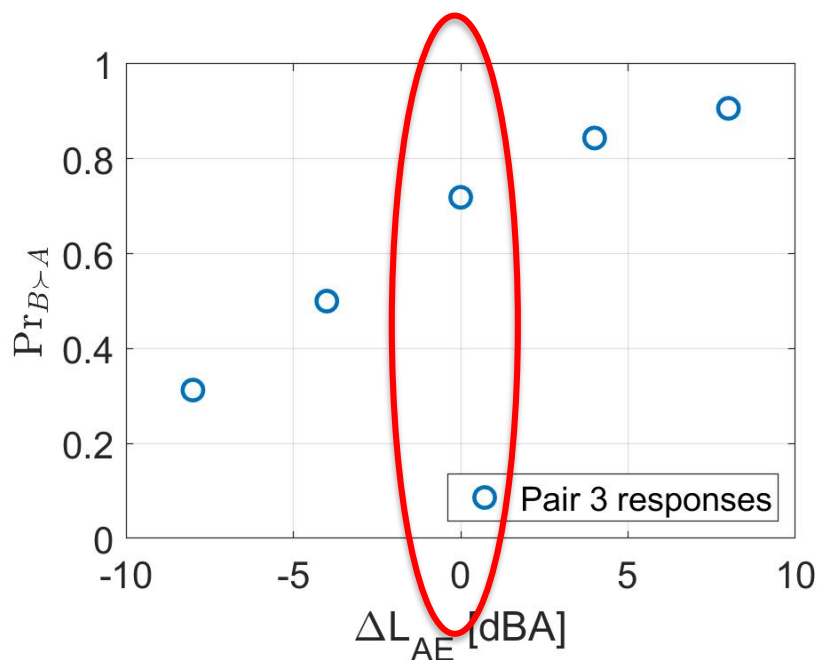


Is 0dB relative level included in interval of likely Equal Annoyance Points?

Analysis Techniques: Evaluation of efficacy of SEL

Binomial test:

- Raw responses at 0dB rel. level
- Can annoyance responses be explained by a coin flip?

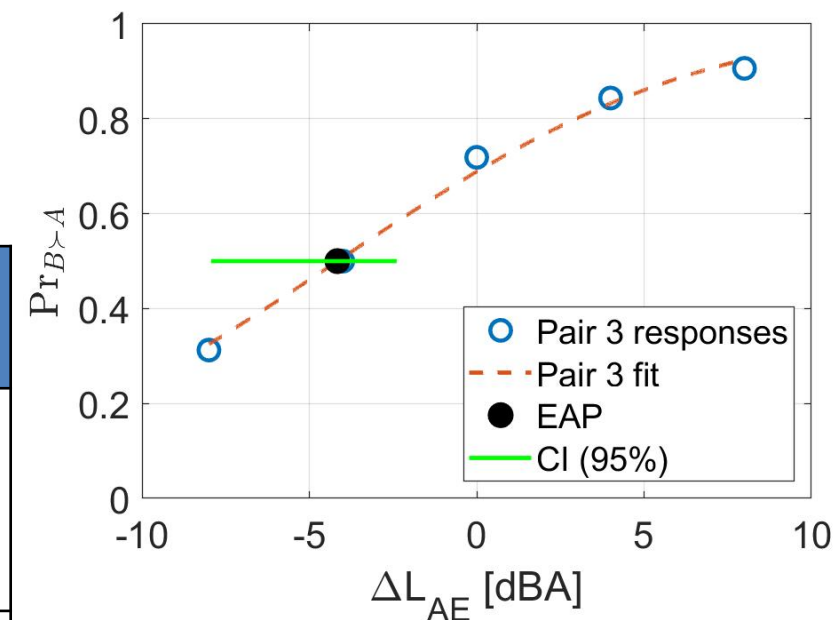


- Binomial test passes
- Binomial test fails

Efficacy of SEL	Conclusion
<input checked="" type="checkbox"/>	No aspects of sound found that affect annoyance outside SEL
<input type="checkbox"/>	Some aspects of sound that affect annoyance not included in SEL

Markov Chain Monte Carlo:

