Analysis of Helicopter and UAM Laboratory Comparison (HULC) Psychoacoustic Test

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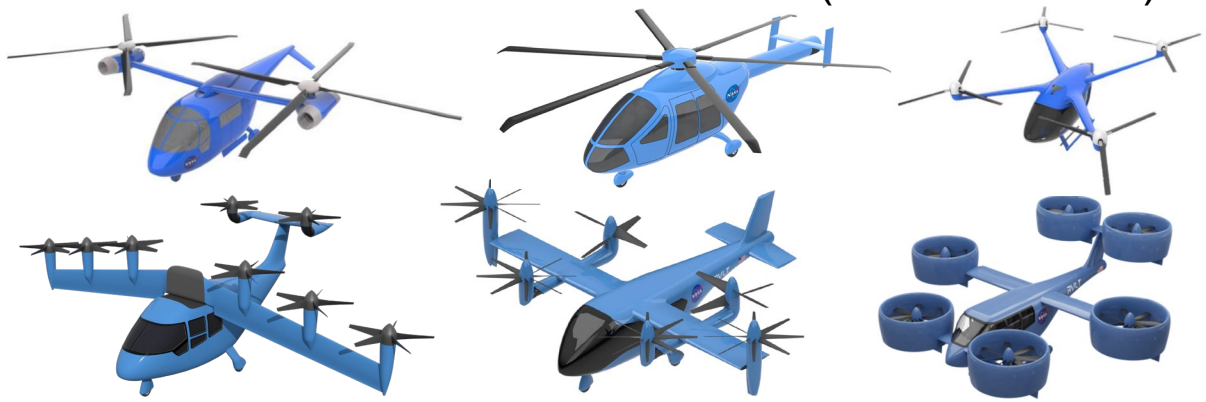
Community integration of Urban Air Mobility requires understanding of human response to novel aircraft noise



Comparing UAM vehicles with helicopters provides essential reference points for understanding community noise response

UAM vehicles (6 total in HULC test)

NASA UAM Reference Vehicles (some included)



Additional UAM sounds from OEMs

OEM 1 OEM 2 OEM #...

Lightweight Helicopters (all 4 included in HULC test)

AS350B3



Marek Slusarczyk

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Bell 206L3



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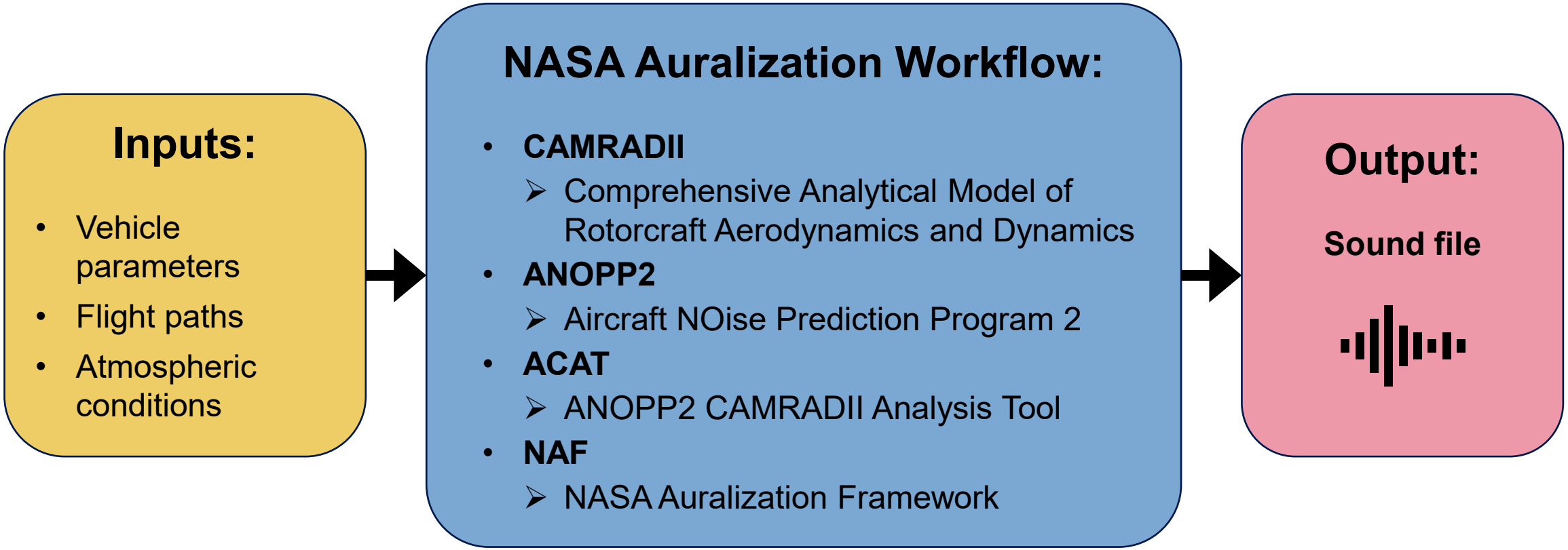
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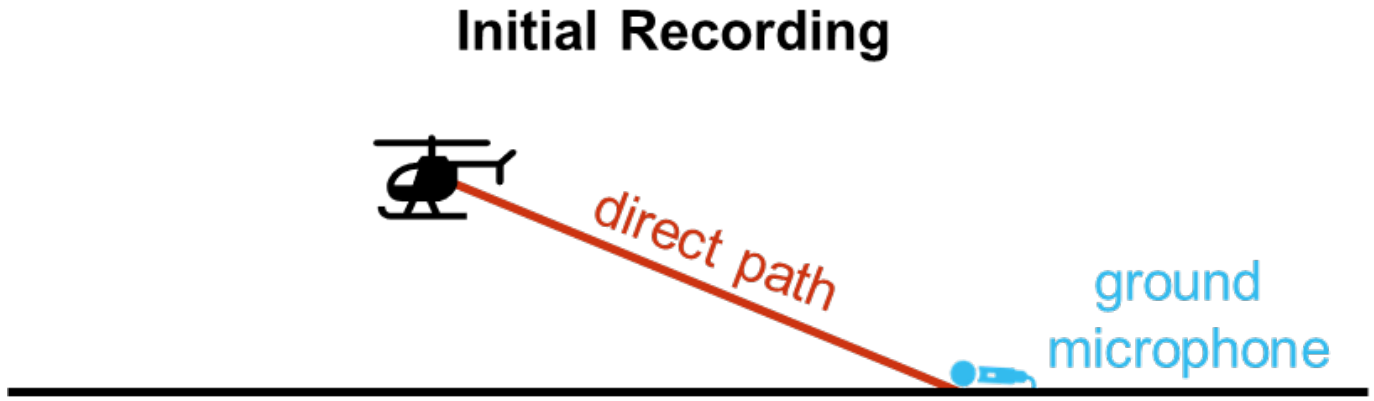
NASA-developed and other auralization tools were used to generate physics-based simulation of UAM vehicle sounds

