Characterization of Urban Air Mobility Vehicle Operational Noise and Community Noise Impact

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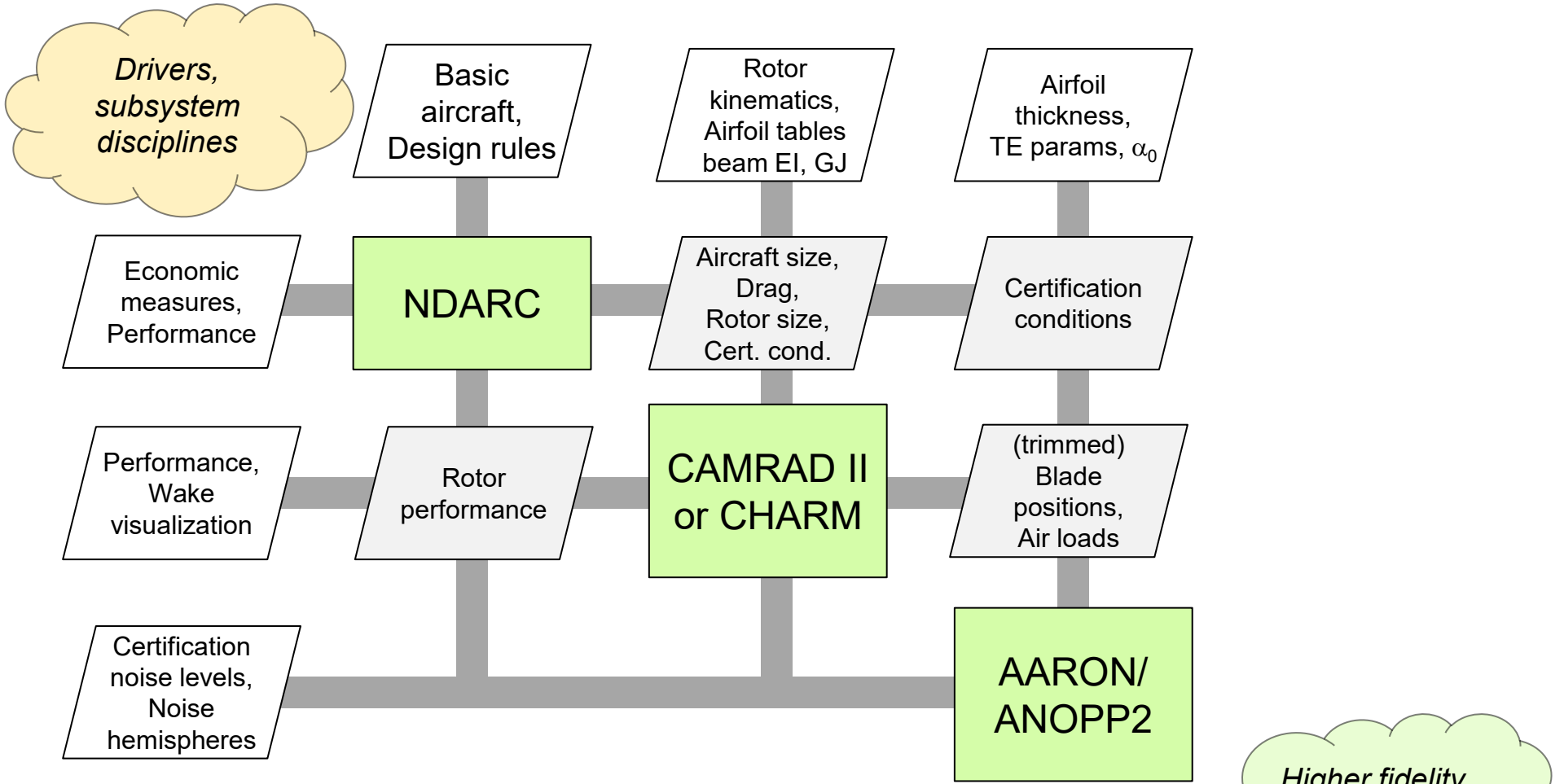
Le Transport Urbain de Passagers par Aéronefs Electriques
(Urban Transportation of Passengers by e-VTOL)
Académie de L'air et de L'espace (AAE)
21-22 September 2022

AAM and UAM

- Advanced Air Mobility (AAM) missions characterized by < 300-500 nm range
- Vehicles require increased automation and are likely electric or hybrid-electric
- Rural and urban operations are included
- Missions can be public transportation, cargo delivery, air taxi, or emergency response
- Urban Air Mobility (UAM) is a subset of AAM and is a segment that is projected to have high economic benefit and be the most difficult to develop
  - UAM requires an airspace system to handle high-density operations
  - UAM requires an advanced urban-capable vehicle
  - UAM vehicle variants can target other missions

The Revolutionary Vertical Lift Technology Project and Transformational Tools and Technologies Project are two of seven NASA projects that support the AAM Mission.

