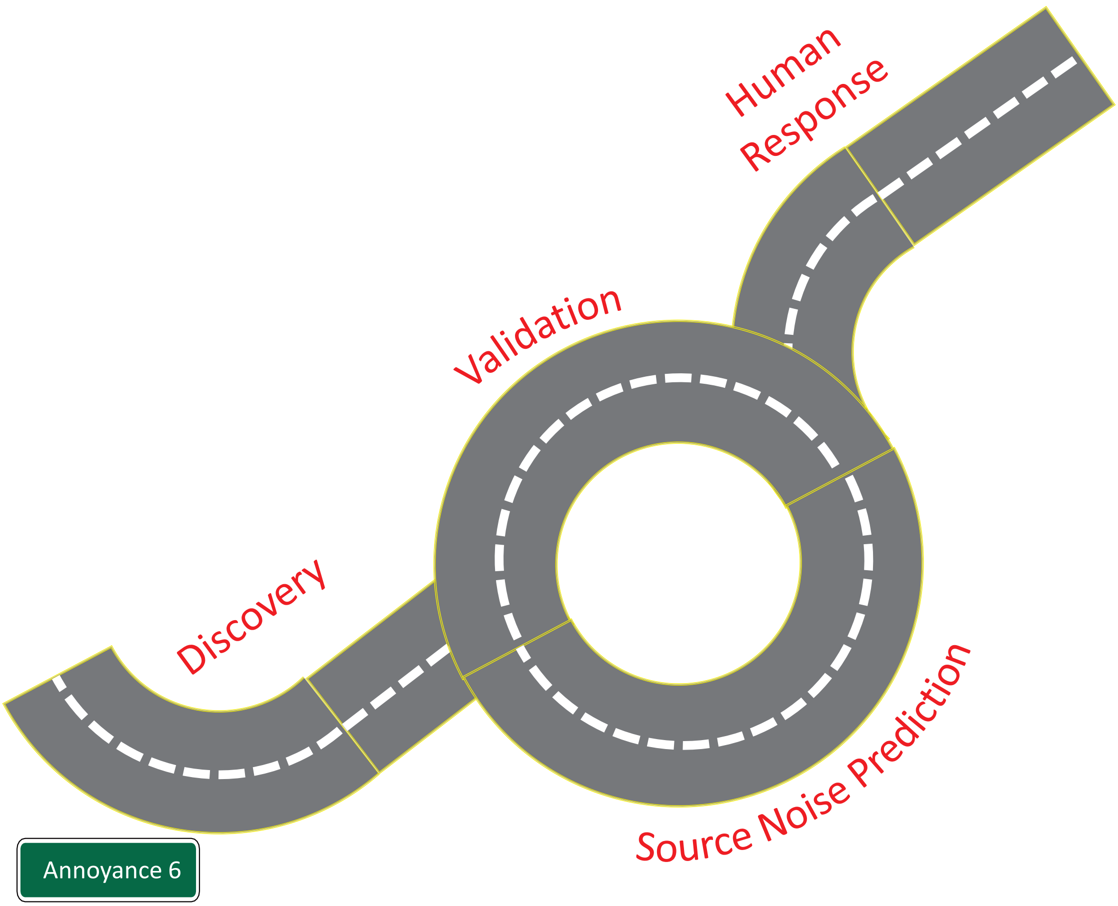
Photo by Denys Nevozhai on Unsplash

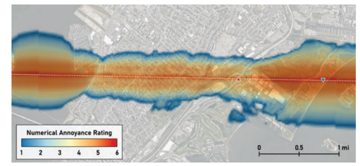
The Road to Annoyance

Stephen A. Rizzi
Senior Researcher for Aeroacoustics
NASA Langley Research Center

Aeroacoustics Lecture
2025 AIAA AVIATION Forum
31st AIAA/CEAS Aeroacoustics Conference
Las Vegas, NV
24 July 2025

The Road



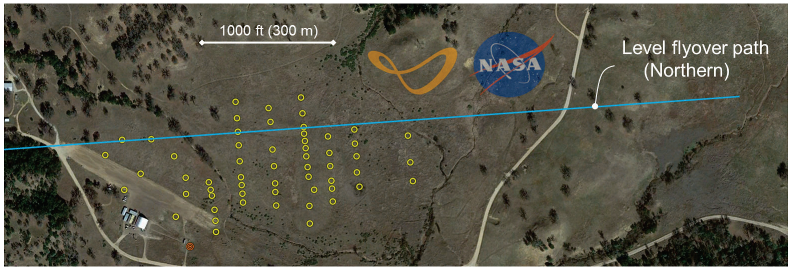


- Discovery
  - The Importance of Broadband Noise
- Source Noise
  - Modeling Framework & Prediction
  - Exp. and Numerical Validation
- Human Response
  - Auralization
  - Psychoacoustic Testing
  - Annoyance Model

Why Not Just Build an Annoyance Model from Sound Jury Data?

- Sound jury tests often used to assess human response, <u>but</u>
  - Sound at observer unsteady due to source and propagation
  - Exact reproduction is not possible

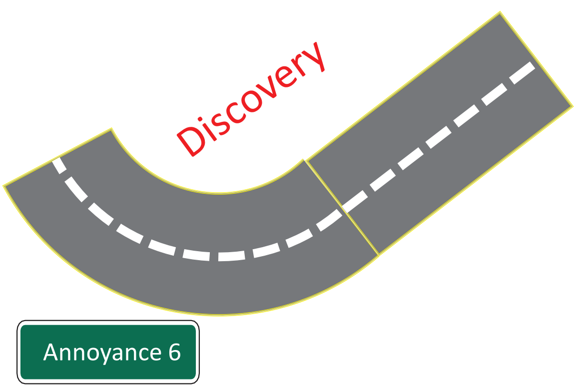
Joby Aviation preproduction prototype vehicle (Source: NASA and Joby Aviation)



Pascioni, Watts, Houston, Lind, Stephenson, and Bain, "Acoustic Flight Test of the Joby Aviation Advanced Air Mobility Prototype Vehicle," *28th AIAA/CEAS Aeroacoustics Conference*, AIAA-2022-3036, Southampton, UK, 2022, https://doi.org/10.2514/6.2022-3036.

Watts, Conner, Smith, "Joint Eglin Acoustic Week III Data Report," *NASA/TM-2010-216206*, 2010, https://ntrs.nasa.gov/citations/20100012762.

The Road



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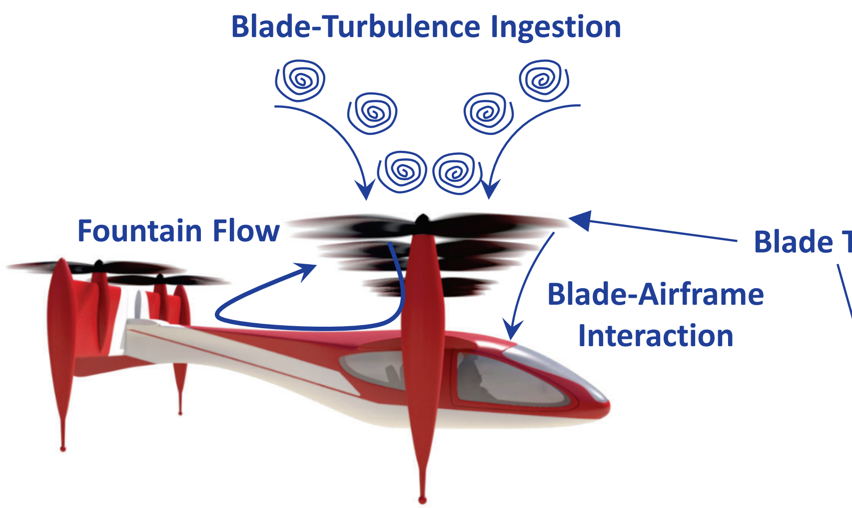
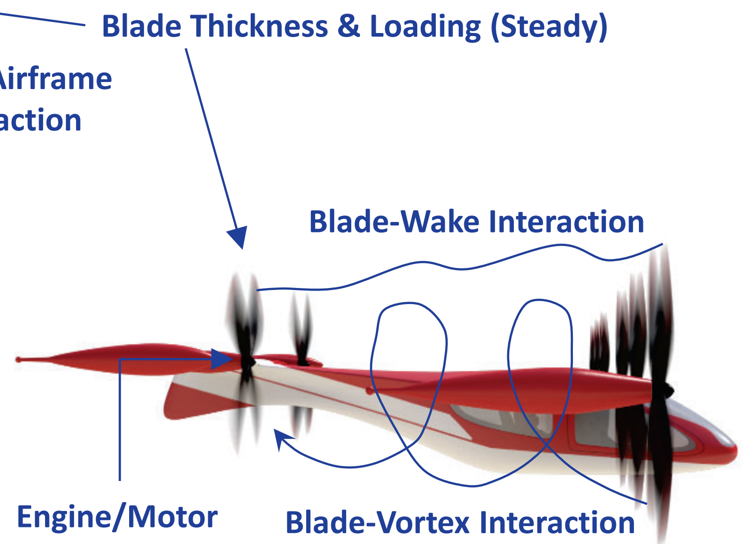
Discovery

eVTOL Noise Sources

Two broad categories:
- Tonal Noise (Deterministic)
- Broadband Noise (Stochastic)



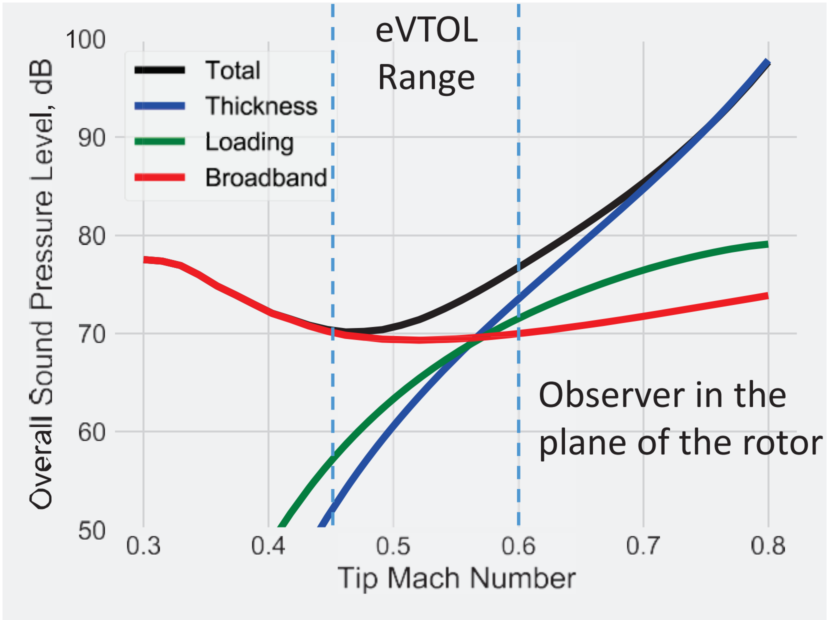


Stochastic Noise Sources
- Blade Self-Noise
- Blade-Wake Interaction
- Blade-Turbulence Interaction

Deterministic Noise Sources
- Blade Thickness
- Blade Steady Loading
- Blade Unsteady Loading
  - Blade-Vortex Interaction
  - Blade-Airframe Interaction
- Engine/Motor

Discovery

The Importance of Broadband Noise for eVTOL



Variation in noise with tip Mach number†

- This figure does not directly reflect human response.
- The importance of broadband noise remains for other observers but the relative contribution of thickness and loading noise changes.

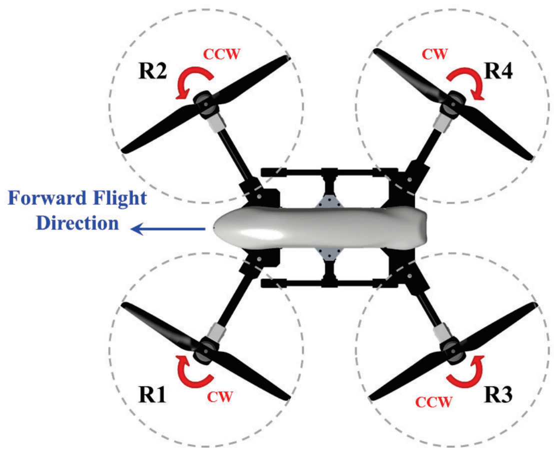
† Greenwood, Brentner, Rau, and Gan, "Challenges and Opportunities for Low Noise Electric Aircraft," *International Journal of Aeroacoustics*, Vol. 21, No. 5-7, pp. 315-381, 2022, https://doi.org/10.1177/1475472X221107377.