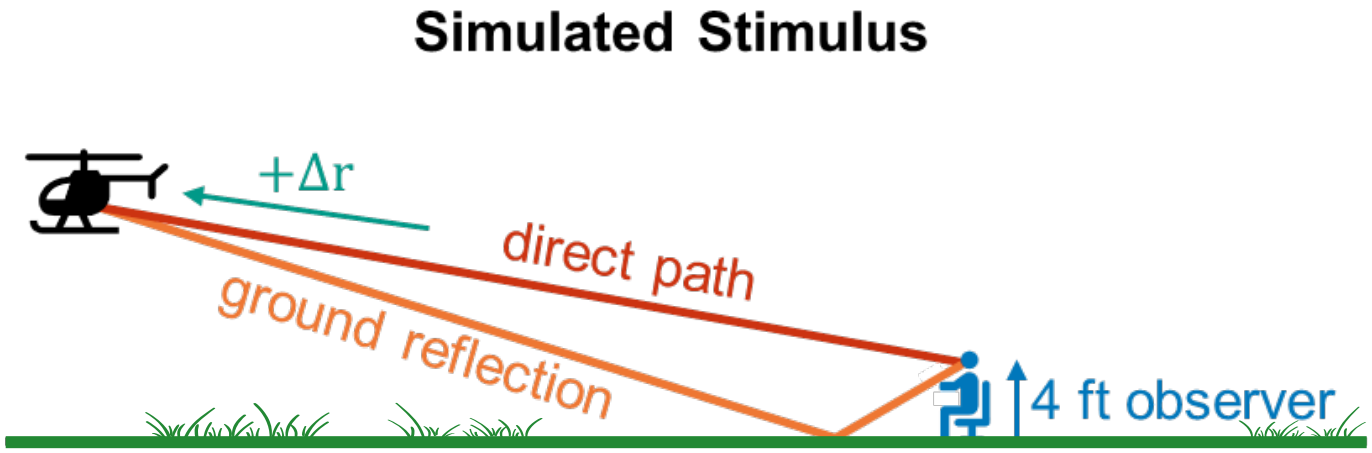


We used signal processing to prepare stimuli from recordings with simulated propagation effects at realistic distances