NASA Toolchain for Analysis of Noise and Performance of VTOL Vehicles



Example Concept Vehicles

Quadrotor†

- All-electric variant
- 3-bladed rotors
- 6469 lb. GTOW
- V_{max} 109 KTAS

Lift Plus Cruise†

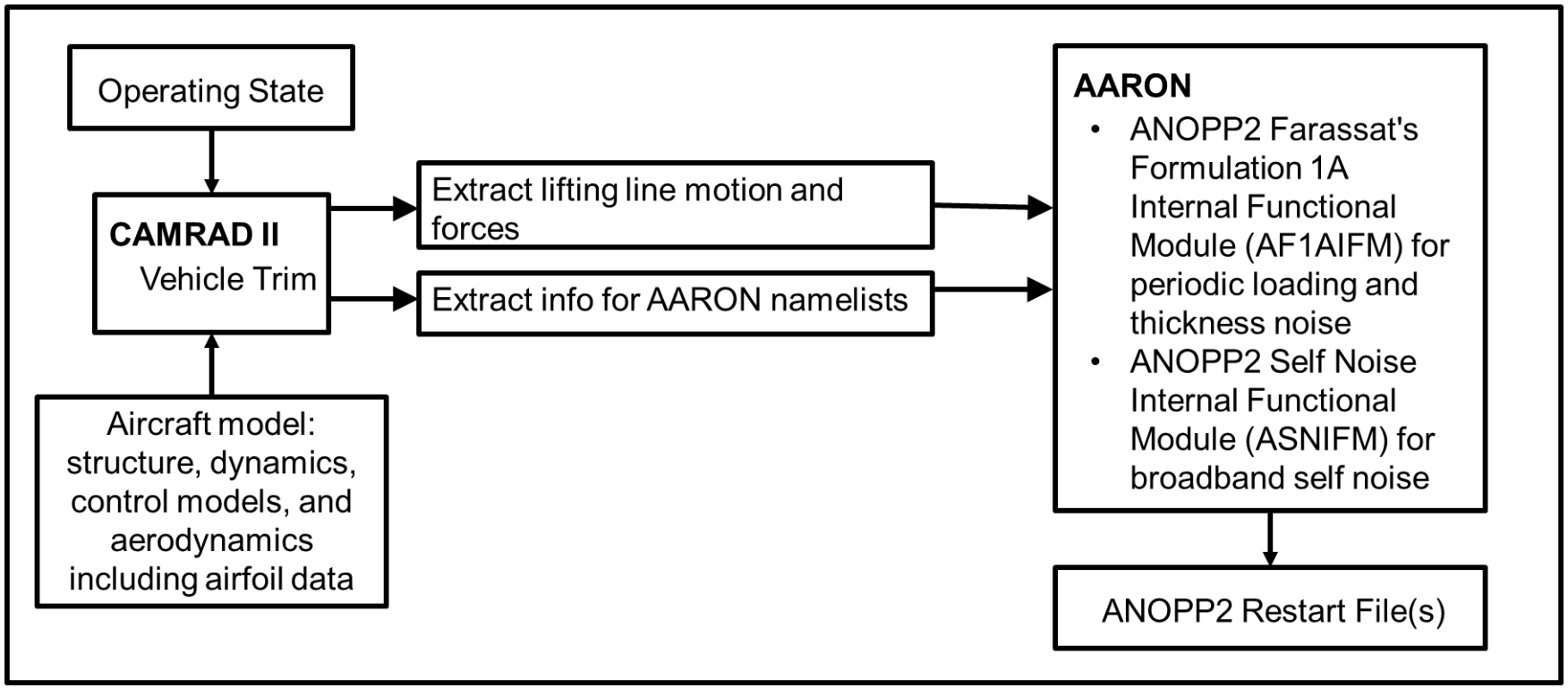
- Turboelectric variant
- (8) 2-bladed lifting rotors
- 3-bladed pusher propeller
- 5903 lb. GTOW
- V_{max} 123 KTAS

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

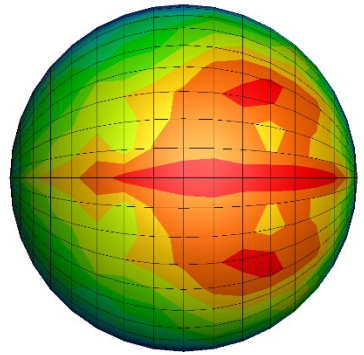
† Silva et al., "VTOL Urban Air Mobility Concept Vehicles for Technology Development," AIAA Aviation Forum, Atlanta, GA, June 2018, AIAA-2018-3847, https://doi.org/10.2514/6.2018-3847.

‡ Patterson et al., "A Proposed Approach to Studying Urban Air Mobility Missions Including an Initial Exploration of Mission Requirements," *AHS International 74th Annual Forum,* Phoenix, AZ, May 2018

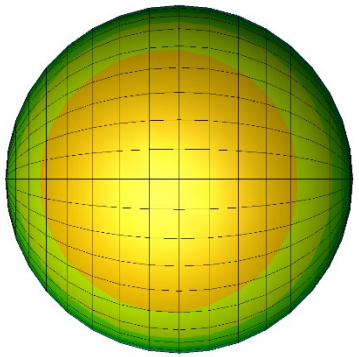
Source Noise Prediction

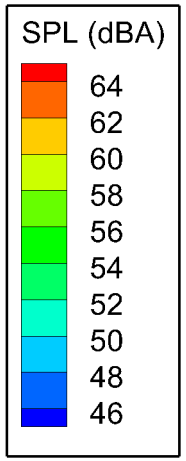


Loading and Thickness Noise



Broadband Self Noise

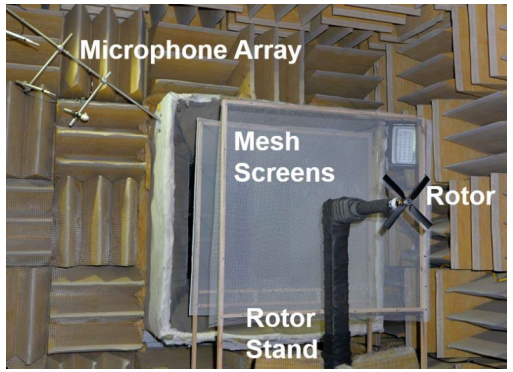




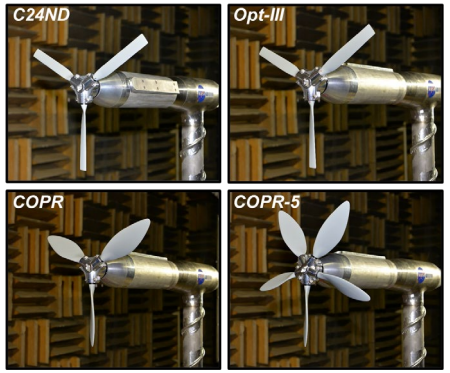
- Quadrotor was trimmed utilizing collective pitch control and constant RPM. The same trim mode was used for all speeds.
- Lift plus Cruise was trimmed utilizing collective pitch control with constant RPM. Three different trim modes used for low, moderate, and high speeds.