Discovery

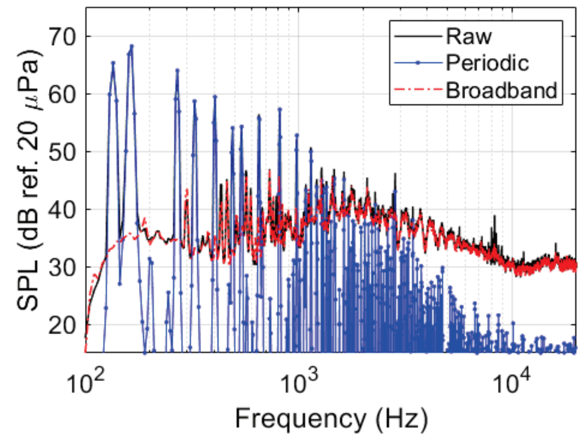
Experimental Observations from sUAS

SUI Endurance

Fixed-Pitch Blades



Source Separation

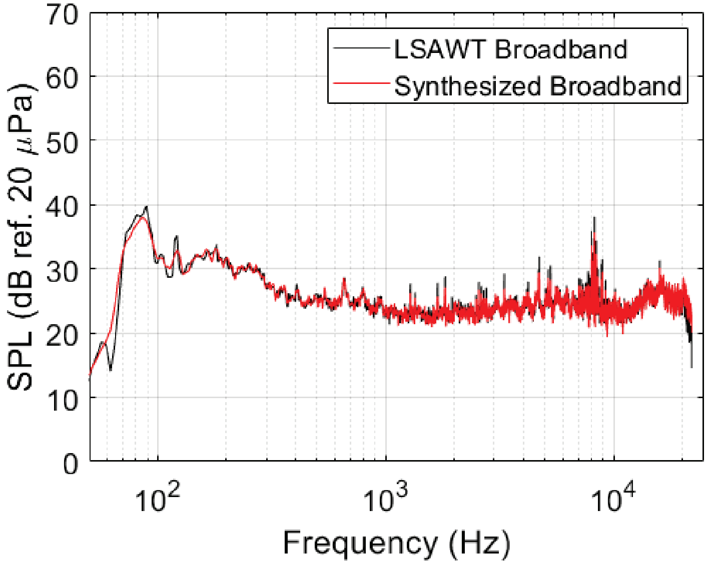


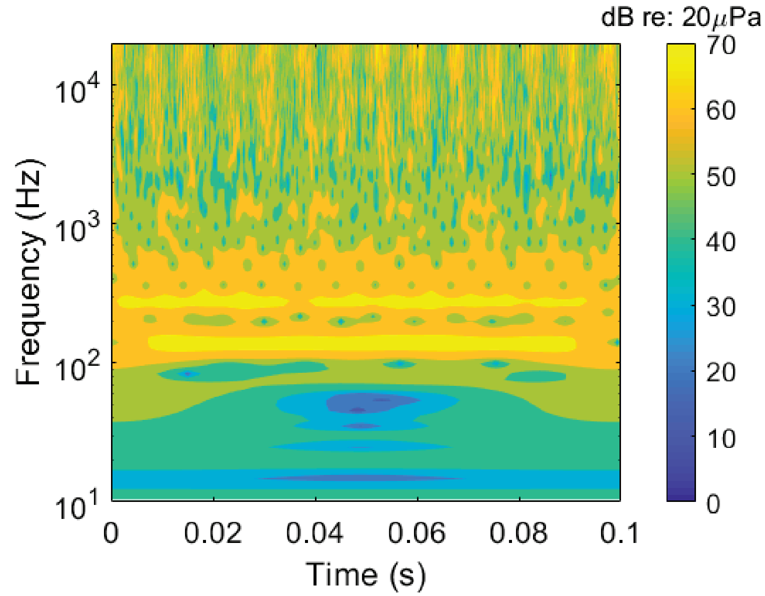
Zawodny and Pettingill, "Acoustic Wind Tunnel Measurements of a Quadcopter in Hover and Forward Flight Conditions," *InterNoise 2018,* Chicago, IL, 2018, https://ntrs.nasa.gov/citations/20200002564.

Discovery

Experimental Observations from sUAS

Broadband Noise Synthesis





Synth. (64.2 dB)

LSAWT (64.9 dB)

We address the lack of modulation in the synthesized broadband noise later in this presentation.

Rizzi, Zawodny, and Pettingill, "On the use of Acoustic Wind Tunnel Data for the Simulation of sUAS Flyover Noise," *25th AIAA/CEAS Aeroacoustics Conference*, AIAA 2019-2630, Delft, The Netherlands, 2019, https://doi.org/10.2514/6.2019-2630.

Discovery

Experimental Observations from Helicopters

Bell 206B

"The modulation is important subjectively, because the continuously changing character of the sound renders it more noticeable, and thus both more irritating and more detectable."

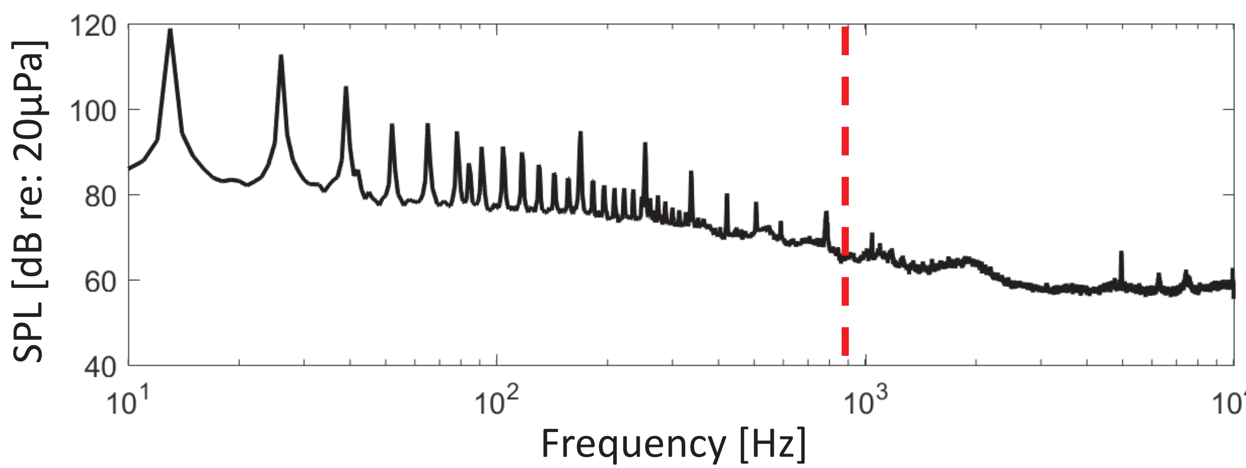
Lowson, "Thoughts on Broad Band Noise Radiation by a Helicopter," *Wyle Laboratories Report WR 68-20*, 1968.

Time-Averaged Spectrum (Mic A3)

Recording

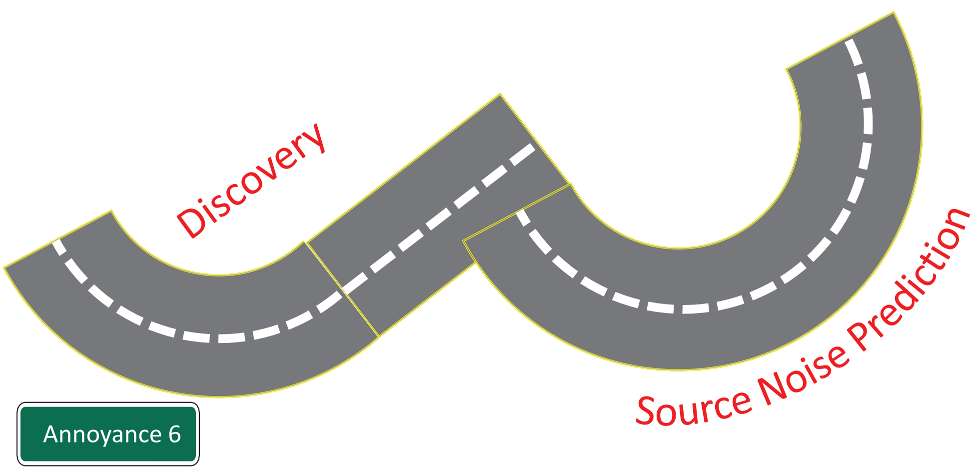
Low-Pass

High-Pass



Christian, Caston, and Greenwood, "Regarding the Perceptual Significance and Characterization of Broadband Components of Helicopter Source Noise," *Vertical Flight Society 75th Annual Forum,* Philadelphia, PA, 2019, https://doi.org/10.4050/F-0075-2019-14449.

The Road



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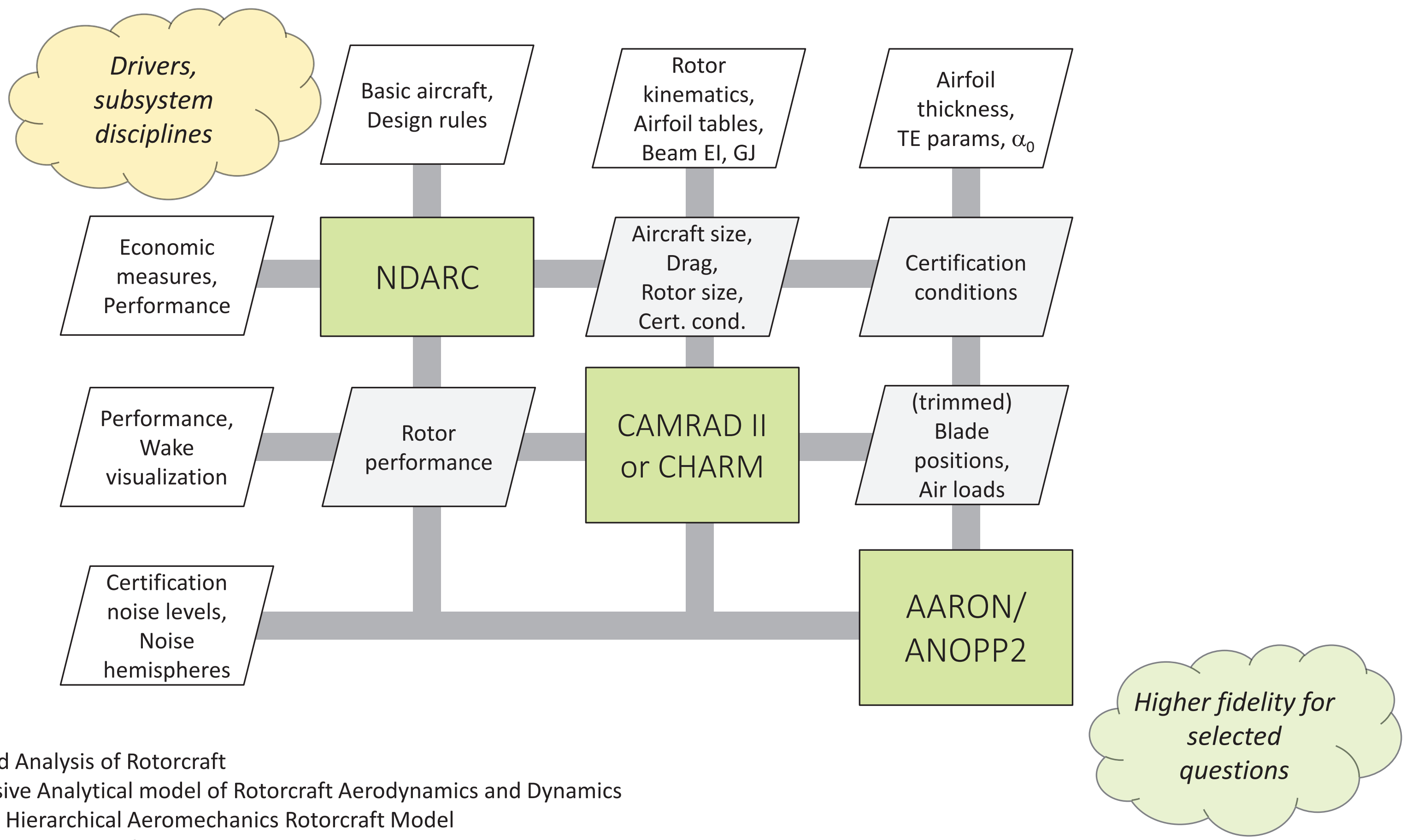
Source Noise Prediction

NASA Toolchain for Analysis of Noise and Performance of eVTOL Vehicles



NDARC: NASA Design and Analysis of Rotorcraft
CAMRAD II: Comprehensive Analytical model of Rotorcraft Aerodynamics and Dynamics
CHARM: Comprehensive Hierarchical Aeromechanics Rotorcraft Model
ANOPP2: NASA 2nd Generation Aircraft Noise Prediction Program
AARON: ANOPP2 Aeroacoustic Rotor Noise Tool

RVLT Concept Vehicles

<u>Quadrotor</u>†

- All-electric variant
- (4) 3-bladed rotors
- 2934 kg (6469 lb.) GTOW
- V_{max} 109 KTAS

<u>Lift Plus Cruise</u>†

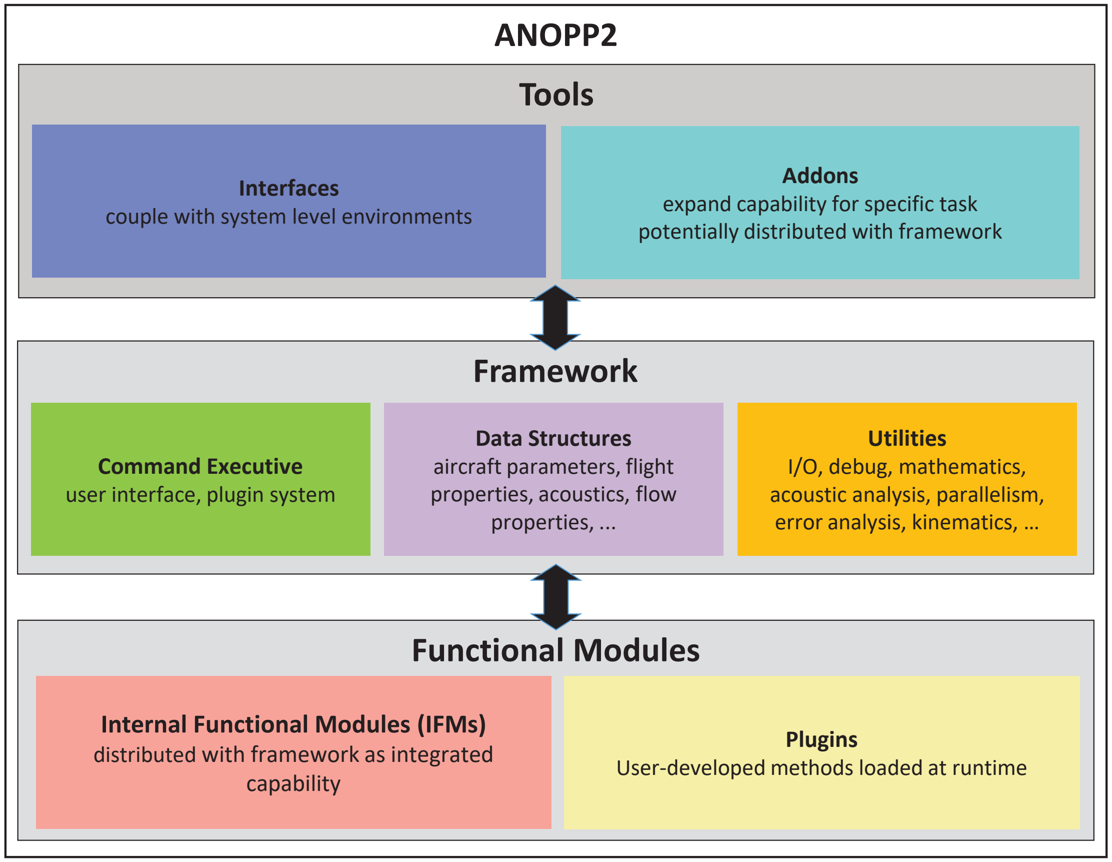
- Turboelectric variant
- (8) 2-bladed lifting rotors
- 3-bladed pusher propeller
- 2678 kg (5903 lb.) GTOW
- V_{max} 123 KTAS

- Both vehicles sized for 544 kg (1200 lb.) payload (up to six passengers) executing a representative mission profile.‡

† Silva, Johnson, Solis, Patterson, and Antcliff, "VTOL Urban Air Mobility Concept Vehicles for Technology Development," *2018 AIAA Aviation Forum*, Atlanta, GA, AIAA-2018-3847, 2018, https://doi.org/10.2514/6.2018-3847.