- Most likely values of the EAP
- Gives a confidence interval on the EAP



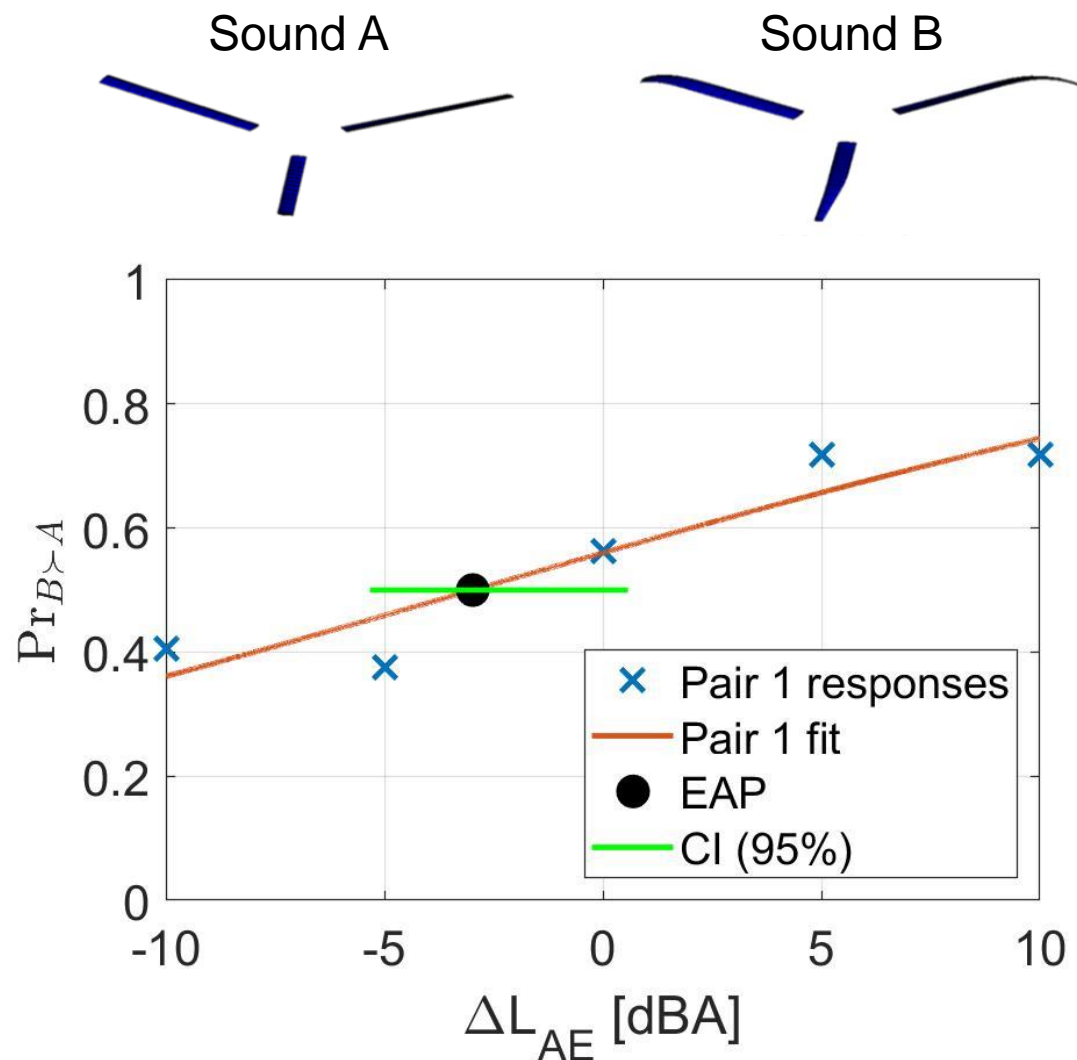
- CI (95%) contains 0dB relative level
- CI (95%) does not contain 0dB relative level

Baseline rotor design vs. SEL-optimized rotor

- ✔ Passes binomial test at 0dBA
 - **Not** significant difference in annoyance
 - (Same for EPNL-optimized rotor, not shown)
- ✔ 95% Confidence interval = [-5.33, 0.57] dBA
 - **CI overlaps with 0dBA**
 - **Not** significant difference in annoyance
- **EAP = -2.98 dBA**

SEL can be an effective metric to minimize when designing low noise rotors.

Recommended to minimize both main and tail rotors.



(a) Probability that the L_{AE} -optimized rotor is more annoying than the baseline rotor.