Propagation effects

- Ground reflections
- Time delay
- Atmospheric absorption
- Geometric spreading

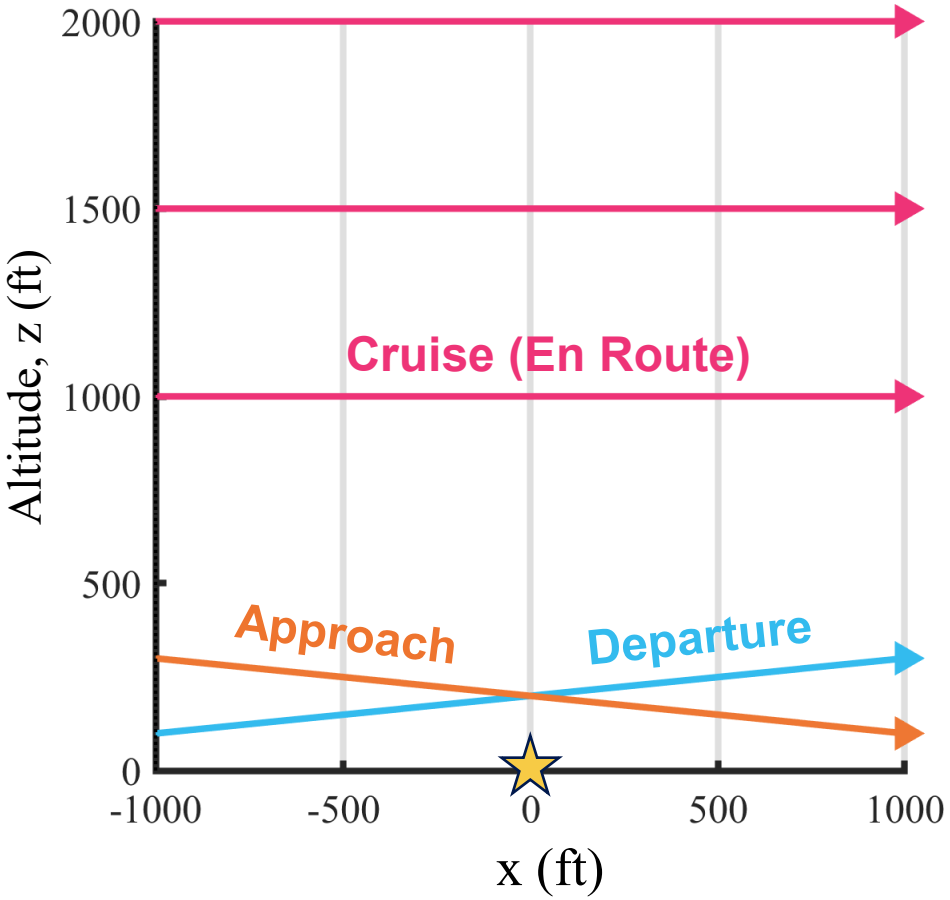


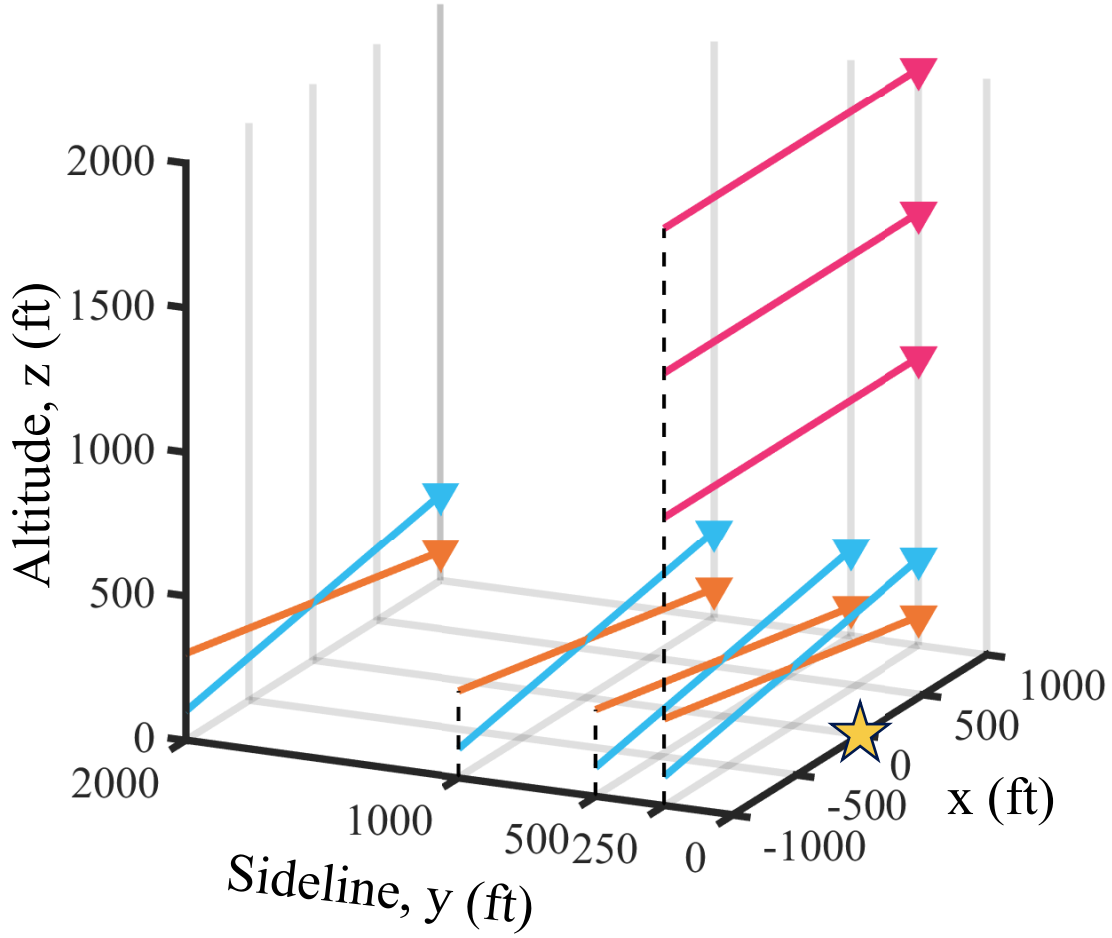


References:

- A. R. Aumann, S. A. Rizzi, and S. L. Heath, “Receiver-based auralization of broadband aircraft flyover noise using the NASA Auralization Framework,” in *INTERNOISE and NOISE-CON Congr. and Conf. Proc.* 258(7), 411–420 (**2018**).
- A. R. Aumann, B. C. Tuttle, W. L. Chapin, and S. A. Rizzi, “The NASA Auralization Framework and Plugin Architecture,” in *INTER-NOISE and NOISE-CON Congr. and Conf. Proc.* 250(5), 1932–1942 (**2015**).