Experimental databases for validation of noise prediction models

- Recent isolated propellers and rotors



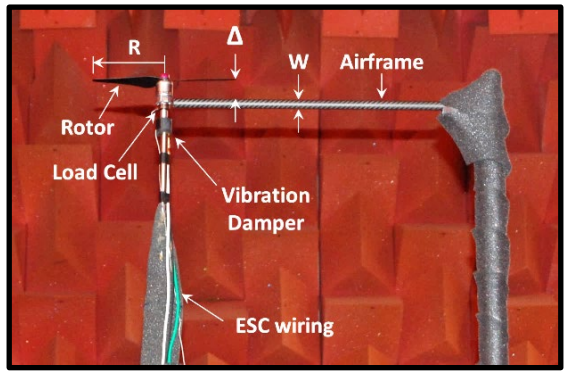
Ideally Twisted Rotor
AIAA-2021-1928



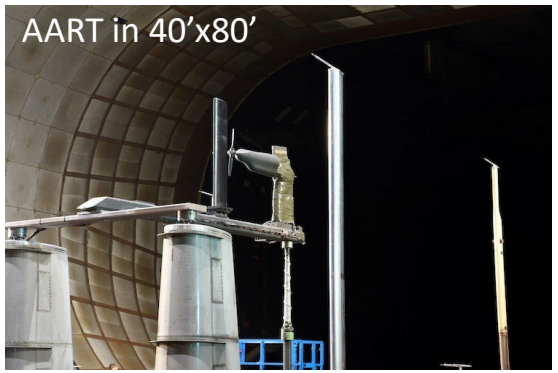
Optimized Proprotor
NASA ATWG Spring 2022

Cruise and High Lift Propellers
AIAA-2018-3448

- Recent installed propellers and rotors



Rotor-Airframe Interaction
73rd AHS Forum 2017

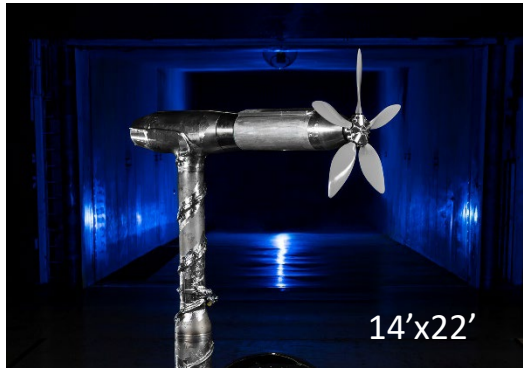


Pusher Configuration
77th VFS Forum 2021

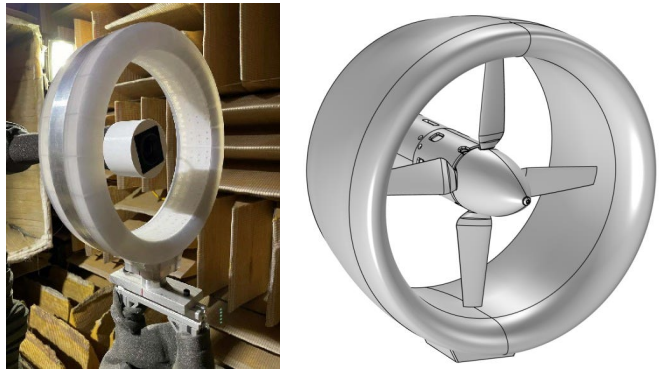
Tractor Configuration
AIAA-2021-0714

Experimental databases for validation of noise prediction models

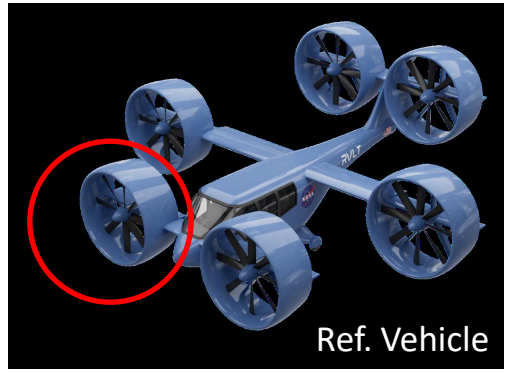
… more installed propellers, rotors, ducted rotors and tiltrotors



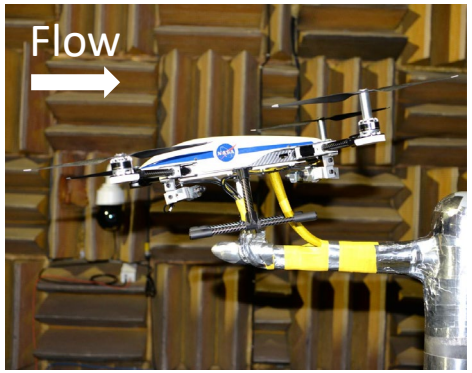
Tilting Vertical Lift Propeller
Aero Performance - Summer 2022
Acoustic Test – Start May 2023



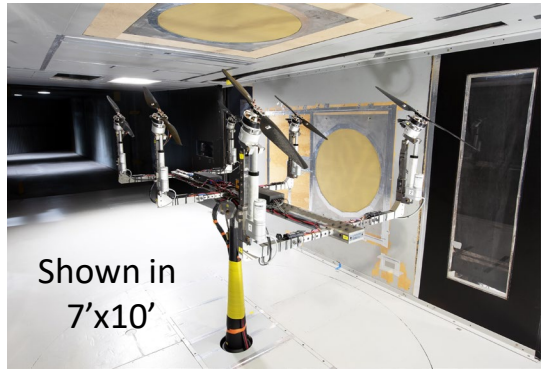
Ducted Speaker & Rotor
NASA ATWG Spring 2022



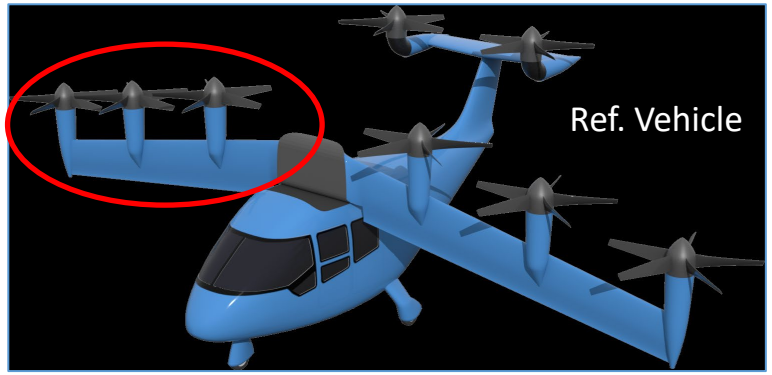
Tilt Duct Acoustic Test (40’x80’)
FY 23-25