AS350 low-noise approach vs EC130 low-noise approach

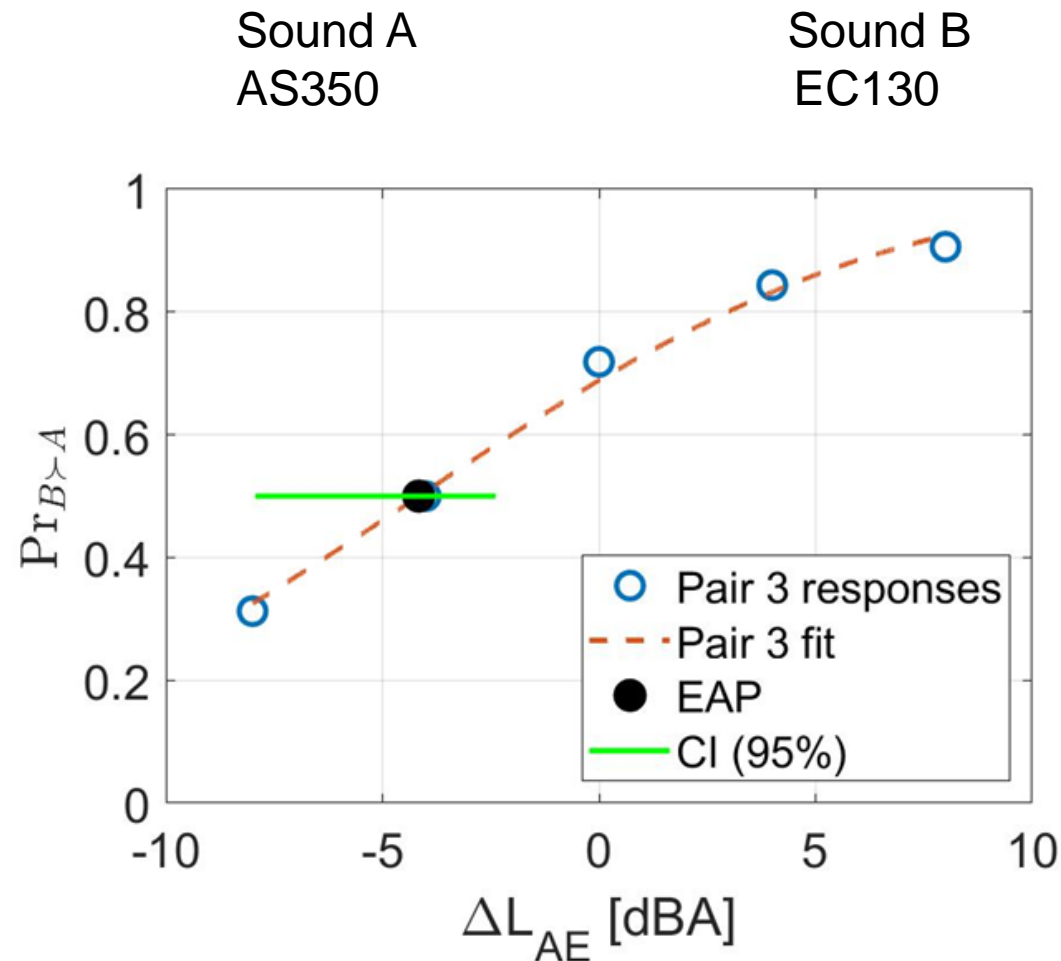


- ❌ Binomial test at 0dBA
 - Pr = 75% at 0dBA
 - There IS significant difference in annoyance
- ❌ 95% Confidence interval = [-7.93, -2.39] dBA
 - **CI does not overlap with 0dBA**
 - There IS significant difference in annoyance
- **EAP = -4.2 dBA**

SEL may not be a good indicator of annoyance when comparing different helicopters.

Change in rotor technology can affect perception.

Temporal, spectral or spatial components not contained in the SEL calculation are important.



(c) Probability that the EC130 is more annoying than the AS350 for a low noise approach.