‡ Patterson, Antcliff, and Kohlman, "A Proposed Approach to Studying Urban Air Mobility Missions Including an Initial Exploration of Mission Requirements," *AHS International 74th Annual Forum,* Phoenix, AZ, 2018, https://ntrs.nasa.gov/citations/20190000991.

Aircraft Noise Prediction Program 2 (ANOPP2)



<u>ANOPP2 Distribution</u>
Framework
IFMs
Tools

<u>Separate Distributions</u>
Plugins
Tools

Lopes and Burley, "ANOPP2 User's Manual: Version 1.2," *NASA/TM-2016-219342*, 2016, https://ntrs.nasa.gov/citations/20160014858.

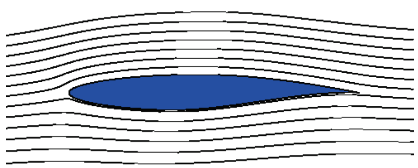
AF1AIFM Tonal Noise Prediction

Ffowcs Williams–Hawkings Equation

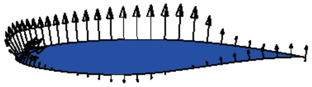
- Rearrangement of Navier-Stokes equations into an inhomogeneous wave equation

$$\Box^2 p' = \frac{\partial}{\partial t}[\rho_0 v_n \delta(f)] - \frac{\partial}{\partial x_i}[p\, n_i \delta(f)] + \frac{\partial^2}{\partial x_i \partial x_j}[H(f)\, T_{ij}]$$

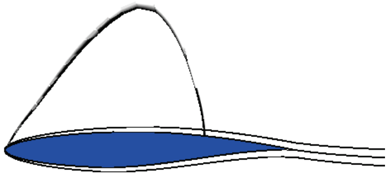
Thickness
Fluid Displacement



Loading
Accelerating Force Distribution



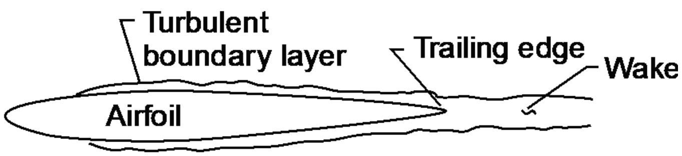
Quadrupole
Volume Sources



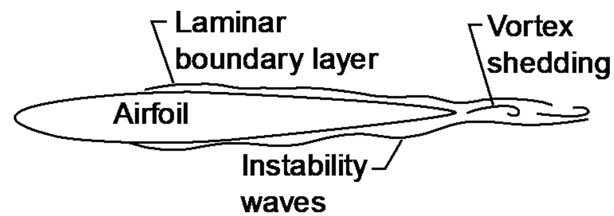
Brentner and Farassat, "Modeling Aerodynamically Generated Sound of Helicopter Rotors," *Progress in Aerospace Sciences*, Vol. 39, No. 2-3, pp. 83–120, 2003, https://doi.org/10.1016/S0376-0421(02)00068-4.

ASNIFM Broadband Self Noise Prediction

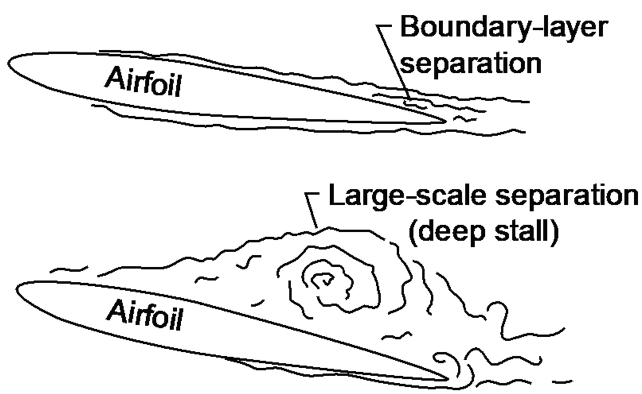
Annoyance 4



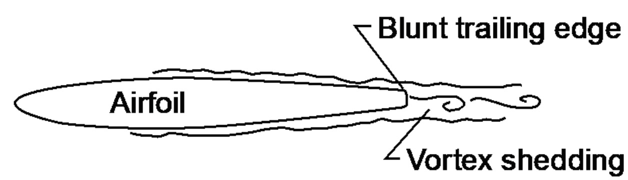
Turbulent boundary layer - trailing edge (TBL-TE) noise



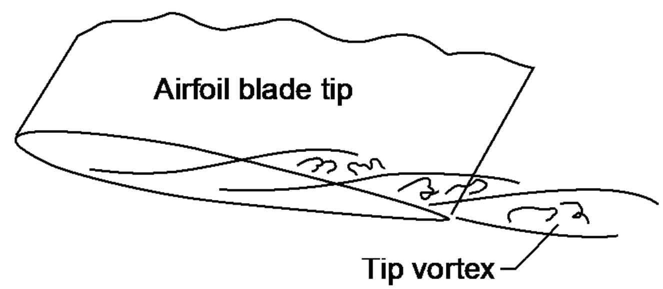
Laminar-boundary-layer—vortex shedding (LBL-VS) noise



Angle dependence for TBL-TE noise



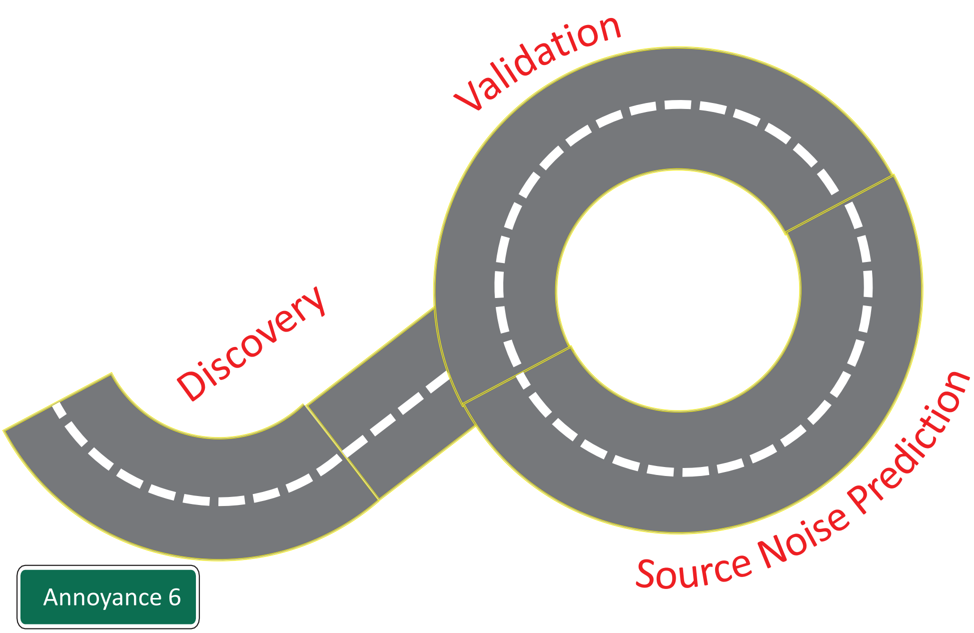
Bluntness vortex shedding (BVS)



Tip noise

Brooks, Pope, and Marcolini, "Airfoil Self-Noise and Prediction, *NASA-RP-1218*, 1989, https://ntrs.nasa.gov/citations/19890016302.

The Road



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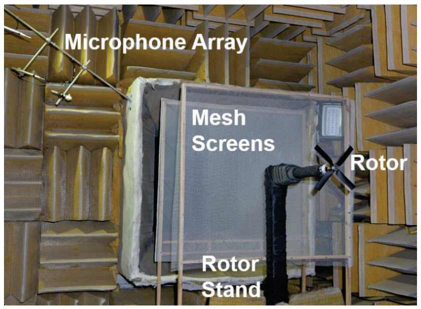
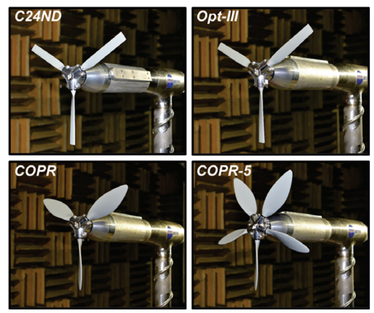
Validation

Experimental Databases for Model Validation

- Isolated propellers and rotors



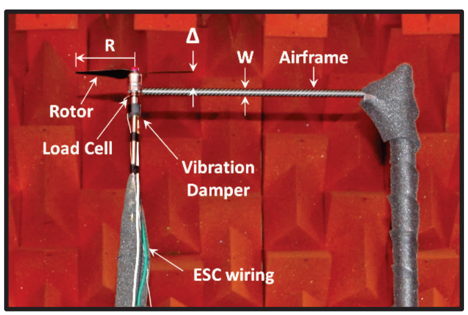
Ideally Twisted Rotor (SHAC)
AIAA-2021-1928



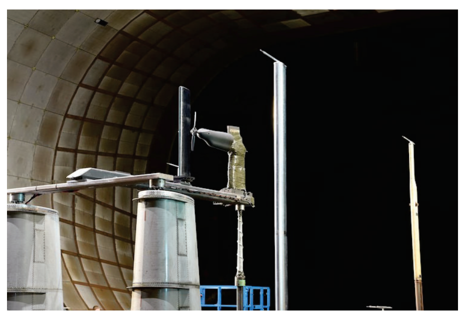
Optimized Proprotor (LSAWT)
NASA-TM-20220015637

Tilting Proprotor (14'x22')
Aero Performance - VFS 79-2023-0140
Acoustic Test – 2025

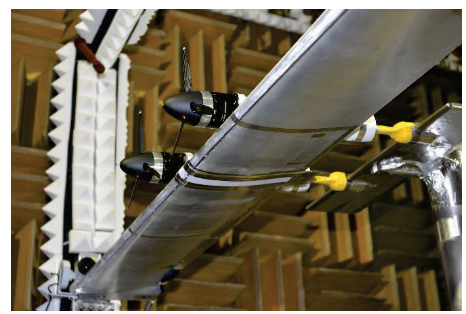
- Installed propellers and rotors



Rotor-Airframe Interaction (SALT)
73rd AHS Forum 2017



Aero & Acoustic Rotorprop Test (40'x80')
77th VFS Forum 2021

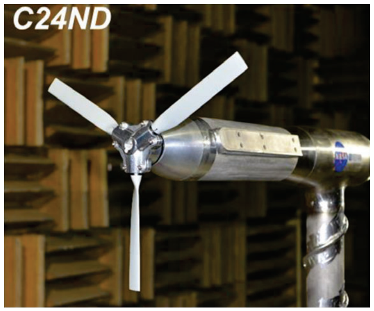


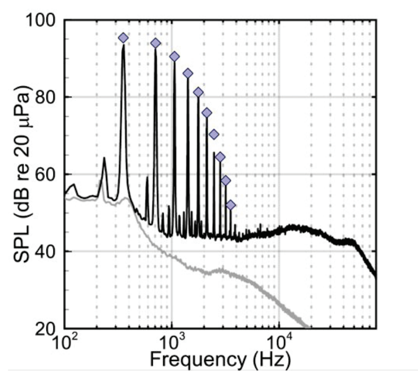
Tractor Configuration (LSAWT)
AIAA-2021-0714

Validation

Validation of Tonal and Broadband Noise Prediction

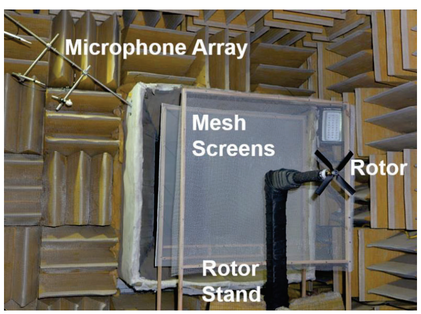
Tonal

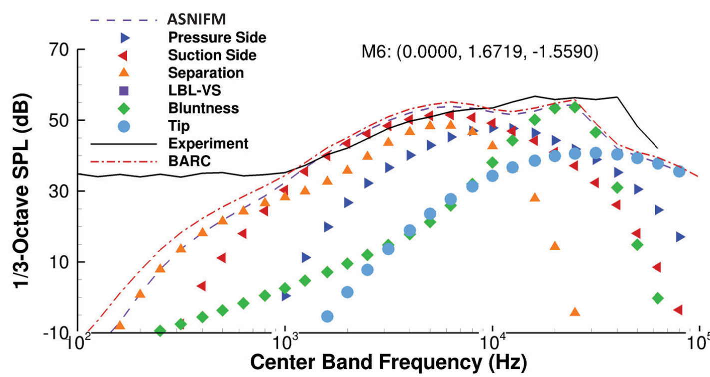


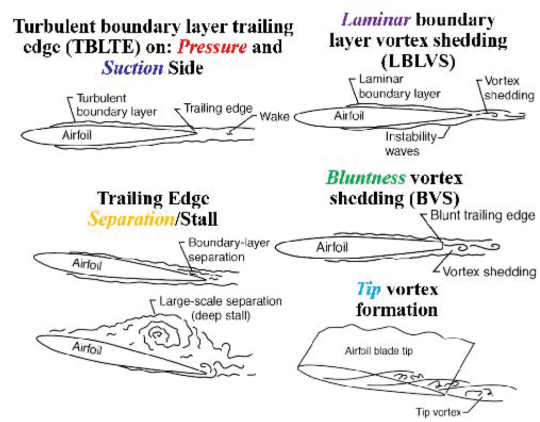


Zawodny, Pettingill, Lopes, and Ingraham, "Experimental Validation of an Acoustically and Aerodynamically Optimized UAM Proprotor, Part 1: Test Setup and Results," *NASA TM-20220015637*, 2023, https://ntrs.nasa.gov/citations/20220015637.

