Prediction-based Auralization of the RVLT Quadrotor Reference Vehicle

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Urban Air Mobility Noise Working Group, November 5, 2020

Contributors

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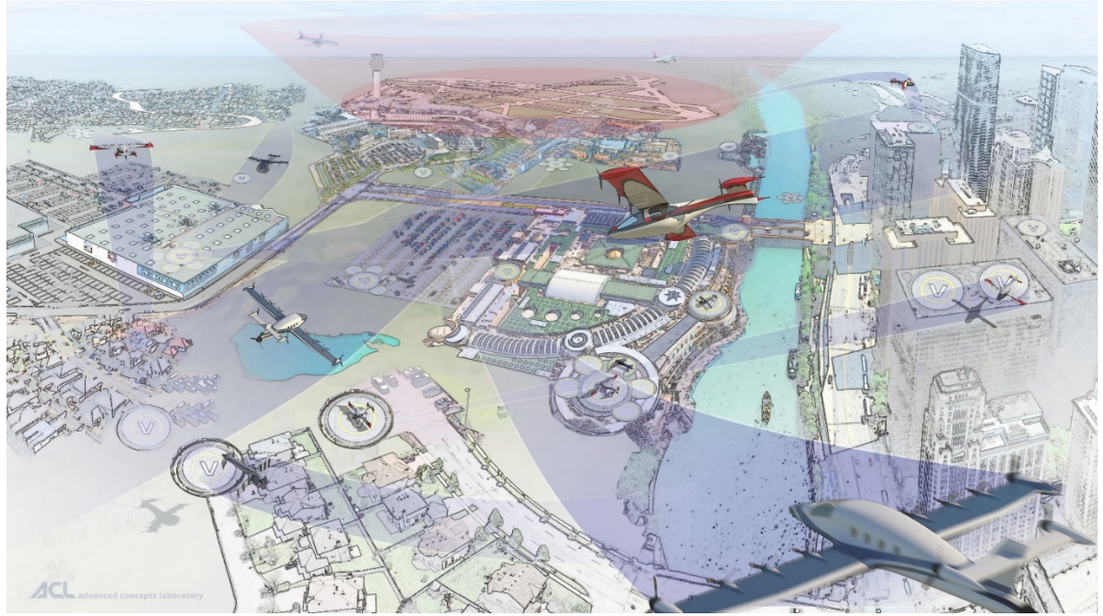
- Brian C. Tuttle, Analytical Mechanics Associates, Inc.
- Leonard V. Lopes, Aeroacoustics Branch, NASA Langley Research Center
- Andrew W. Christian, Structural Acoustics Branch, NASA Langley Research Center
- Aric R. Aumann, Analytical Services and Materials, (Science Applications International Corporation before November 1, 2020).

Motivation

- **Need to understand community response to noise from future advanced air mobility vehicles**
- **Play recorded or auralized sounds of these aircraft in NASA Langley Exterior Effects Room to test subjects**
  - Auralizations: sounds generated from numerical data