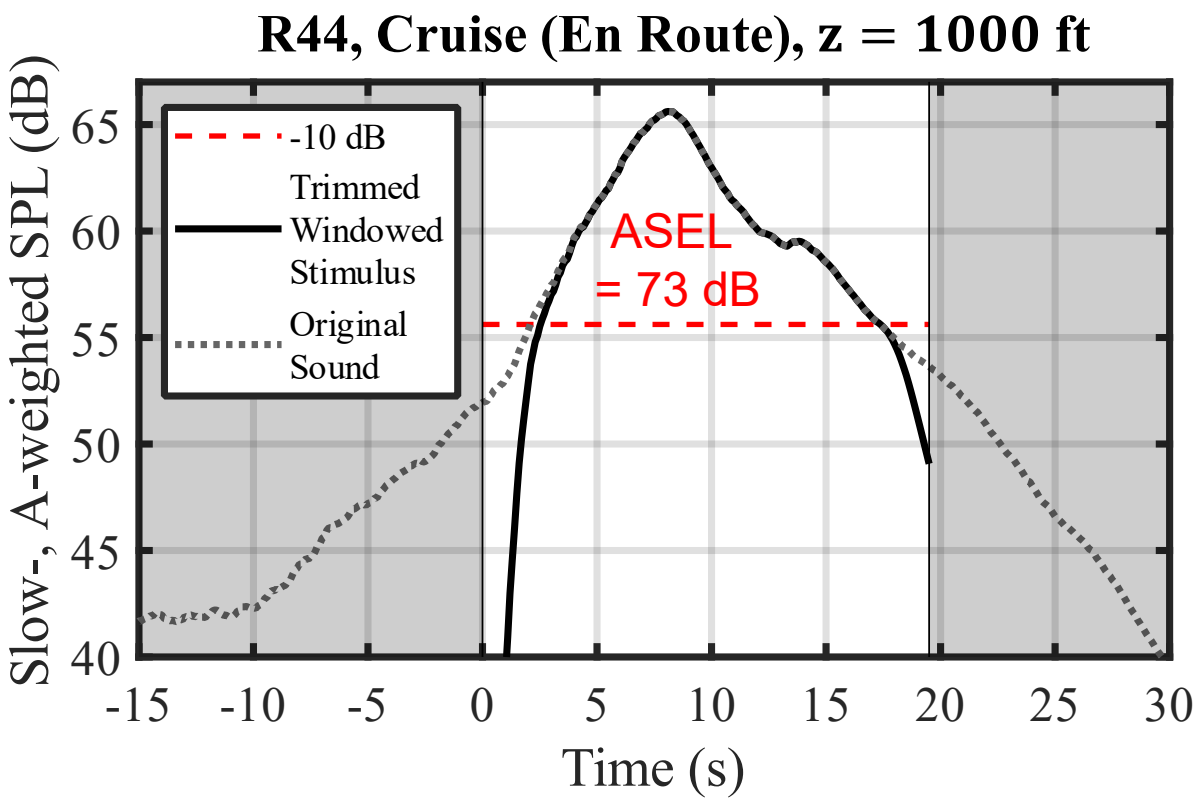
Sound stimuli are from three steady-state flight phases (departure, cruise (en route), approach) at various distances