Broadband



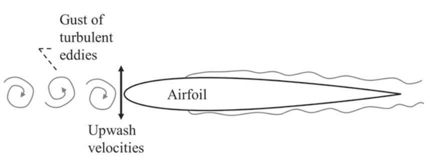


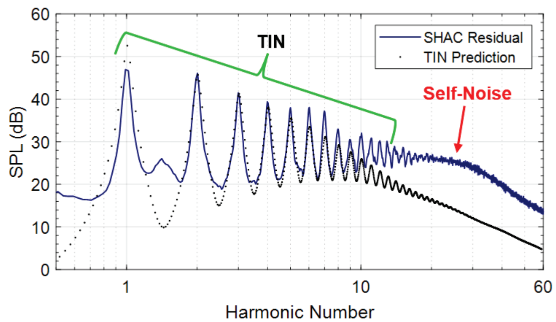


Pettingill, Zawodny, Thurman, and Lopes, "Acoustic and Performance Characteristics of an Ideally Twisted Rotor in Hover," *2021 AIAA SciTech Forum*, AIAA-2021-1928, 2021, https://arc.aiaa.org/doi/10.2514/6.2021-1928.

Recent and On-Going Research

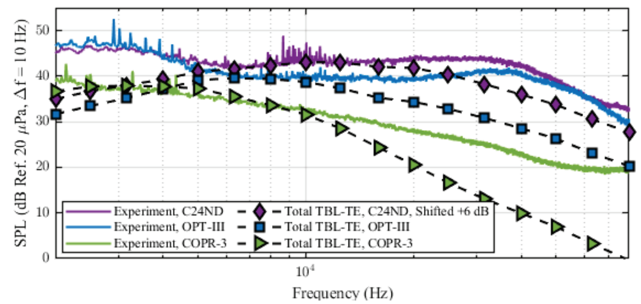
Amiet's Turbulence Ingestion Noise (TIN)





Zawodny and Lopes, "Reviving Amiet's Model for Noise Produced by Turbulent Flow Into a Rotor," *Spring 2025 NASA Acoustics Technical Working Group*, 2025. (Available upon request)

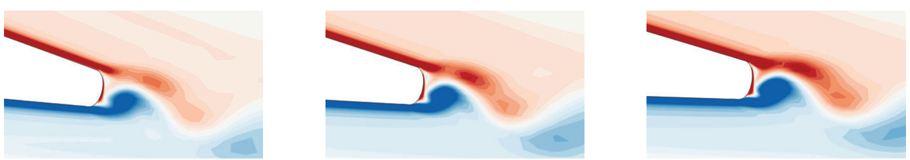
Turbulent Boundary Layer Trailing Edge (TBL-TE) Noise



Possible dependency of TE δ* on Mach number indicates need for further development of BPM TBL-TE model.

Blake, Thurman, Zawodny, and Lopes, "Broadband Predictions of Optimized Proprotors in Axial Flight," *2023 AIAA Aviation Forum*, AIAA-2023-4183, 2023, https://doi.org/10.2514/6.2023-4183.

Bluntness Vortex Shedding (BVS) Noise

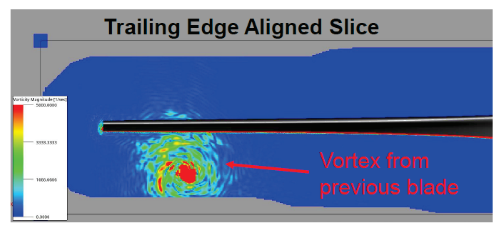


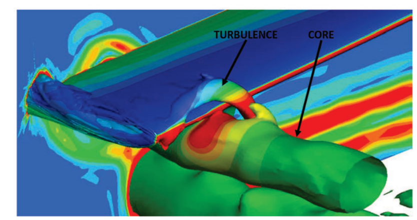
r=0.55R r=0.65R r=0.75R

Spanwise vorticity contours at the trailing edge using 2-D hybrid RANS/LES airfoil simulation.

Blake, Thurman, and Zawodny, "A Computational Study of Bluntness Vortex Shedding Noise Generated by a Small Canonical Rotor for UAM Applications," *VFS 81st Annual Forum*, 2025, https://doi.org/10.4050/F-0081-2025-112.

Blade-Wake Interaction (BWI) Noise





BWI and BWI-amplified BVS noise found significant (+7 dB) for small hovering rotors.

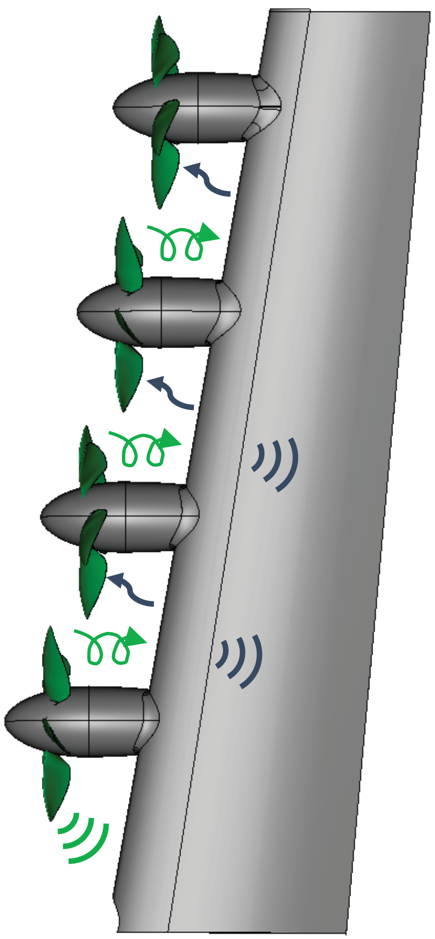
Thurman, "Broadband Noise Prediction for Advanced Air Mobility: A Computationalist Perspective," Politecnico di Milano, Aerospace Science and Technology Department PhDAER Seminar, Milan, Italy, 2025.

Won and Lee, "Effect of Trailing-Edge Vortex Shedding on Rotor Noise Using High-Fidelity Numerical Simulations," *2025 AIAA Aviation Forum*, AIAA-2025-3366, 2025, https://doi.org/10.2514/6.2025-3366.

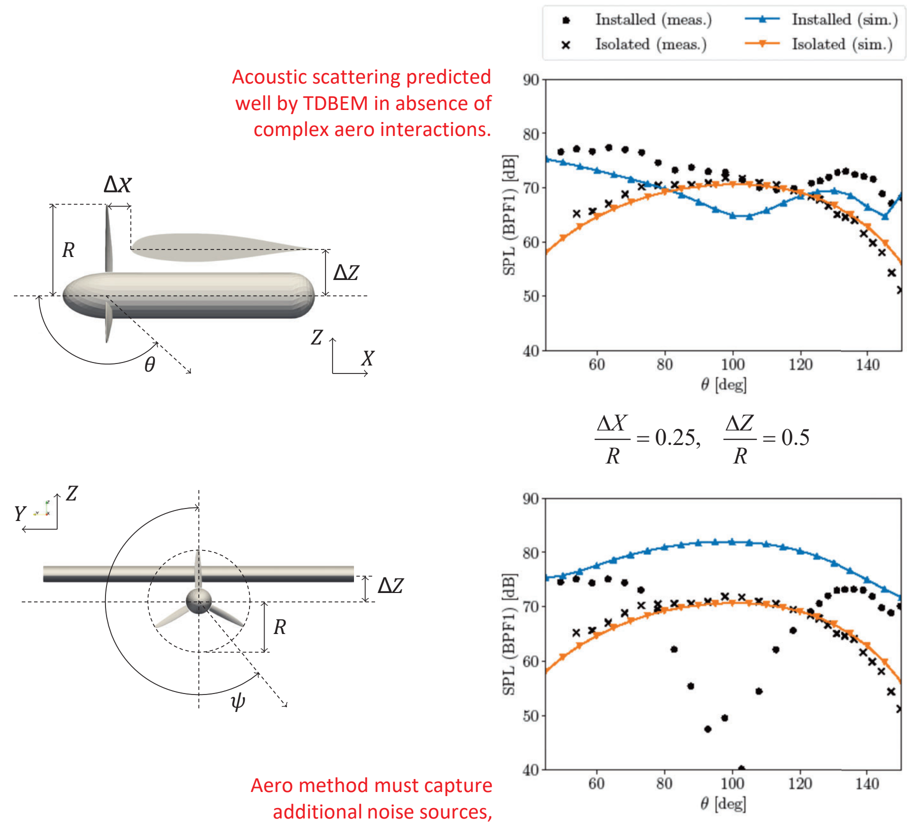
Blade-Airframe Interaction

Installed Propellers:
Prop-to-Wing Interactions

- **Scattering/shielding of propeller acoustic source (source directivity important)**
- **Effects of wing flow field on propeller blade loading may result in modification of resultant propeller source**
- **Propeller wake impinging on aircraft surfaces may affect aerodynamic performance and produce additional noise sources**



Acoustic scattering predicted well by TDBEM in absence of complex aero interactions.



$\frac{\Delta X}{R} = 0.25, \quad \frac{\Delta Z}{R} = 0.5$

$\frac{\Delta X}{R} = 0.25, \quad \frac{\Delta Z}{R} = 0.75$

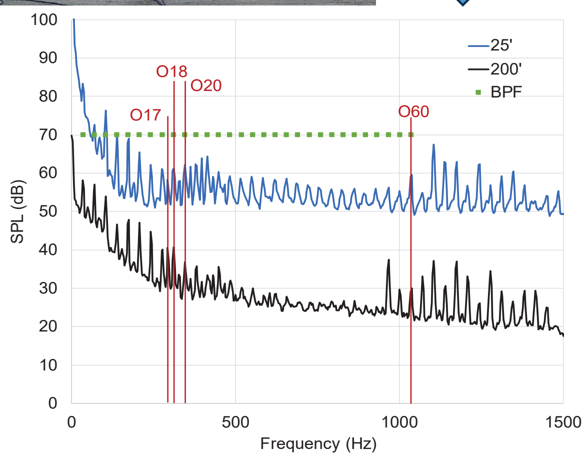
Aero method must capture additional noise sources, but TDBEM still captures scattered field.

Groom, Zhou, and Lopes, "Numerical Investigation of Propeller-Wing Interaction Noise with Scattering and Shielding," *2025 AIAA Aviation Forum*, AIAA-2025-3369, 2025, https://doi.org/10.2514/6.2025-3369.

Discovery, Source Noise Prediction, and Validation

Electric Motor Noise Measurement and Modeling

Full scale Moog S-250 measurements†
- Ground run-up with and without rotors
- Hover – 15’ and 60’

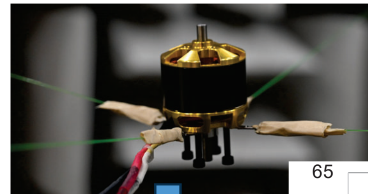


Some evidence of electric motor noise at O17-20 in ground run-up spectra

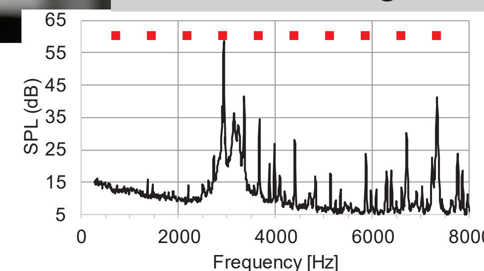
Model‡ predicts motor tones from simple high-level motor parameters
- Diameter
- Power
- Motor windings, etc.

Suitable for trade studies & extendable to larger motors.