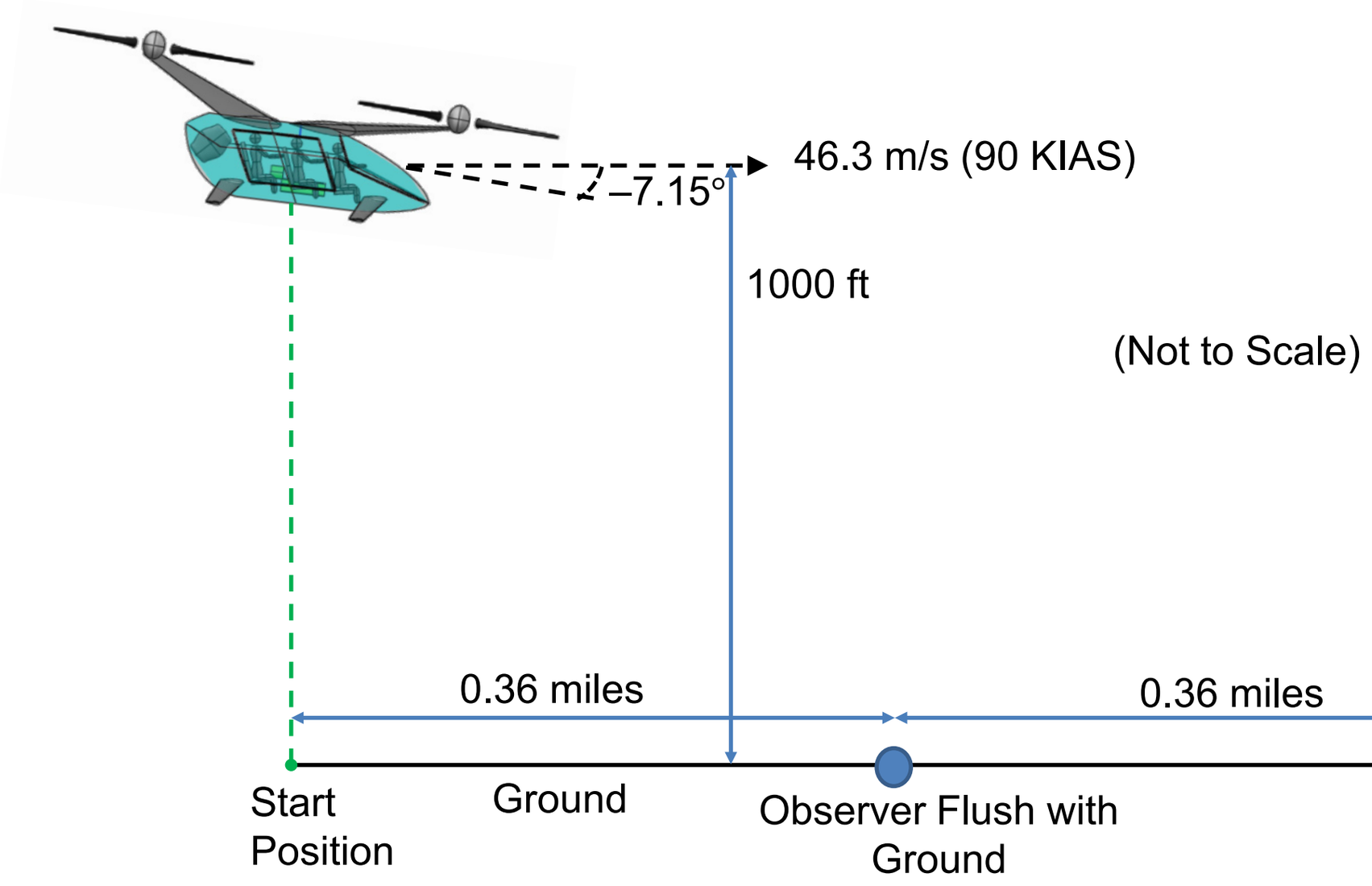


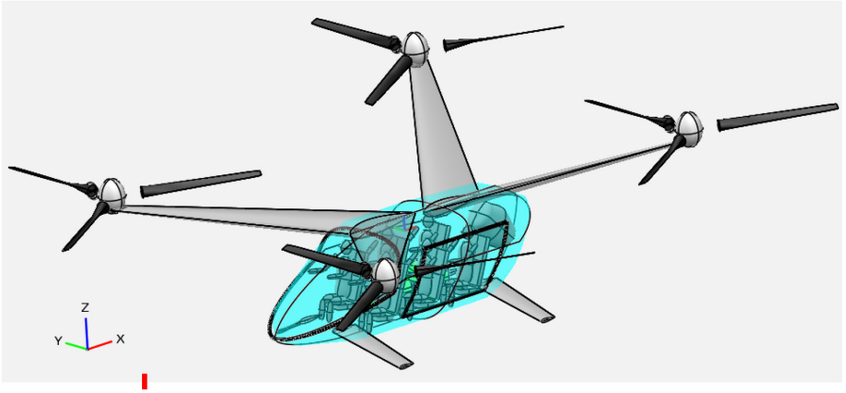
From NASA Advanced Air Mobility National Campaign Overview website