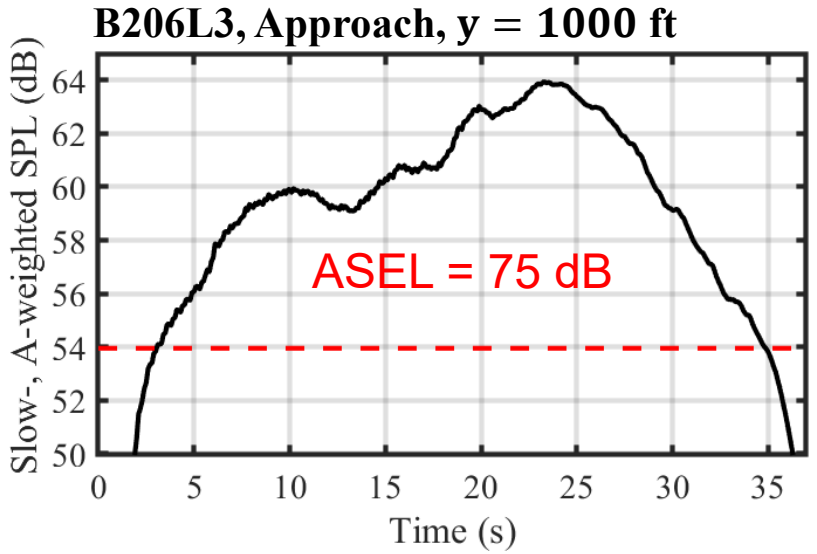


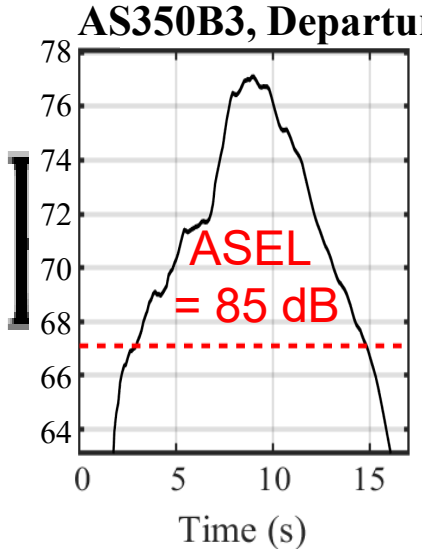


Observer at (0,0,4) ft

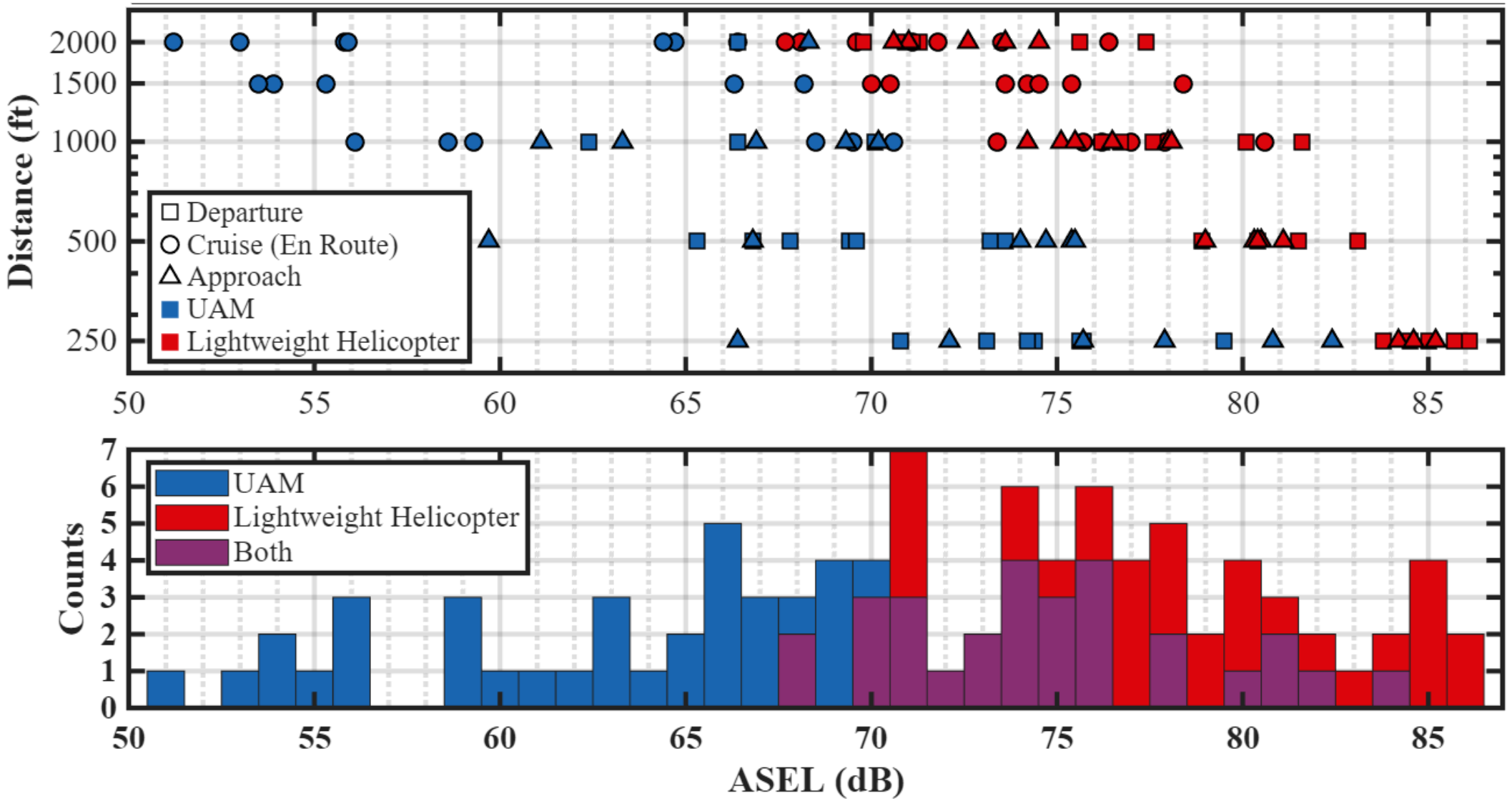
Stimuli are trimmed and windowed to contain the 10-dB down portion used for calculating (A-weighted) sound exposure level