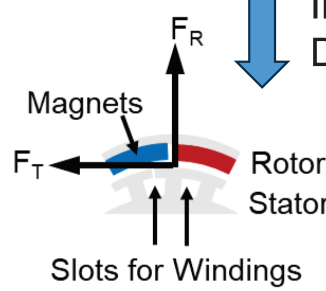
Motivates Development



1 – 4 kW outrunner motor laboratory acoustic testing



Informs Model Development



Force from Magnetic Field

Structural Vibration

Acoustic Radiation

Acoustic prediction tool development models three subcomponents

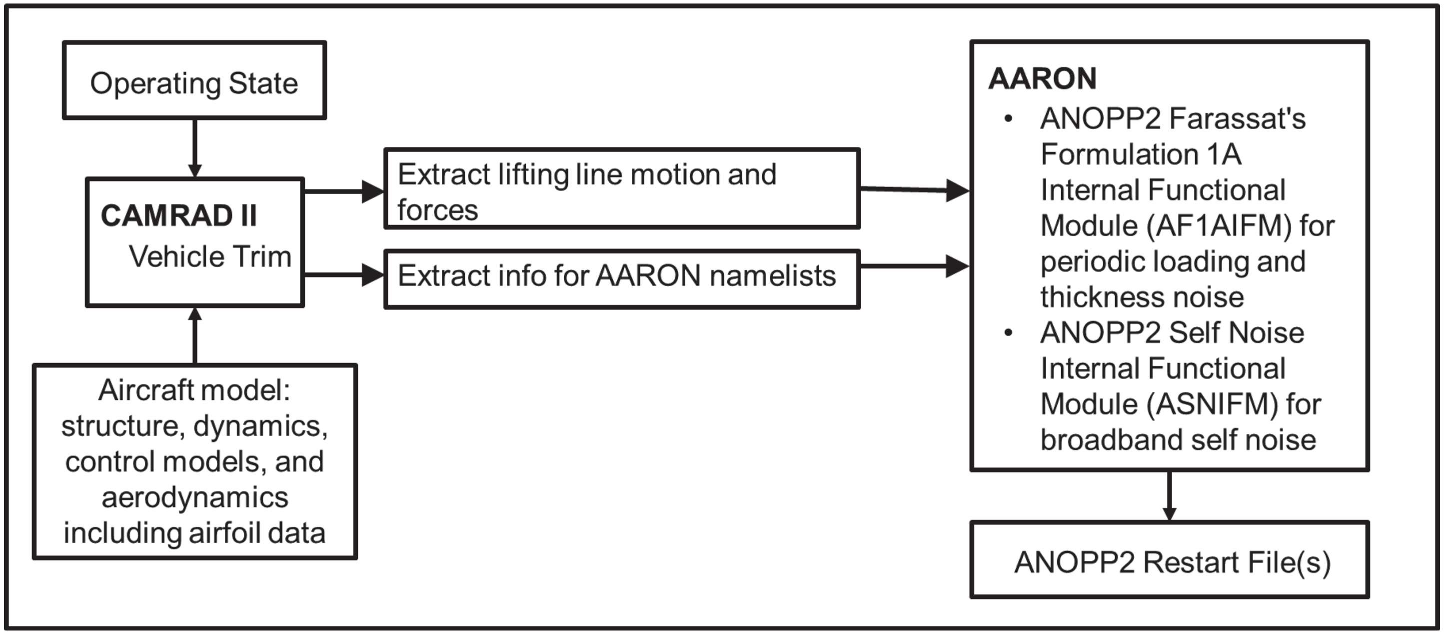
†Henderson, et al., “Acoustic Measurements for the Moog S-250 Vehicle in Hover,” *30th AIAA/CEAS Aeroacoustics Conference*, AIAA-2024-3275, Rome, IT, 2024, https://doi.org/10.2514/6.2024-3275.
‡Busch, et al., “An Initial Vibro-Acoustic Model for Predicting Electric Motor Noise,” *Fall 2024 NASA Acoustics Technical Working Group Meeting*, 2024, https://ntrs.nasa.gov/citations/20240012196.

Mid-Fidelity Source Noise Prediction

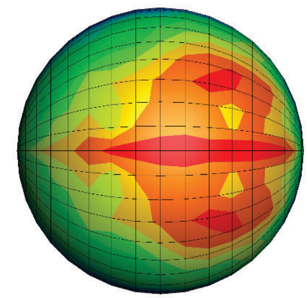
- Noise prediction method development, implementation, and validation efforts continue.
- The computational framework allows the human response effort to make use of the best available validated noise prediction methods at various points in time.

Source Noise Prediction

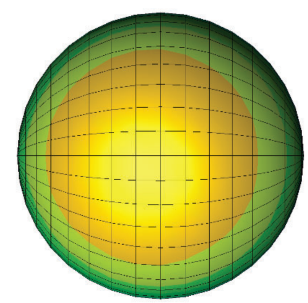
Mid-Fidelity Source Noise Prediction

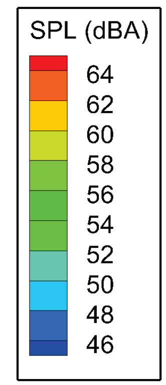


Loading and Thickness Noise



Broadband Self Noise

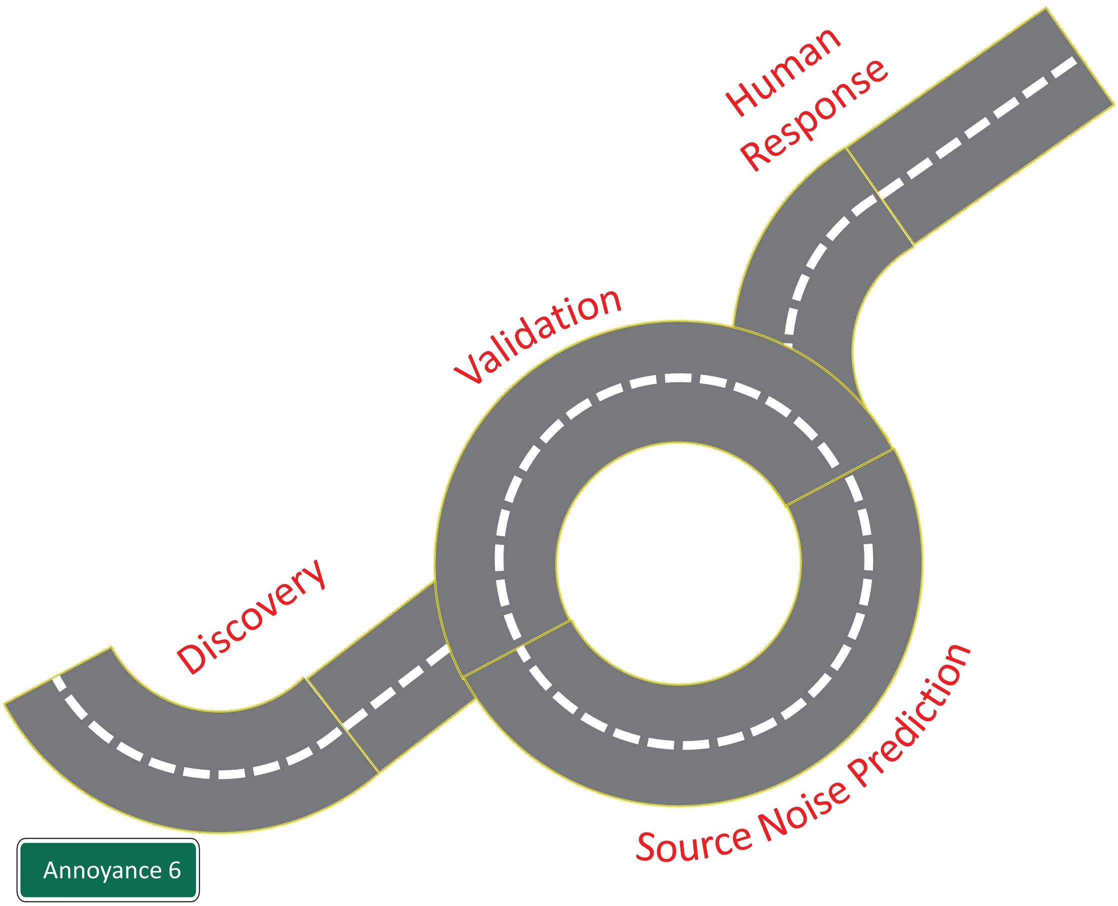




- Quadrotor was trimmed utilizing collective pitch control and constant RPM. The same trim mode was used for all speeds.
- Lift plus Cruise was trimmed utilizing collective pitch control with constant RPM. Three different trim modes used for low, moderate, and high speeds.

Rizzi, Letica, Boyd, and Lopes, "Prediction of Noise-Power-Distance Data for Urban Air Mobility Vehicles," *AIAA Journal of Aircraft*, Vol. 61, No. 1, pp. 166-182, 2024, https://doi.org/10.2514/1.C037435.

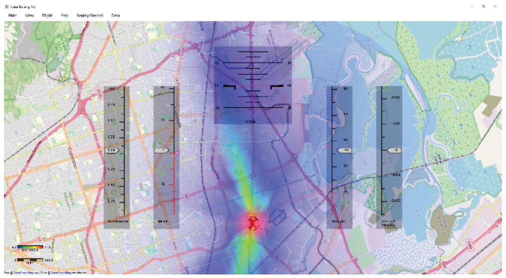
The Road

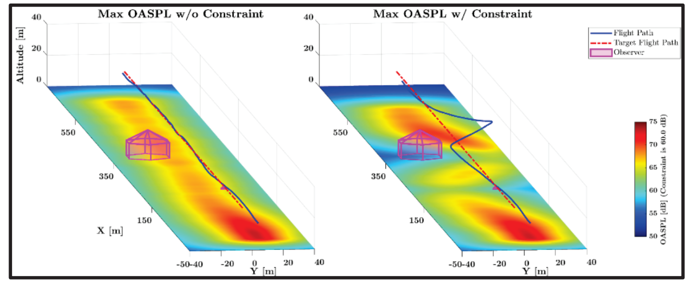


- Discovery
  - The Importance of Broadband Noise
- Source Noise
  - Modeling Framework & Prediction
  - Exp. and Numerical Validation
- Human Response
  - Auralization
  - Psychoacoustic Testing
  - Annoyance Model