Quadrotor – Blade Sets & Standoffs
AIAA-2022-3110 & InterNoise 2022

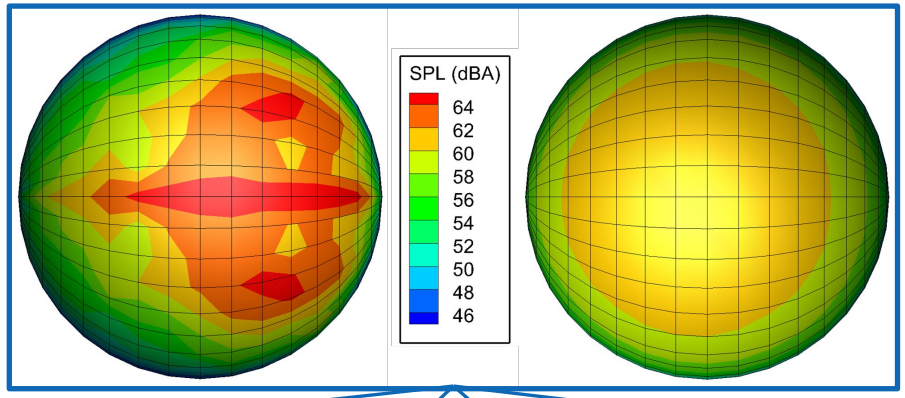


Multirotor Test Bed Acoustic Test (40’x80’)
FY 23-25

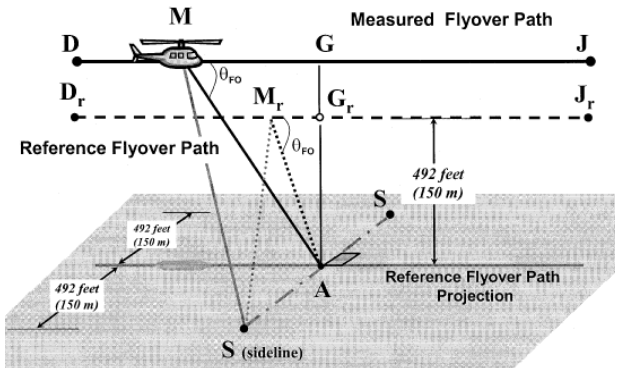


Tiltwing Acoustic Test (14’x22’)
FY 23-25

Utilization of Source Noise Predictions



Noise Certification Analyses

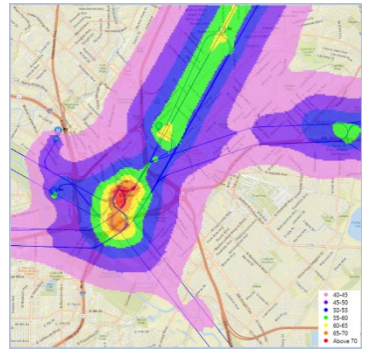


https://federalregister.gov/a/04-12069

Perception-Influenced Acoustic Design

Auralization and Psychoacoustic Studies

Operational Fleet Noise Assessments



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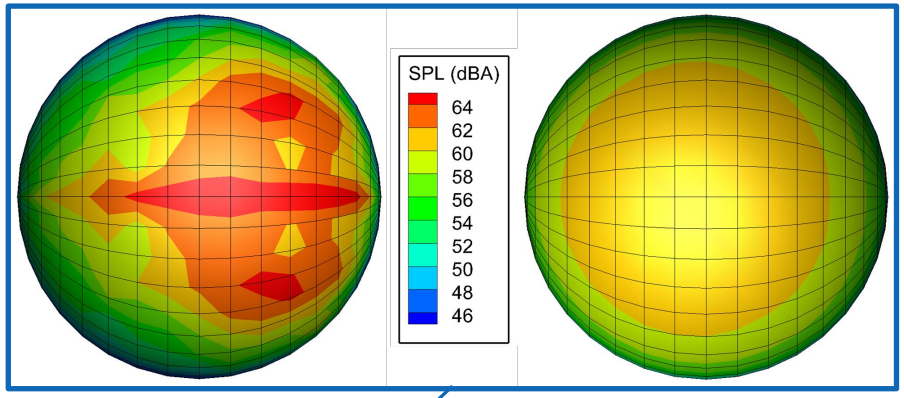
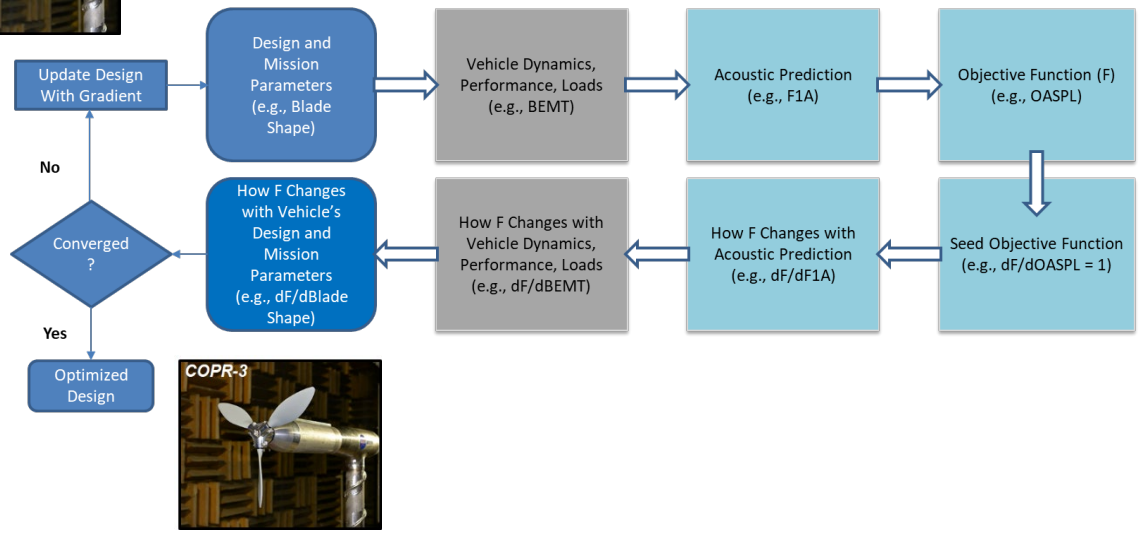
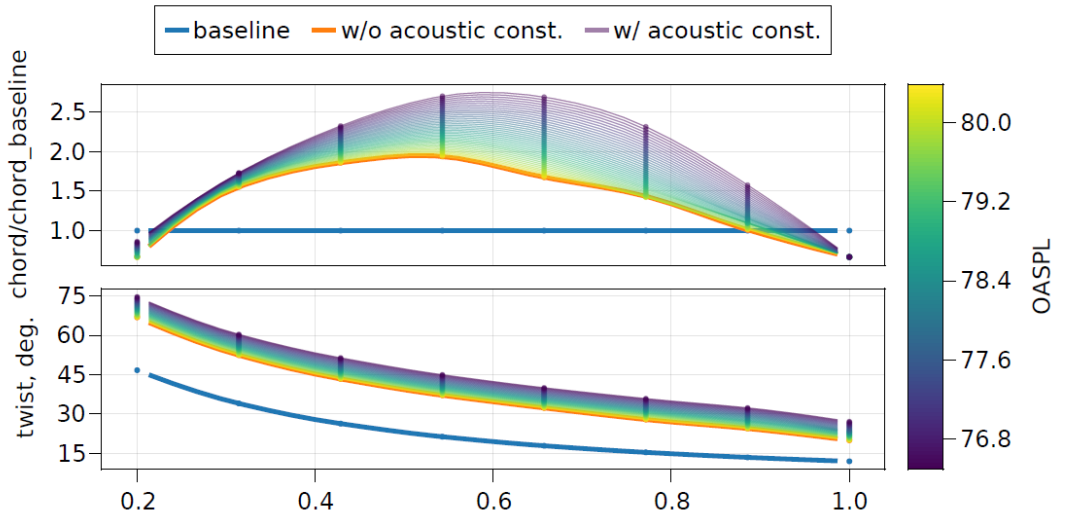