Exterior Effects Room, NASA Langley Research Center

Quadrotor Flyover

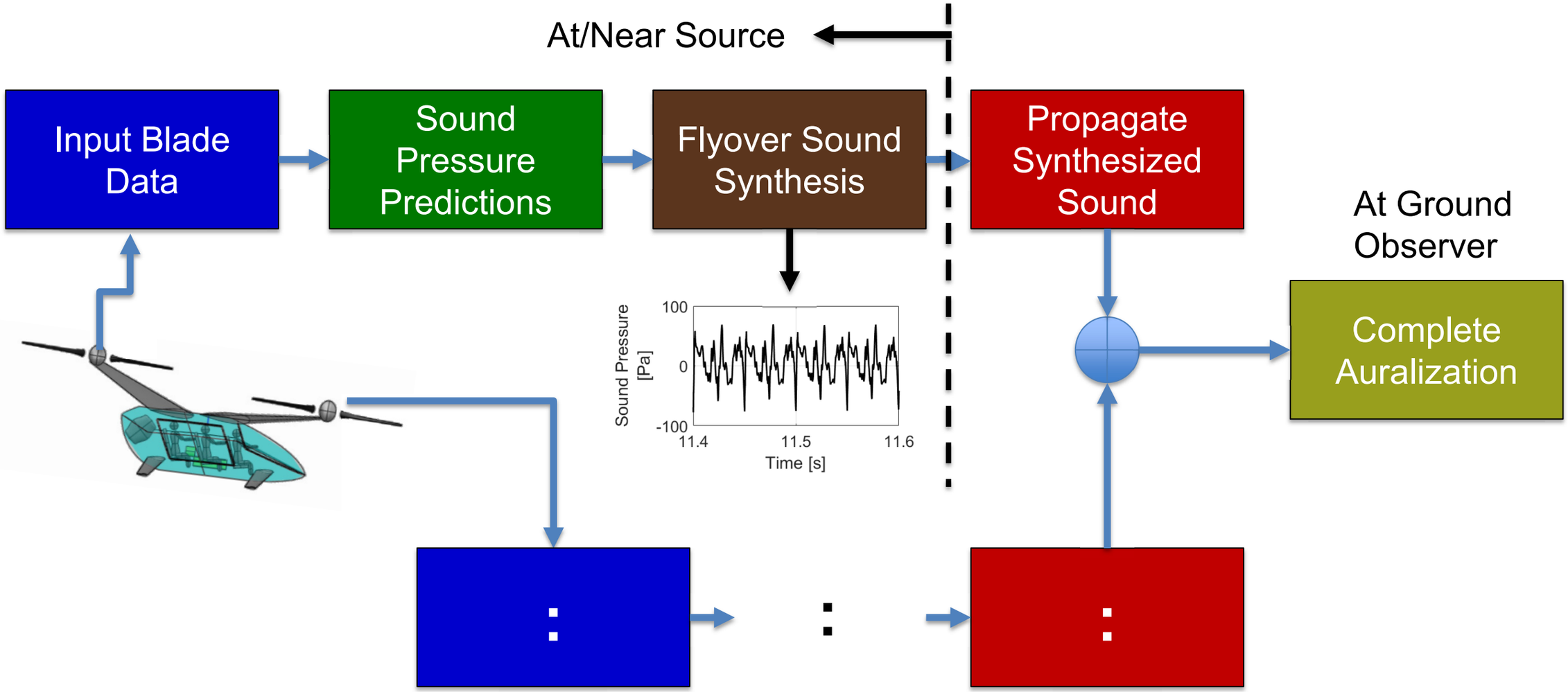
- **Auralize straight and level flyover of NASA Quadrotor eVTOL concept**