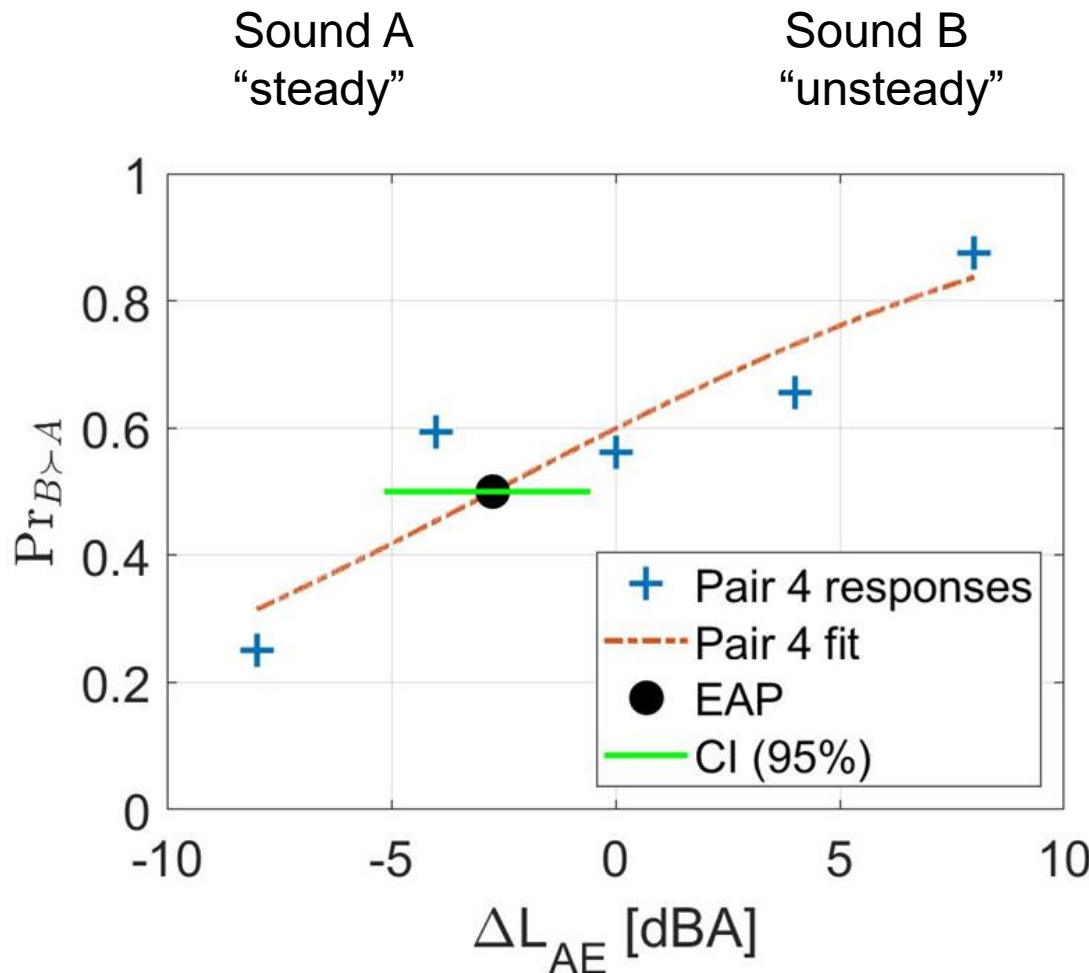
AS350 “steady” sound vs AS350 “unsteady” sound

- ✔ Passes binomial test at 0dBA
 - **Not** significant difference in annoyance
 - (Same for EPNL-optimized rotor, not shown)
- ✘ 95% Confidence interval = [-5.16, -0.56] dBA
 - **CI does not overlap with 0dBA**
 - There **IS** significant difference in annoyance
- **EAP = -2.74 dBA**

SEL did not fully capture annoyance responses when comparing different maneuvers for the same helicopter.

Changes in flight path can affect perception.

Temporal, spectral or spatial components not contained in the SEL calculation are important.



(b) Probability that the unsteady AS350 flight is more annoying than the steady AS350 flight.



Summary

- **Psychoacoustic test to evaluate efficacy of SEL in terms of annoyance to helicopter noise**
 - Included auralizations of noise-optimized rotors and recordings from flight test of lightweight helicopters
 - Analysis focused on differences in annoyance for pairs of sounds of equal SEL and relative differences of SEL

	Binomial test (0dB)	CI contains 0dB
Different helicopters	✗	✗
Different maneuvers	✓	✗
Different rotor designs	✓	✓



- **SEL does not fully capture annoyance responses when:**

1. Comparing different vehicles
2. Comparing different maneuvers

- **Designing rotors for low SEL, no additional sound characteristics found that affect annoyance**

Outlook

- **A parallel psychoacoustic test included 13 recorded flights from AS350 and EC130. Put SEL and annoyance on same axis.**
- **Toward an annoyance model for rotorcraft noise** (from all recent rotorcraft psychoacoustics test)
- **Related to audibility, noticeability and annoyance work for urban air mobility**



Thank you!

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