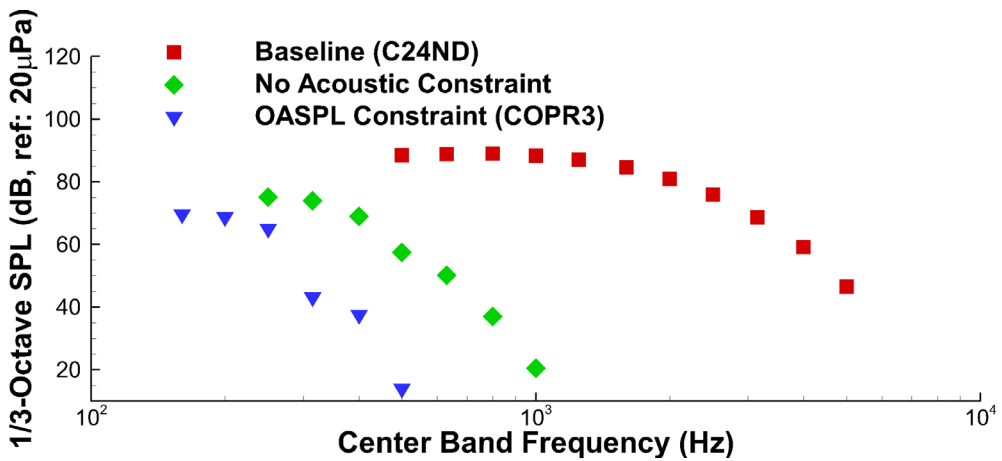
Perception-Influenced Acoustic Design

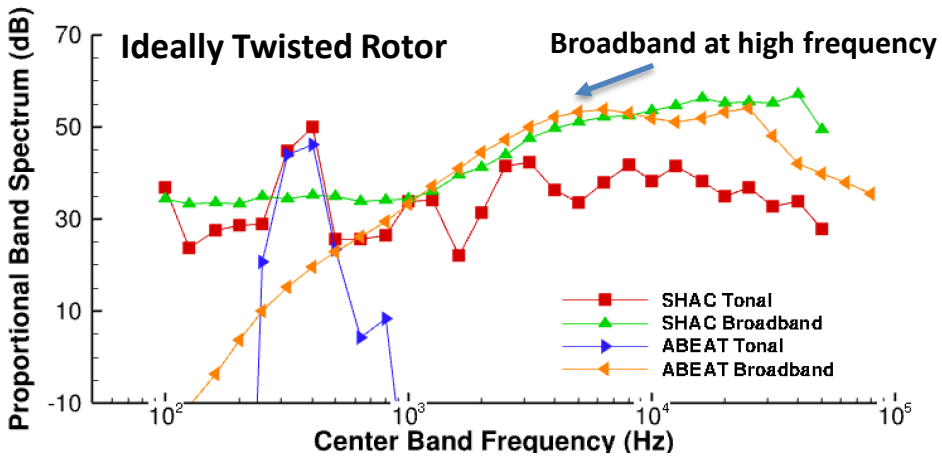
Perception-Influenced Acoustic Design

Zawodny, Lopes, Ingraham, "Preliminary Results of Adjoint-Based Proprotor Designs," NASA Acoustics Technical Working Group Meeting, April 2022