Human Response

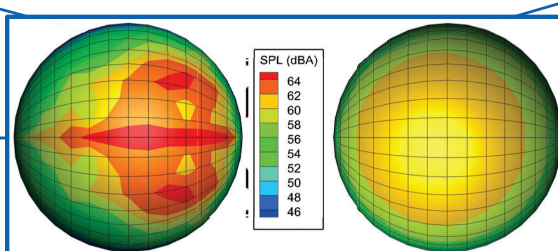
Annoyance-Related Off-Ramps



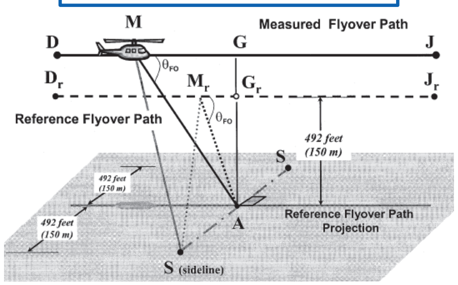


Acoustic Flight Simulator

Acoustically Aware Flight Control

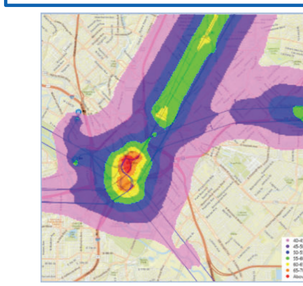


Noise Certification Analyses



https://federalregister.gov/a/04-12069

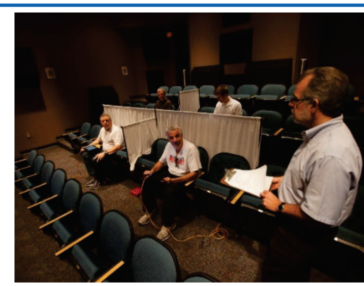
Operational Fleet Noise Assessments



Annoyance 4

Perception-Influenced Design

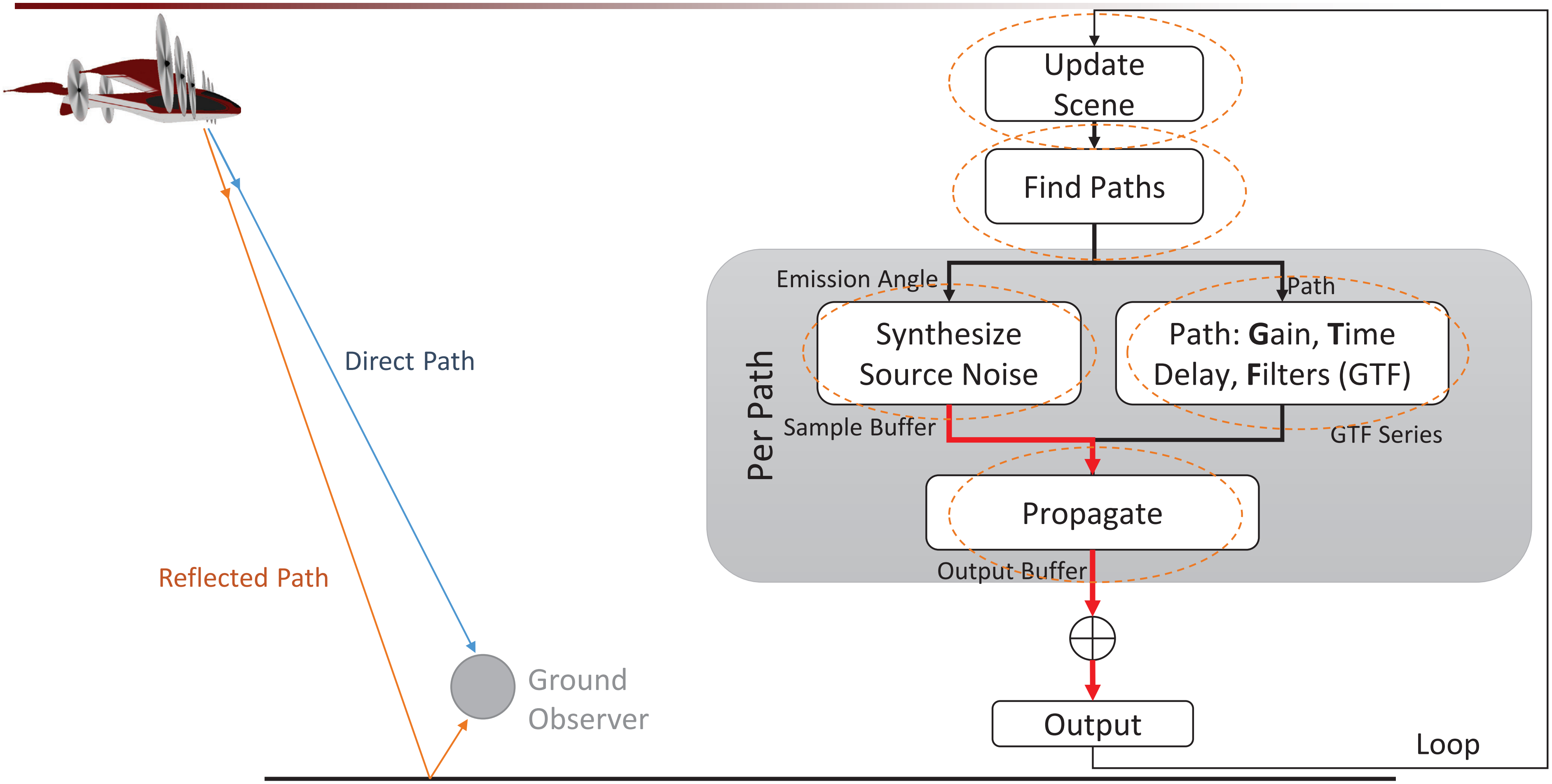
Auralization & Psychoacoustics



Human Response

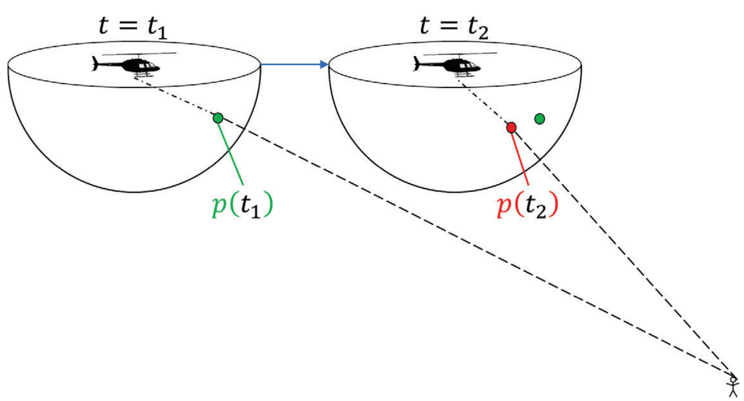
Auralization

Rizzi and Sahai, "Auralization of Air Vehicle Noise for Community Noise Assessment," *CEAS Aeronautical Journal*, 2019, https://doi.org/10.1007/s13272-019-00373-6.



eVTOL Tonal and Broadband Noise Synthesis

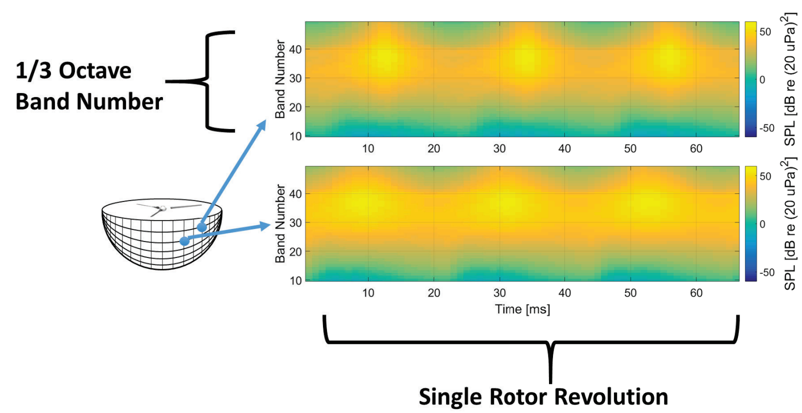
Synthesis of Loading and Thickness Noise using ANOPP2 Farassat's Formulation 1A Internal Functional Module (AF1AIFM)



Quadrotor Periodic

Krishnamurthy, Tuttle, and Rizzi, "A Synthesis Plugin for Steady and Unsteady Loading and Thickness Noise Auralization", *2020 AIAA AVIATION Forum*, AIAA-2020-2597, 2020, https://doi.org/10.2514/6.2020-2597.

Self Noise Sound Pressure Predictions from ANOPP2 Self Noise Internal Functional Module (ASNIFM)



1.8mm TE

7.2mm TE

Krishnamurthy, Aumann, and Rizzi, "A Synthesis Plugin for Auralization of Rotor Self Noise", *2021 AIAA AVIATION Forum*, AIAA-2021-2211, 2021, https://doi.org/10.2514/6.2021-2211.

Level Flyover

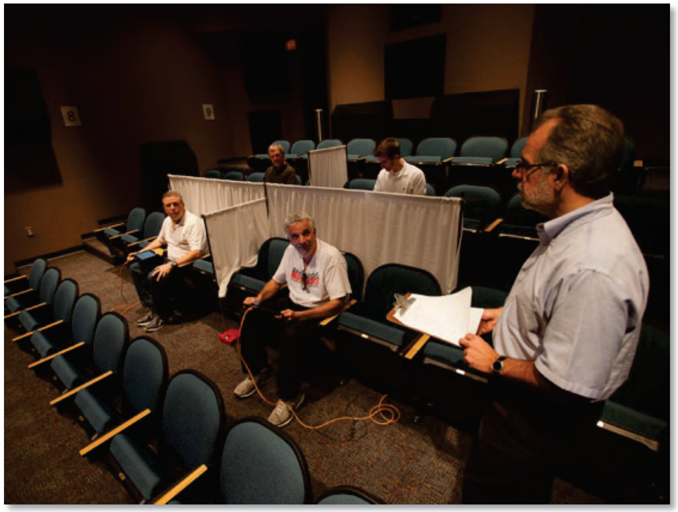
Human Response

Psychoacoustic Studies Utilizing eVTOL Auralizations

Annoyance 2

- Test of UAM Sound Quality – TuSQ (Aug 2022)†
  - Objective: Investigate how annoyance varies with sound quality.
  - Approach: Manipulated baseline auralizations to vary SQ attributes.
  - Main Findings:
    - UAM sounds judged more annoying than a reference sound presented at the same loudness level. Loudness not only factor affecting annoyance.
    - Positive correlation of tonality, impulsiveness, and roughness with annoyance.
- Test of Noise and Numbers – NaN (January 2023)‡
  - Objective: Investigate how annoyance varies with number of operations.
  - Approach: Present flyover auralizations from 0.5 to 8 ops/min at 3 Leq levels
  - Main Findings:
    - Mean annoyance ratings for frequent discrete sounds (< 2 ops/min) differed from those for constant sounds (≥ 2 ops/min).
    - Annoyance to frequent discrete sounds grows faster with increasing number than for constant sounds (3 dB/doubling).
- Test of Detection, Noticeability, and Annoyance – DNA (Oct 2023)*
  - Objective: Investigate how annoyance varies in presence of masking noise.
  - Approach: Measure *d'* and equal annoyance points for UAM-like tone complex and UAM-like broadband signal in presence of a broadband masker.
  - Main Finding: Most test subjects' annoyance responses were reduced by the presence of masking noise.

Exterior Effects Room (EER)

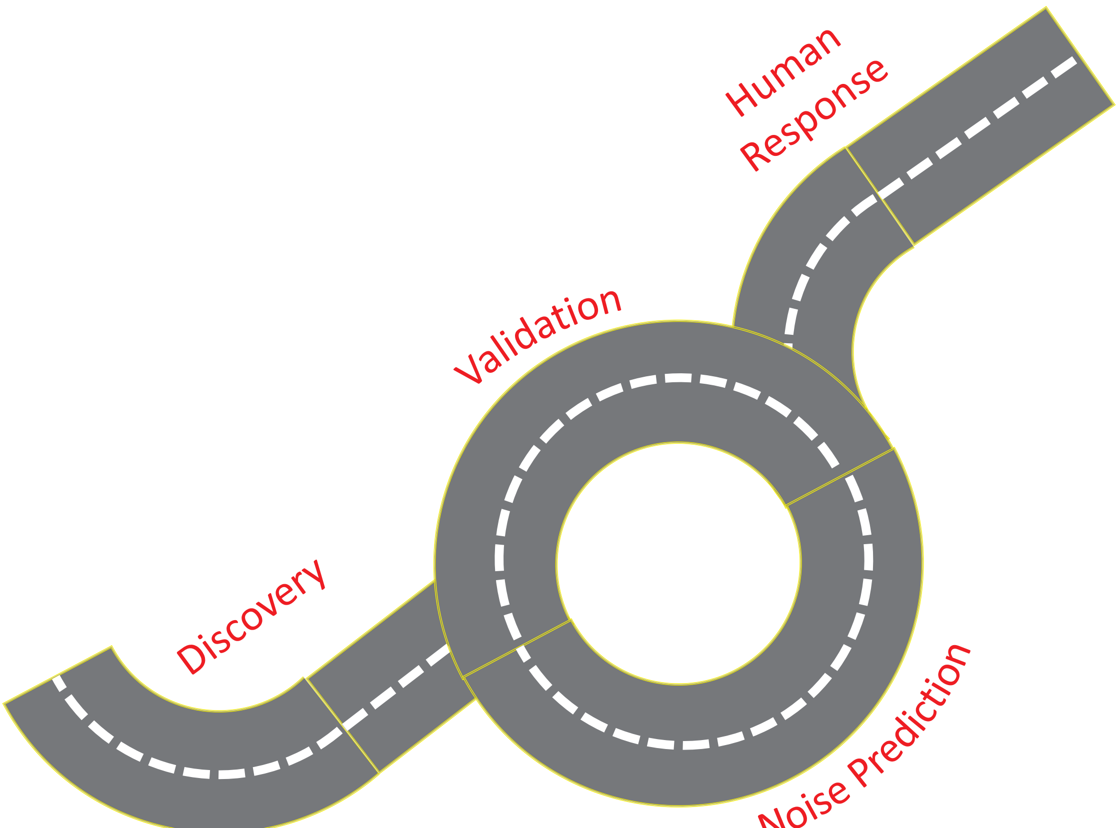


† Boucher, et al., "A Psychoacoustic Test for Urban Air Mobility Vehicle Sound Quality," *SAE International Journal of Advances and Current Practices in Mobility*, Vol. 6, No. 2, 2024, pp. 972-985, https://doi.org/10.4271/2023-01-1107.

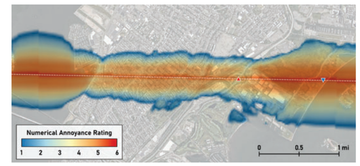
‡ Christian, "A Laboratory Psychoacoustic Test of the Tradeoff Between Frequent UAM Events and Their Level," *Fall 2023 NASA Acoustics Technical Working Group Meeting*, Cleveland, OH, 2023, https://ntrs.nasa.gov/citations/20230014880.

* Boucher, et al., "A Psychoacoustic Test on the Effect of Masking on Annoyance to Urban Air Mobility Vehicle Noise," *186th Meeting of the ASA*, Ottawa, Canada, 2024, https://doi.org/10.1121/10.0027136.

The Road



Annoyance 6



- Discovery
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  - Psychoacoustic Testing
  - **Annoyance Model**

Human Response

Initial UAM Noise Annoyance Model

Annoyance Model

Loudness

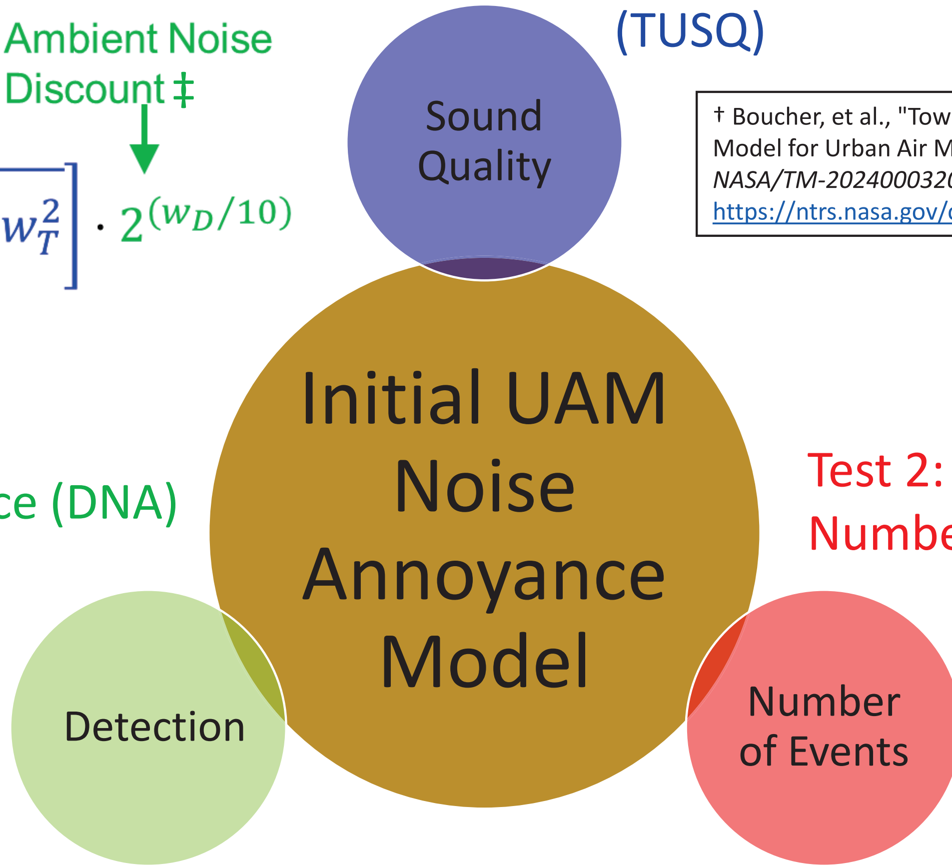
Sound Quality Adjustment†

Ambient Noise Discount‡

$$AM = N \cdot \left[1 + \sqrt{w_{FR}^2 + w_S^2 + w_T^2}\right] \cdot 2^{(w_D/10)}$$

Test 1: Test of UAM Sound Quality (TUSQ)

† Boucher, et al., "Toward a Psychoacoustic Annoyance Model for Urban Air Mobility Vehicle Noise," *NASA/TM-20240003202*, 2024, https://ntrs.nasa.gov/citations/20240003202.