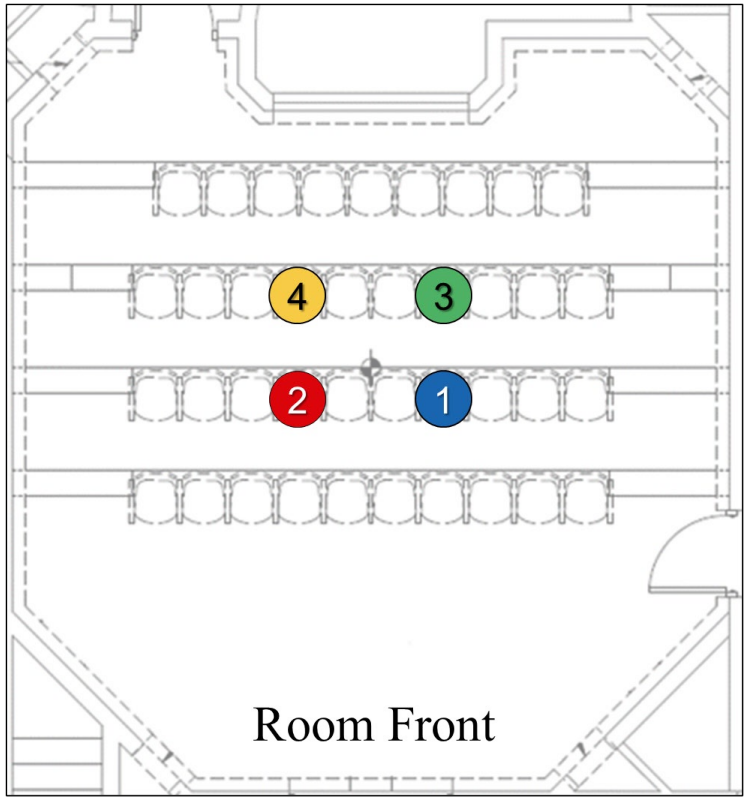


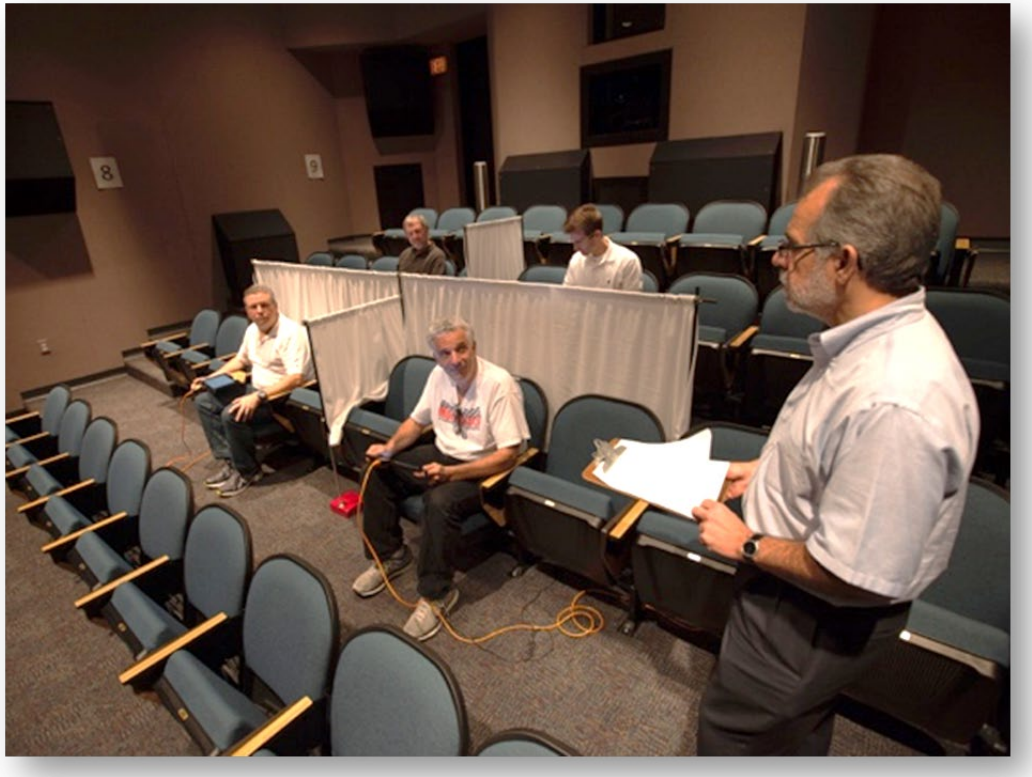


We selected 123 stimuli that balanced representation of aircraft class and flight phase and totaled 52 minutes in duration



The HULC test was conducted in the Exterior Effects Room with 40 subjects from the Hampton Roads, Virginia, region



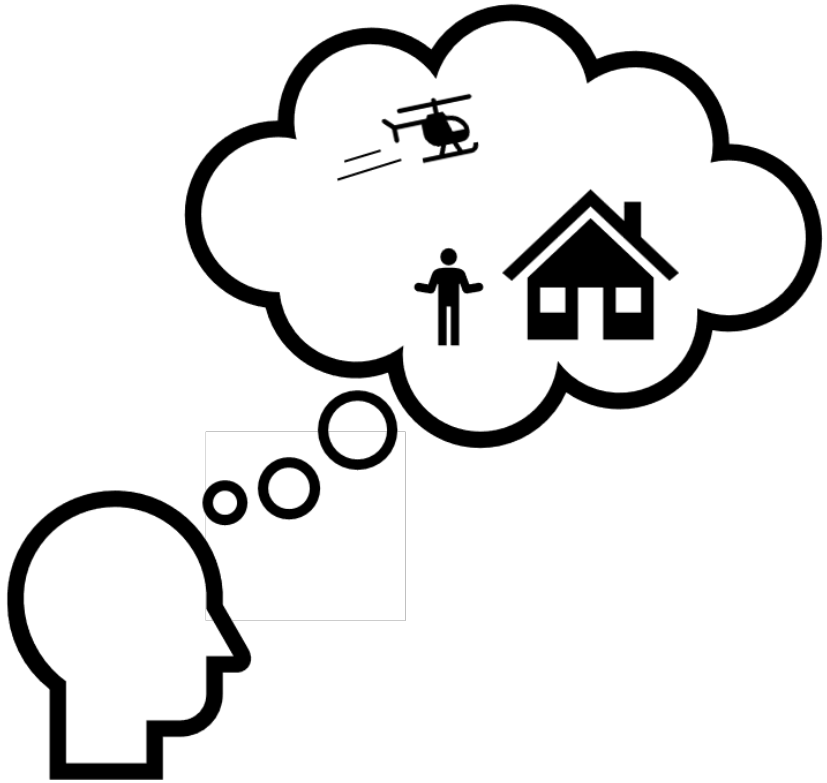


Test protocol approved by the NASA Institutional Review Board

Test subjects rated their annoyance on a 0 to 10 numerical scale from “not at all” to “extremely” annoyed (ref. ISO/TS 15666:2021)

Imagine hearing this sound several times each day
while outdoors and near your home,
how annoying would this sound be to you?