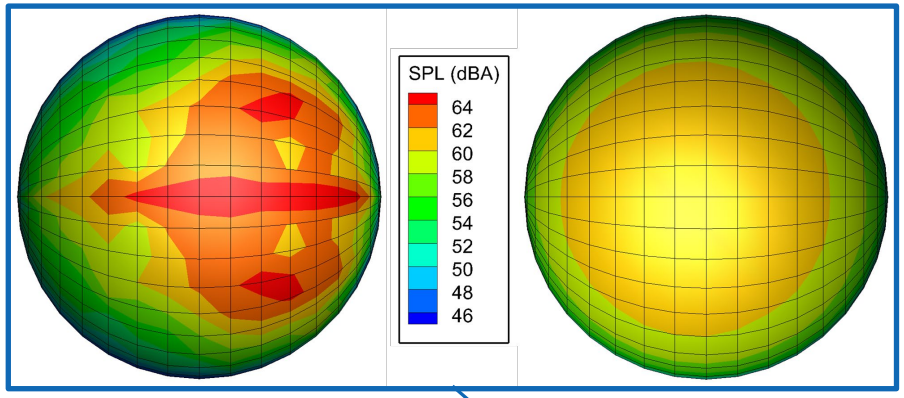








Utilization of Source Noise Predictions

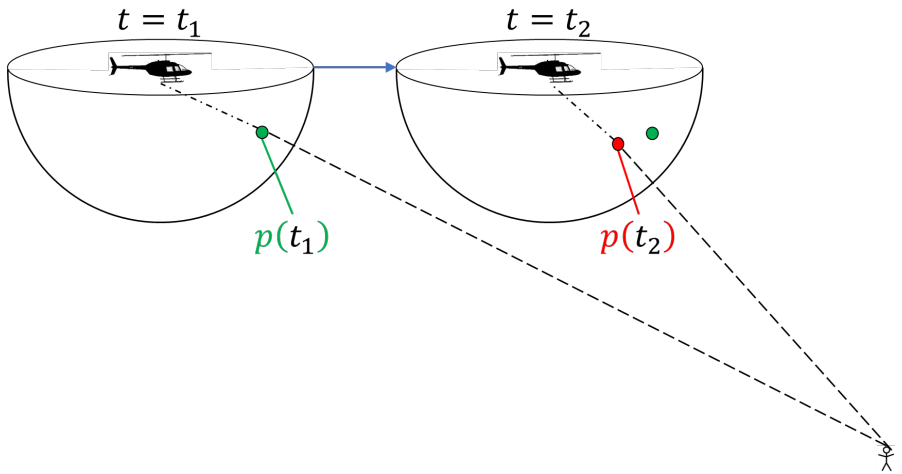


Auralization and Psychoacoustic Studies

Rotary-Wing Source Noise Synthesis

Rizzi, Sahai, "Auralization of air vehicle noise for community noise assessment," *CEAS Aeronautical Journal*, 2019, https://doi.org/10.1007/s13272-019-00373-6/

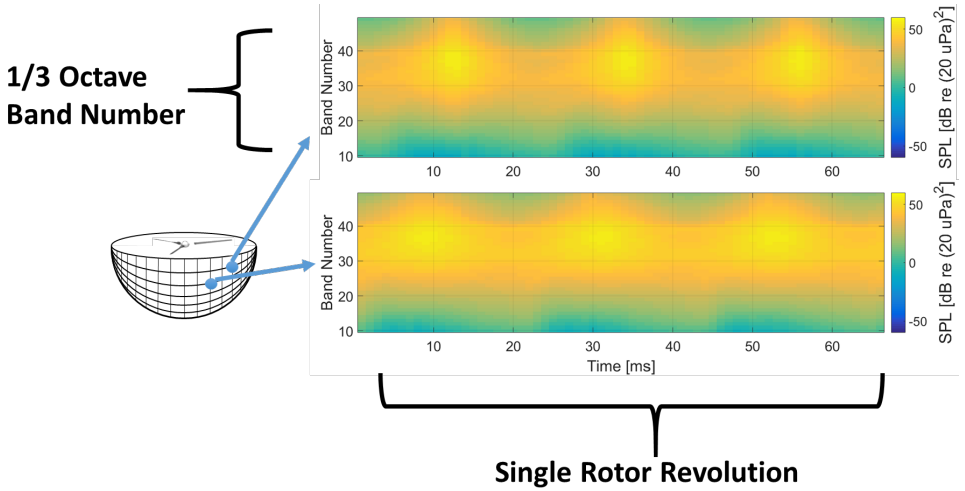
Synthesis of Loading and Thickness Noise using ANOPP2 Farassat's Formulation 1A Internal Functional Module (AF1AIFM)



Quadrotor Periodic

Krishnamurthy, Tuttle, Rizzi, "A Synthesis Plugin for Steady and Unsteady Loading and Thickness Noise Auralization", AIAA AVIATION 2020, AIAA-2020-2597, June 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

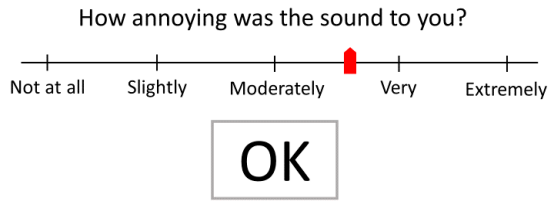
7.2mm TE

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

Level Flyover

Psychoacoustic Studies Utilizing Auralizations

- Test of UAM Sound Quality (completed July 2022)
  - Objective: Investigate how annoyance varies with sound quality.
  - Generated test stimuli spanning a range of loudness, sharpness, tonality, fluctuation strength, and impulsiveness.



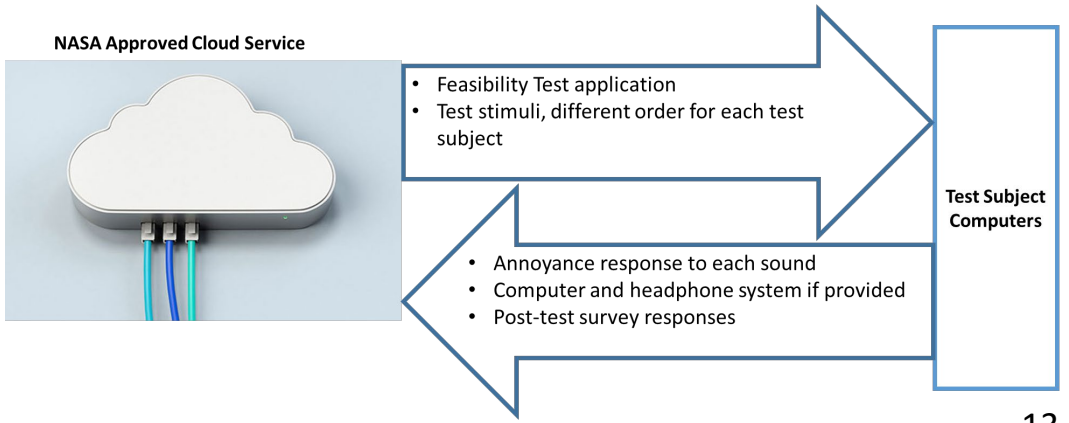
- Test of Noise and Numbers (January 2023)
  - Objective: Investigate how annoyance varies with number of operations, spacing between operations, and makeup of the fleet.