Test 3: Test of Detection, Noticeability, and Annoyance (DNA)

‡ Christian, "A Construction for the Prediction of Noise-Induced Annoyance in the Presence of Auditory Masking," *181st Meeting of the Acoustical Society of America*, Seattle, WA, 2021, https://doi.org/10.1121/10.0008224.

Tracy, et al., "An Annoyance Model for Urban Air Mobility Vehicle Noise in the Presence of a Masker," *Noise-Con 2024*, New Orleans, LA, 2024, https://ntrs.nasa.gov/citations/20240003592.

Test 2: Test of Noise and Numbers (NaN)

Human Response

Annoyance Model in the Presence of Masking

- Desired behaviors
  - Effect of ambient noise on annoyance not strong if signal >> ambient.
  - Reduction in annoyance to the signal if signal at least partially masked by ambient.

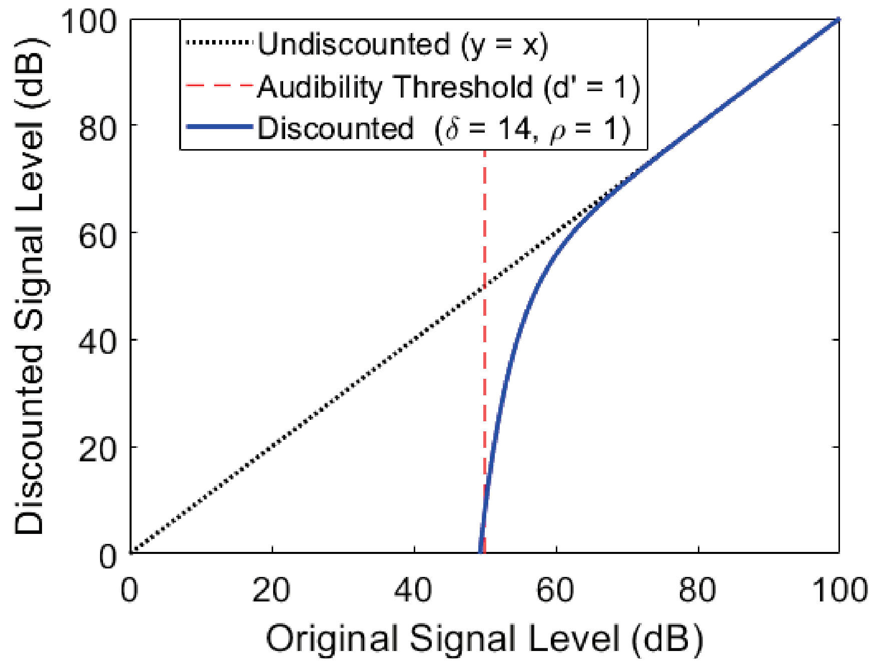
- Discounting model

$$L_{i,t}\big|_{Disc} = L_{i,t} - \frac{\alpha}{\left(\frac{d'_{i,t}}{\delta}\right)^{\rho}} \qquad d'_{i,t} = \mathbb{D}_i \cdot \frac{s_{i,t}}{n_{i,t} + e_i}$$

$L_{i,t}$: signal spectrogram

$d'_{i,t}$: detectability index spectrogram

α, δ, ρ : parameters from human response testing



Rizzi, Christian, Letica, and Lympany, "Annoyance Model Assessments of Urban Air Mobility Operations," *AIAA Journal of Aircraft*, 2025, https://doi.org/10.2514/1.C038188.

Human Response

Modeled Masking Noise

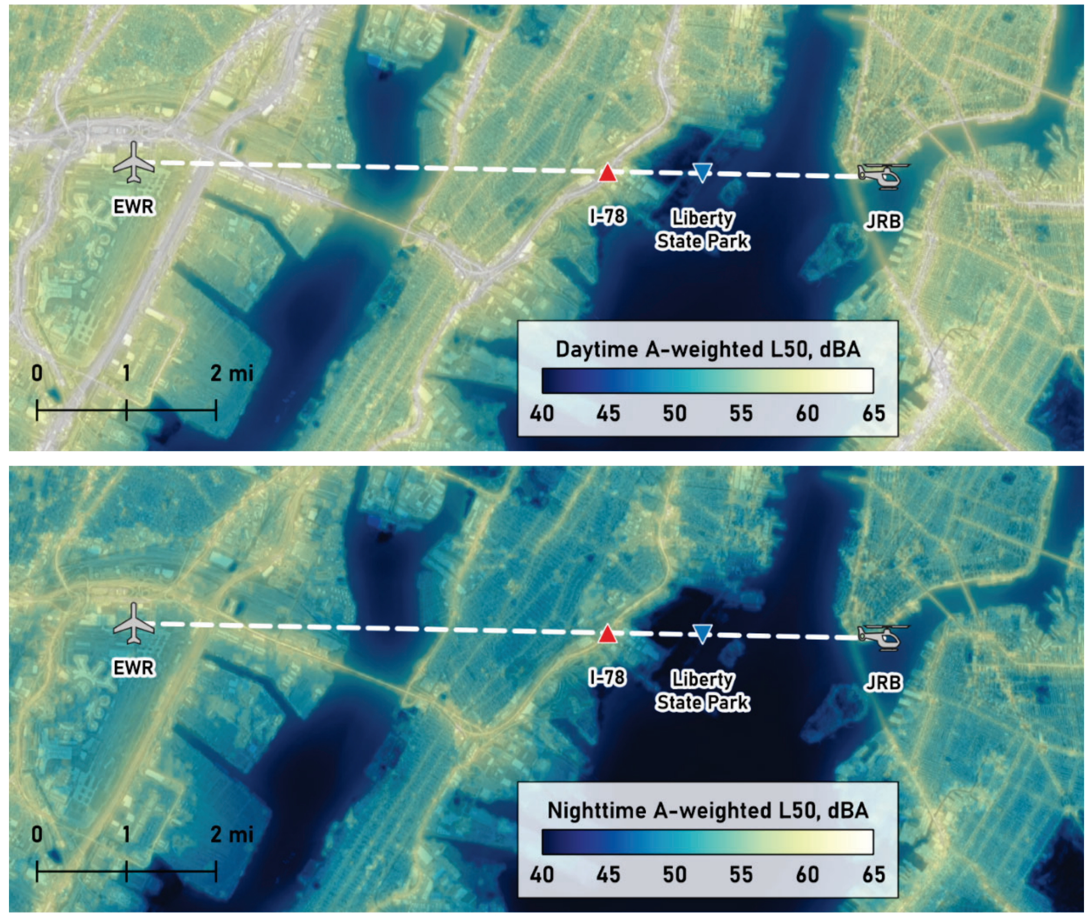
BRRC AMBIENT Model

- A physics-informed machine learning (ML) model of ambient soundscapes.
  - Model composed of anthropogenic, biological, and geophysical sounds.
  - Generates spatially, temporally, spectrally varying maps.

Ambient level = *f* (geospatial features, physics-based noise)

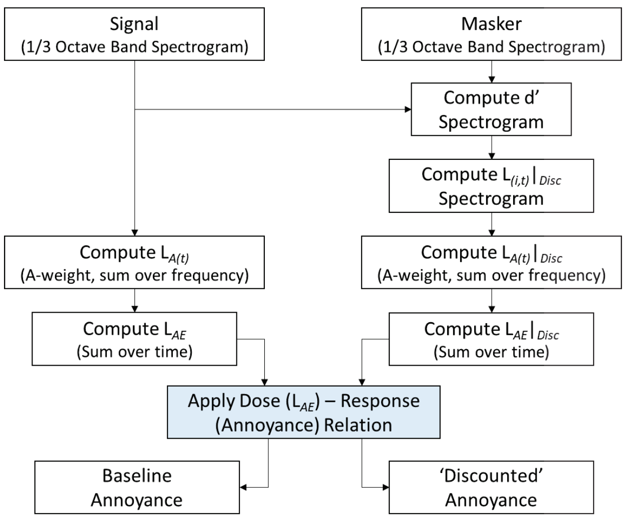
- *f* determined by fitting ensemble of ML regression models at locations where geospatial features, predicted traffic noise, and ambient levels are known.
- Geospatial features at 30 m resolution include population density, land cover, topography, climate.
- Physics-based noise includes road traffic noise, but not (currently) aviation noise.

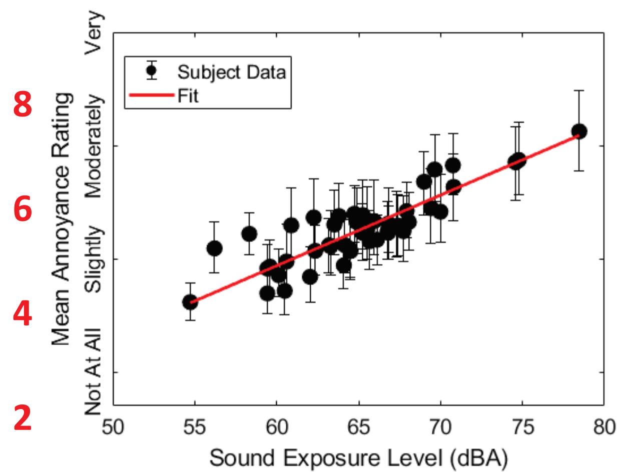
Day/Night Median Noise Levels



Human Response

Dose-Response Relation





sUAS Annoyance = 0.125 L_{AE} – 3.61

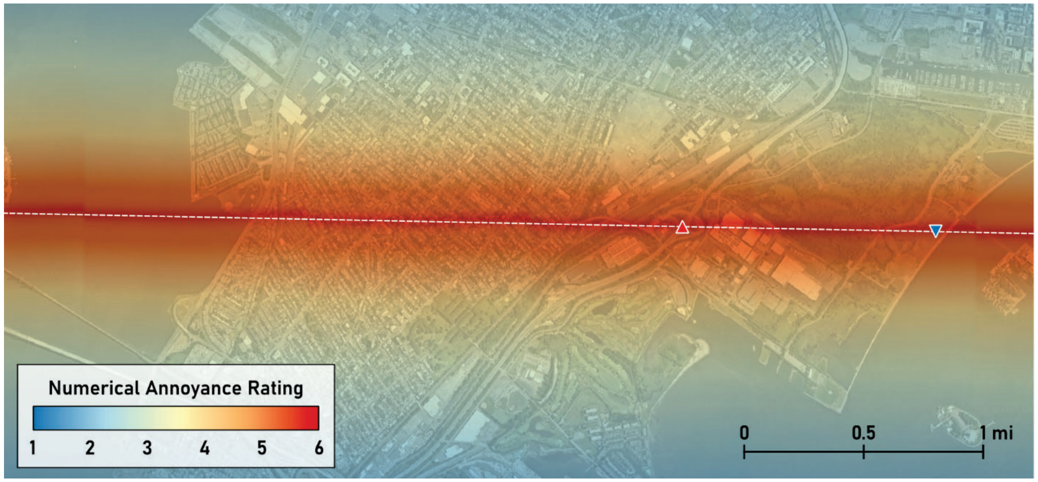
- Single-event relationship between annoyance and L_{AE} for small UAS is a surrogate for UAM-specific relation.
- The road ahead addresses work toward a UAM-specific relation.

Christian and Cabell, "Initial Investigation into the Psychoacoustic Properties of Small Unmanned Aerial System Noise," *23rd AIAA/CEAS Aeroacoustics Conference,* AIAA-2017-4051, Denver, CO, 2017, https://doi.org/10.2514/6.2017-4051.

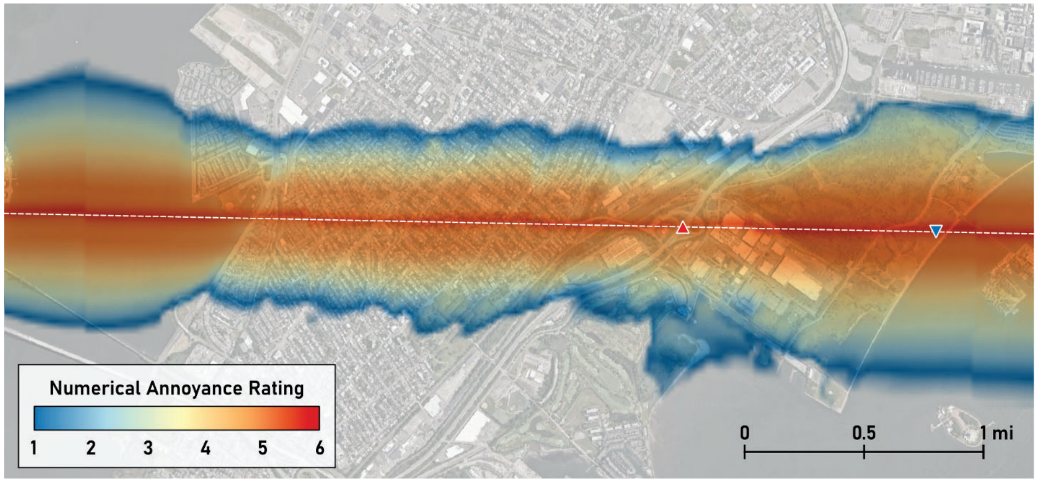
Krishnamurthy, et al., "Remotely Administered Psychoacoustic Test for sUAS Noise to Gauge Feasibility of Remote UAM Noise Study," *SAE International Journal of Advances and Current Practices in Mobility*, Vol. 6, No. 2, pp. 986-999, 2024, https://doi.org/10.4271/2023-01-1106.