Not at all										Extremely
0	1	2	3	4	5	6	7	8	9	10



Reference:

- S. Krishnamurthy, et al., “Remotely Administered Psychoacoustic Test for sUAS Noise to Gauge Feasibility of Remote UAM Noise Study,” SAE Int. J. Adv. Curr. Pract. Mobil. 6(2), 986–999 (**2024**).

Multilevel statistical modeling allows robust comparison of human response to UAM and helicopter noise across flight phases

Fixed (Same) Slope | **Random (Variable) Intercept**

Response ~ Sound_Level + Aircraft_Class*Flight_Phase + (1|Subject_ID)

(Annoyance) (Primary Continuous Predictor) (Indicator Variables) (Subject-specific Intercepts)

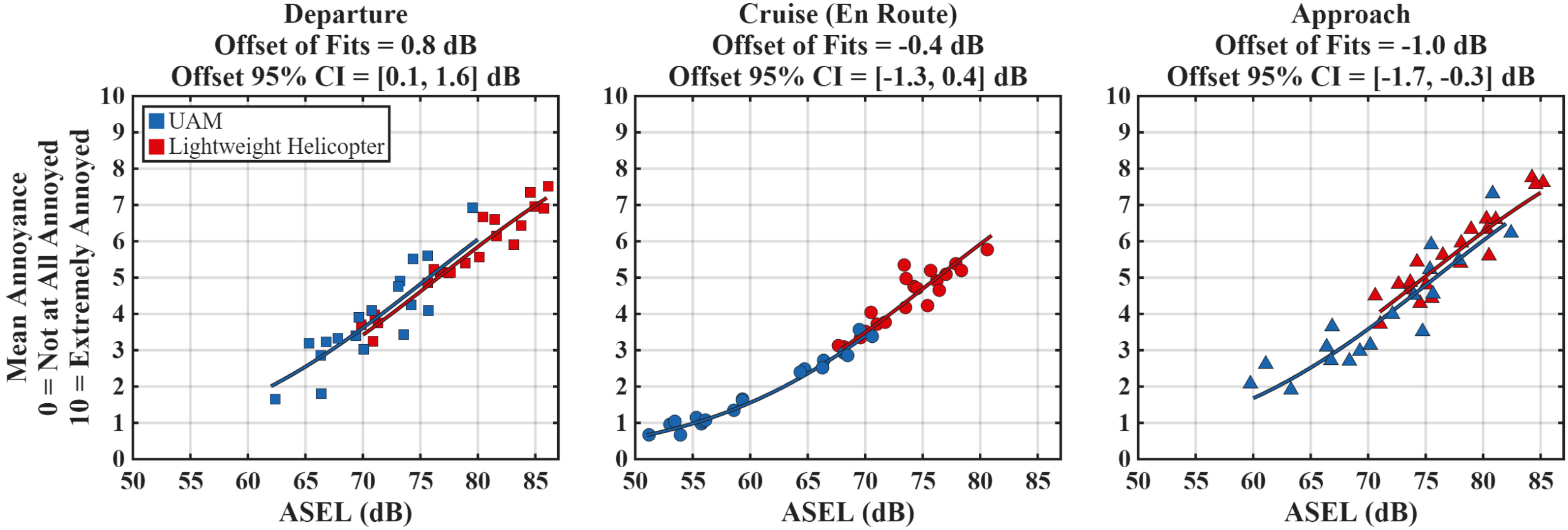
$$\boldsymbol{p_i} = \text{logit}^{-1}\left(\beta_0 + \beta_1 \mathbf{ASEL} + \beta_2 \mathbf{UAM} + \beta_3 \mathbf{Cruise} + \beta_4 \mathbf{Approach} + \beta_5 \mathbf{UAM{:}\,Cruise} + \beta_6 \mathbf{UAM{:}\,Approach} + \boldsymbol{\epsilon_i}\right)$$