- Test of Detection, Noticeability, and Annoyance (Sept 2023)
  - Objective: Investigate how annoyance varies in presence of masking noise, e.g., cityscape.

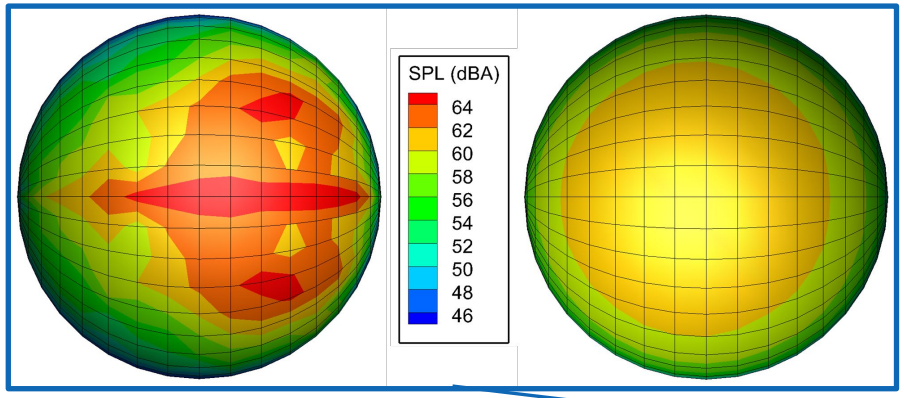
- Cooperative Human Response Study
  - Objective: Verify consistency of remote test platform with prior lab results (Oct 2022).
  - Objectives under consideration include annoyance between geographically distinct communities, near vertiports, number of events, different soundscapes, relative to existing aircraft noise sources (2024).

Exterior Effects Room (EER) at NASA Langley

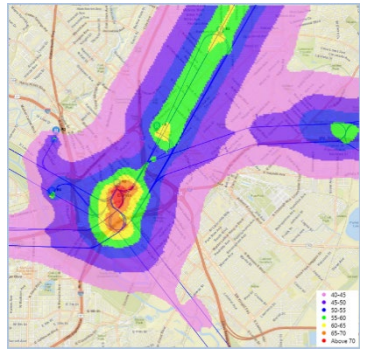
Remote Psychoacoustic Testing Platform



Utilization of Source Noise Predictions

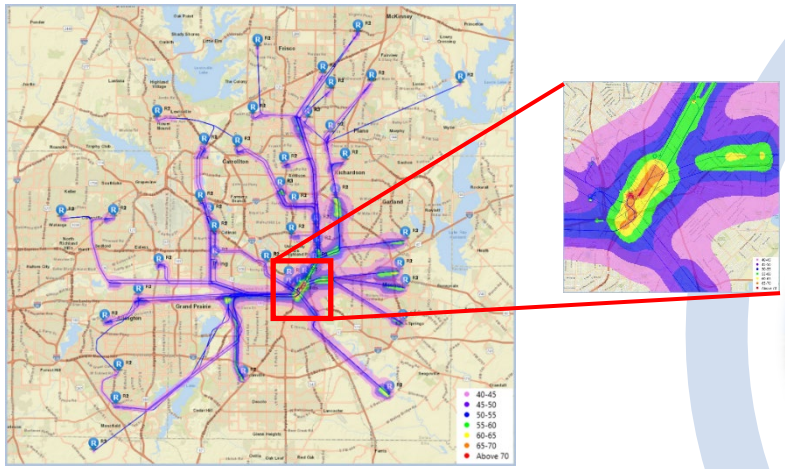


Operational Fleet Noise Assessments



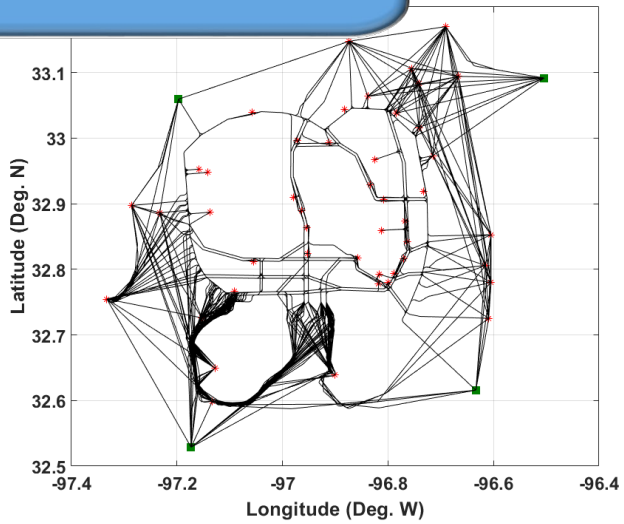
UAM Operational Fleet Noise Assessments

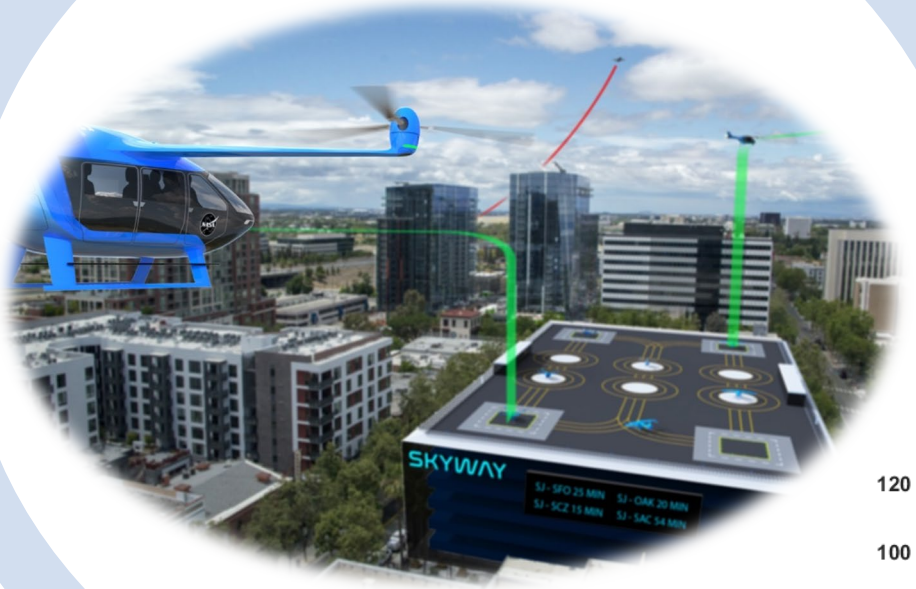
Use AEDT to evaluate community noise, combining all vehicles and operational states