Annoyance Maps

Baseline



Nighttime



- Baseline annoyance does not vary with position along the track but uniformly reduces from "Moderate" (6) below track to "Not at all" (2) with distance.
- Daytime annoyance slightly reduced below track and significantly reduced elsewhere except near LSP.
- Nighttime annoyance shows less reduction than daytime.

Human Response

Comparison of Annoyance Ratings Between Helicopter and Joby S4

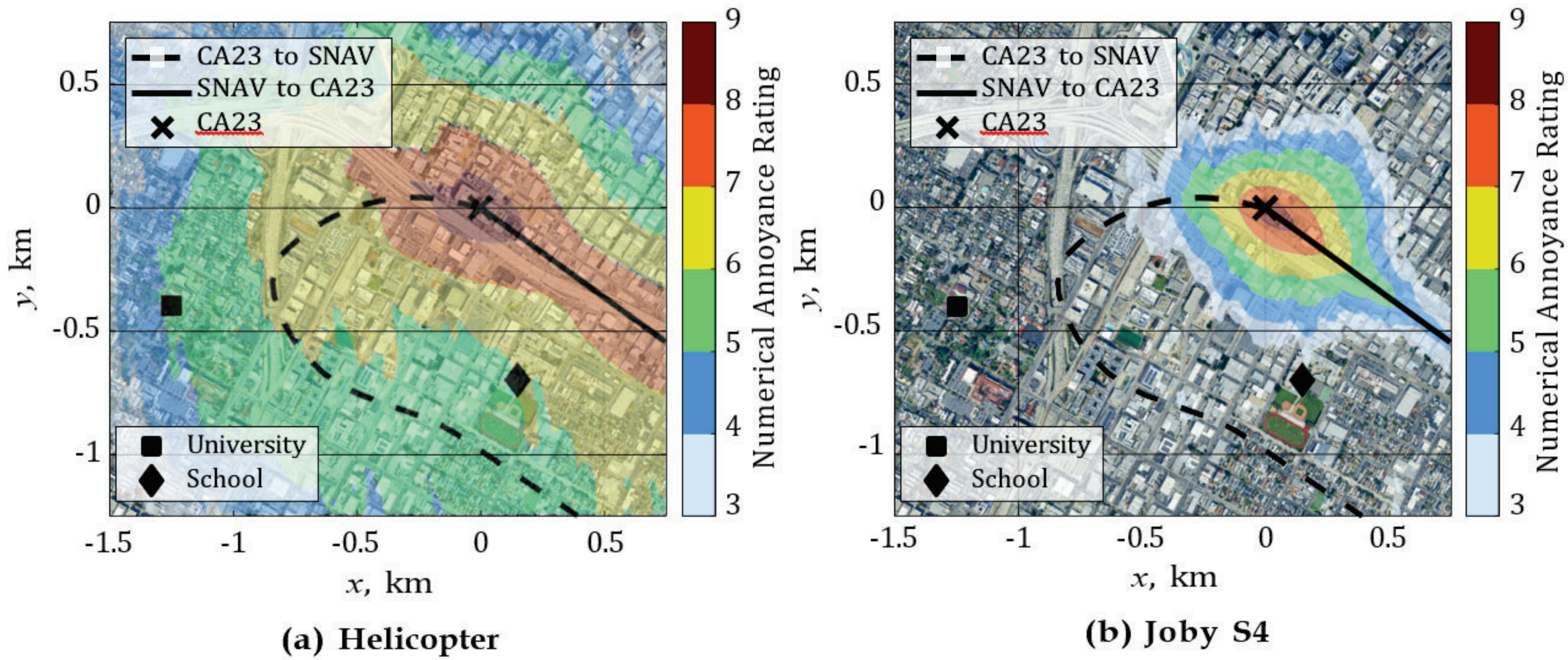


Fig. 14 Annoyance rating of one round-trip flight.

Thai, Bain, Josephson, Naru, Lympany, and Page, "Contextualizing the Acoustics of Joby Aviation Aircraft Operations with an Ambient Noise Model," *2025 AIAA Aviation Forum*, AIAA-2025-3138, Las Vegas, NV, 2025, https://doi.org/10.2514/6.2025-3138.

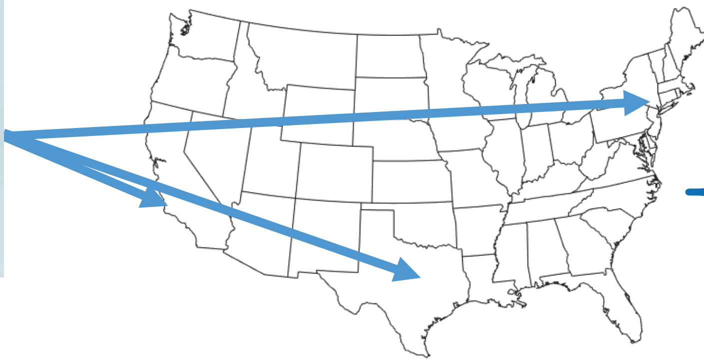
The Road Ahead

Laboratory Testing	EXIT 2025
Community Surveys	EXIT ~2030

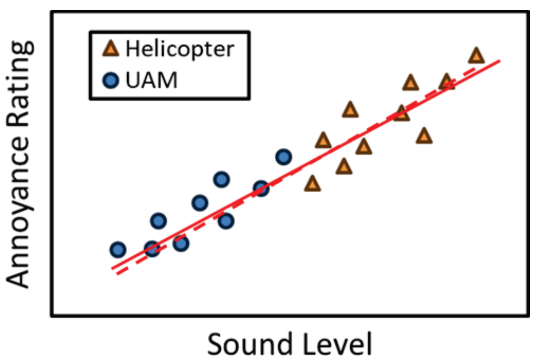
Photo by Meriç Dağlı on Unsplash

The Road Ahead – Laboratory Testing

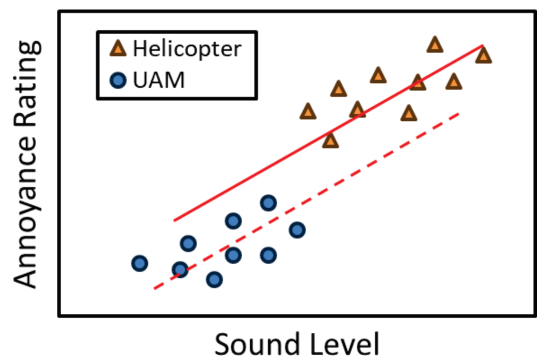
- **Varied AAM Noise and Geographic Area Response Difference (VANGARD) Online Test: Response to variety of single-event UAM flight operations**



- **Helicopter and UAM Laboratory Comparison (HULC) EER Test**



?



Data from VANGARD and HULC tests will be used to form a single-event dose-response relation specific to UAM.

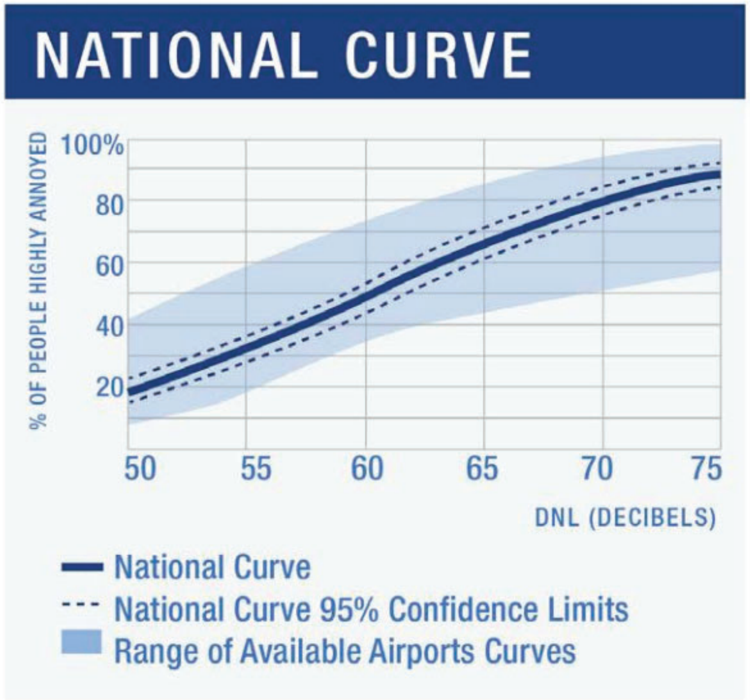
The Road Ahead – Community Surveys

<u>Objective</u>

- Develop a nationally representative long-term exposure-response relationship for UAM aircraft in relation to existing aircraft noise.

<u>Approach</u>

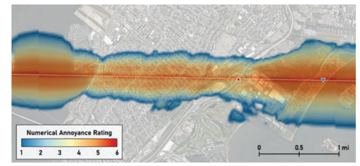
- Conduct an observational study like the FAA Neighborhood Environmental Survey† (NES) using certificated vehicles flying over populations for long periods of time.
  - The survey(s) would be FAA-led with NASA in a support role.

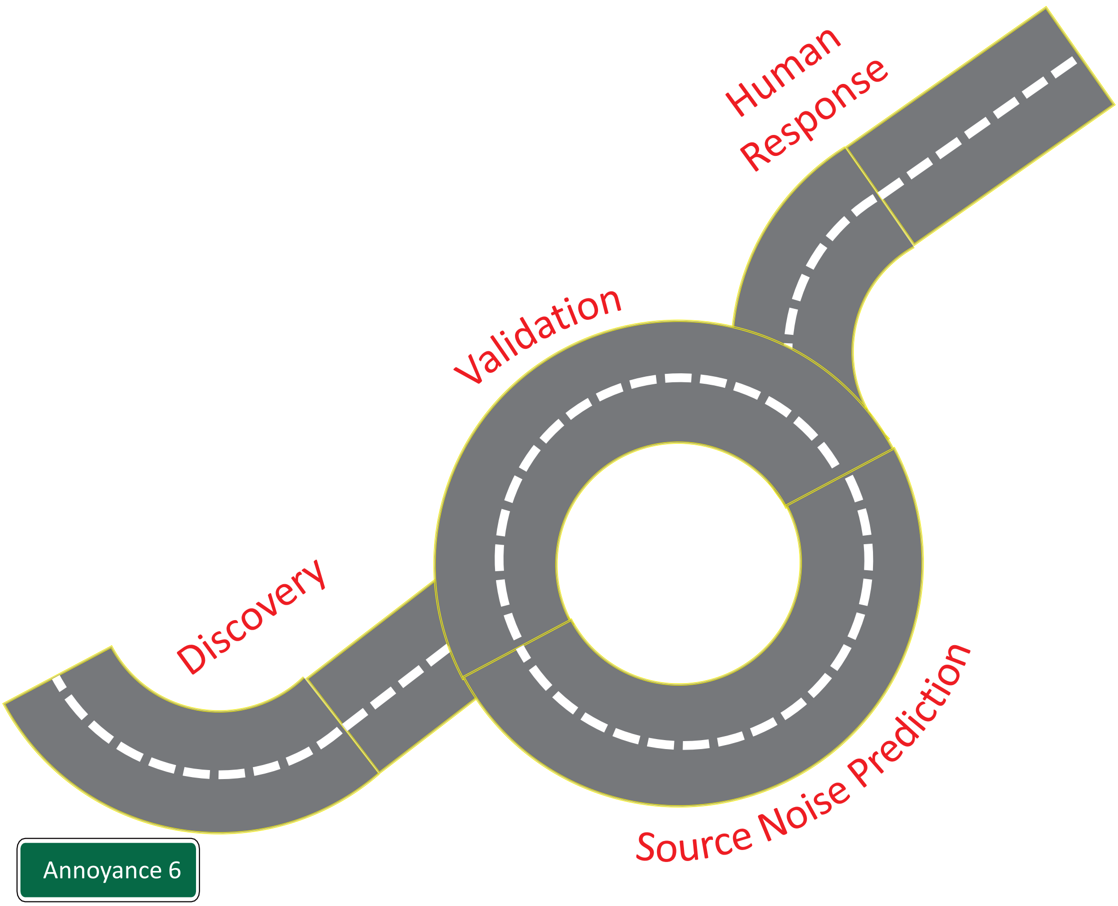


Long-term exposure-response curve establishes the relationship between exposure and annoyance <u>for the existing fleet</u>.

† Miller et al., "Analysis of the Neighborhood Environmental Survey," FAA Hughes Technology Center, *DOT/FAA/TC-21/4*, 2021, https://www.faa.gov/regulations_policies/policy_guidance/noise/survey.

Summary





- The Road to Annoyance was paved over the course of many years through the dedicated and sustained efforts of a multi-disciplinary team of subject-matter experts.
- This effort demonstrates that the whole is, indeed, greater than the sum of its parts.

Thank You

The work presented herein was conducted in support of the NASA Revolutionary Vertical Lift Technology Project and the NASA Transformational Tools and Technology Project.

This presentation is available on the NASA Technical Report Server (https://ntrs.nasa.gov/citations/20250006855).