Indicator Variable combinations for unique intercepts

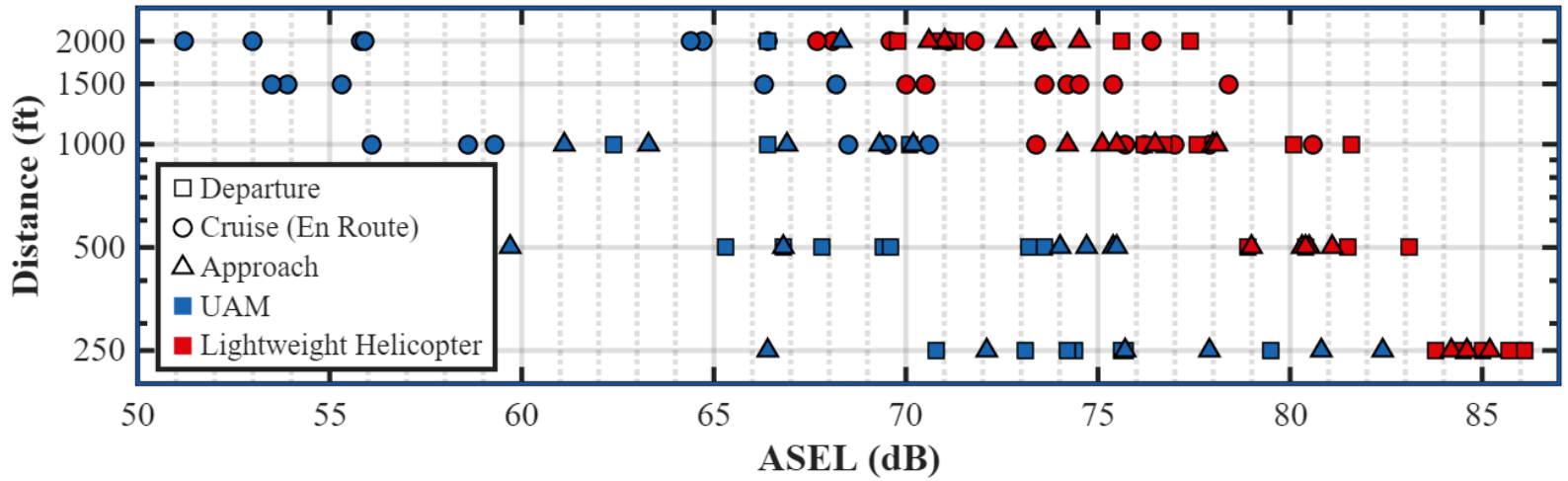
Aircraft Class (AC)	Flight Phase (FP)	UAM	Cruise	Approach	UAM:Cruise	UAM:Approach	Intercept $\beta_{0,AC,FP}$
Helicopter	Departure	0	0	0	0	0	β_0
Helicopter	Cruise	0	1	0	0	0	$\beta_0 + \beta_3$
Helicopter	Approach	0	0	1	0	0	$\beta_0 + \beta_4$
UAM	Departure	1	0	0	0	0	$\beta_0 + \beta_2$
UAM	Cruise	1	1	0	1	0	$\beta_0 + \beta_2 + \beta_3 + \beta_5$
UAM	Approach	1	0	1	0	1	$\beta_0 + \beta_2 + \beta_4 + \beta_6$

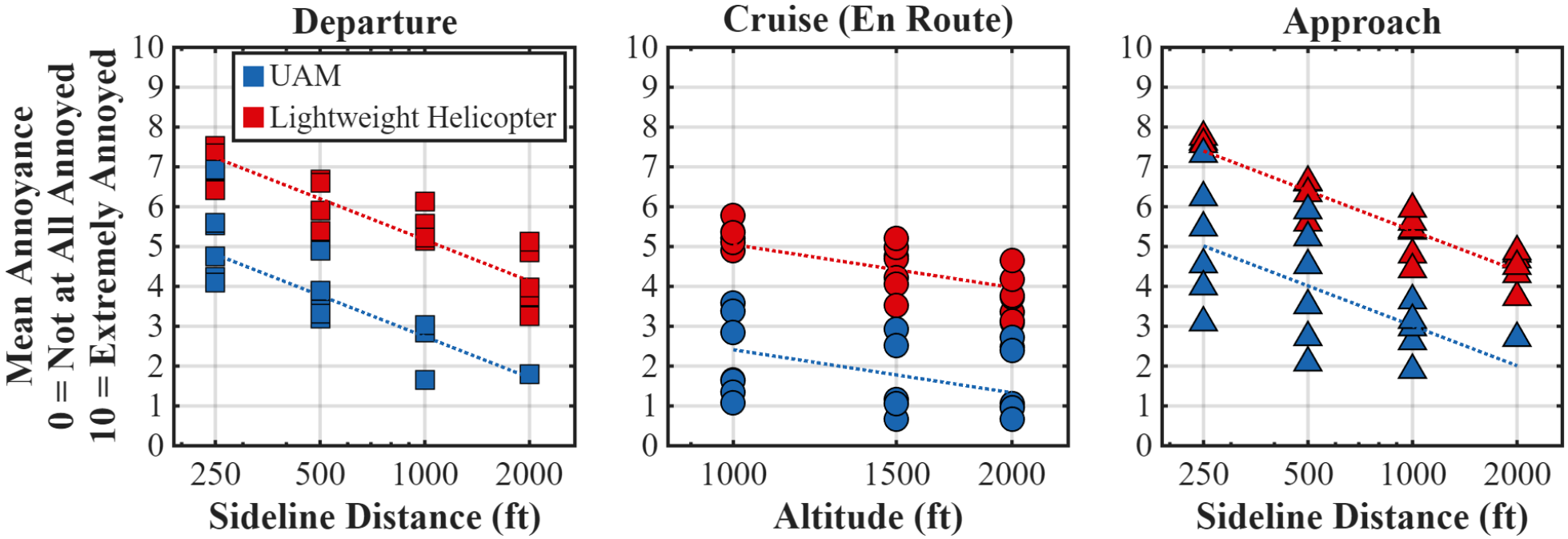
$$\text{Mean Annoyance} = \text{logit}^{-1}\left(\boldsymbol{\beta_{0,\,AC,\,FP}} + \beta_1 \mathbf{ASEL}\right) \times 10$$

UAM vehicles and helicopters produce similar annoyance responses with ASEL as the main predictor for each flight phase



At the same distance, UAM vehicles are quieter and less annoying than helicopters





Conclusions

1. At the same ASEL, UAM vehicles and lightweight helicopters produce similar annoyance responses
2. At equal distances, UAM vehicles are quieter and less annoying than lightweight helicopters

Future work

- Sound quality
- Additional UAM vehicles
- Multi-event
- Transitional flight
- Ambient noise
- Community studies

Acknowledgements

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Questions?

Full paper available: https://ntrs.nasa.gov/citations/20250008984