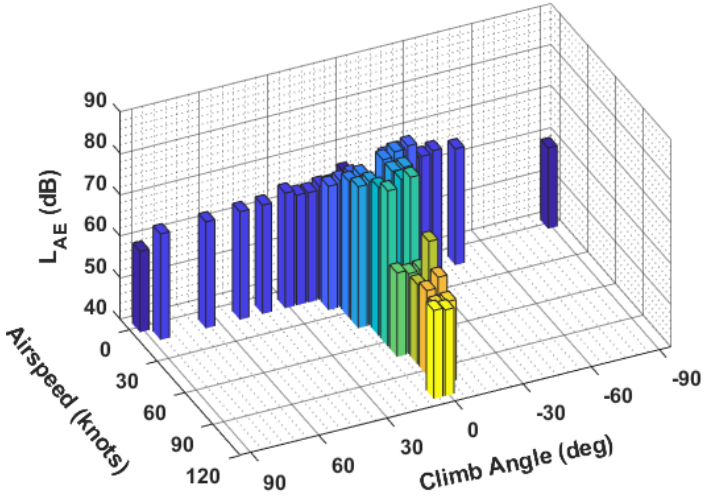


https://doi.org/10.2514/6.2022-2167

Identify routes, trajectories, and aircraft flight conditions



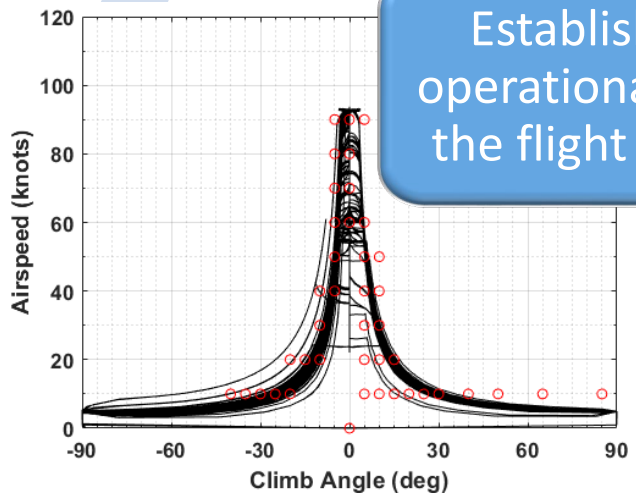




Evaluate source noise and generate noise-power-distance data using AMAT

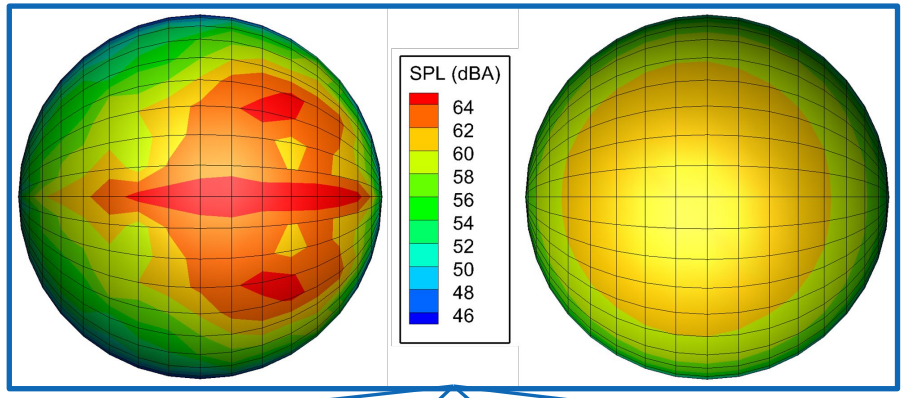
https://doi.org/10.2514/6.2022-2839

Establish aircraft operational states for the flight conditions

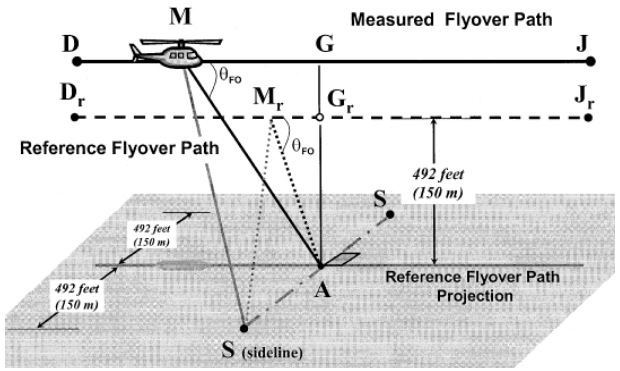


Summary

- **Predictive tools have been developed and validated.**
- **We are in a good position to evaluate UAM vehicle noise and its impact on the community.**



Noise Certification Analyses



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

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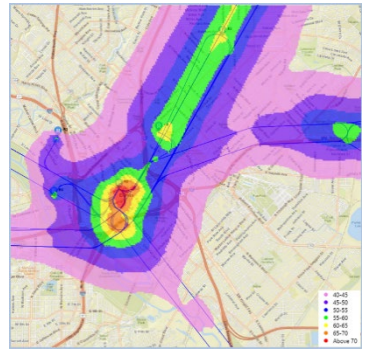
Operational Fleet Noise Assessments



Sounds on slide 12 are available for download at:

https://stabserv.larc.nasa.gov/flyover/

Merci!