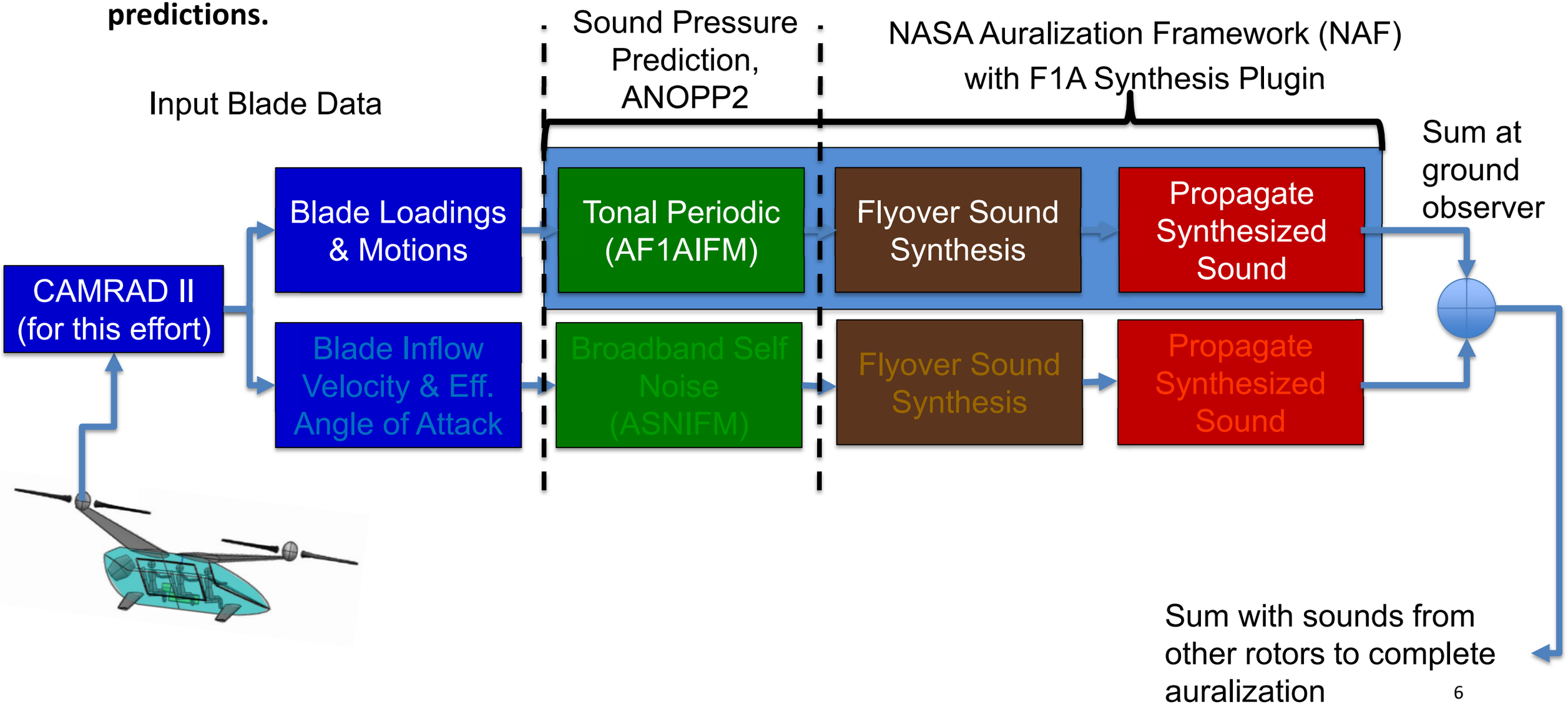
Auralization Process

- **Flyover auralization consists of obtaining input blade data, predicting sound pressures near the source, and propagation of sound pressures to a ground observer.**



Quadrotor Source Noise Predictions

- **Quadrotor flyover auralization to include sounds from both tonal periodic and broadband self-noise predictions.**



NAF F1A Synthesis Plugin

- **F1A Synthesis plugin provides greater audible fidelity for synthesized tonal sounds from rotors compared to earlier additive synthesis method.**

  - **Proof of Concept:** Krishnamurthy, S., Tuttle, B.C., and Rizzi, S.A., "Auralization of Unsteady Rotor Noise using a Solution to the Ffowcs Williams-Hawkings Equation," Paper 48, Proceedings of the 75th Annual Forum, Vertical Flight Society, 2019.
  - **Plugin for NAF:** Krishnamurthy, S., Tuttle, B.C., and Rizzi, S.A., "A Synthesis Plug-in for Steady and Unsteady Loading and Thickness Noise Aurlaization," Paper 2597, AIAA Aviation Forum, 2020.

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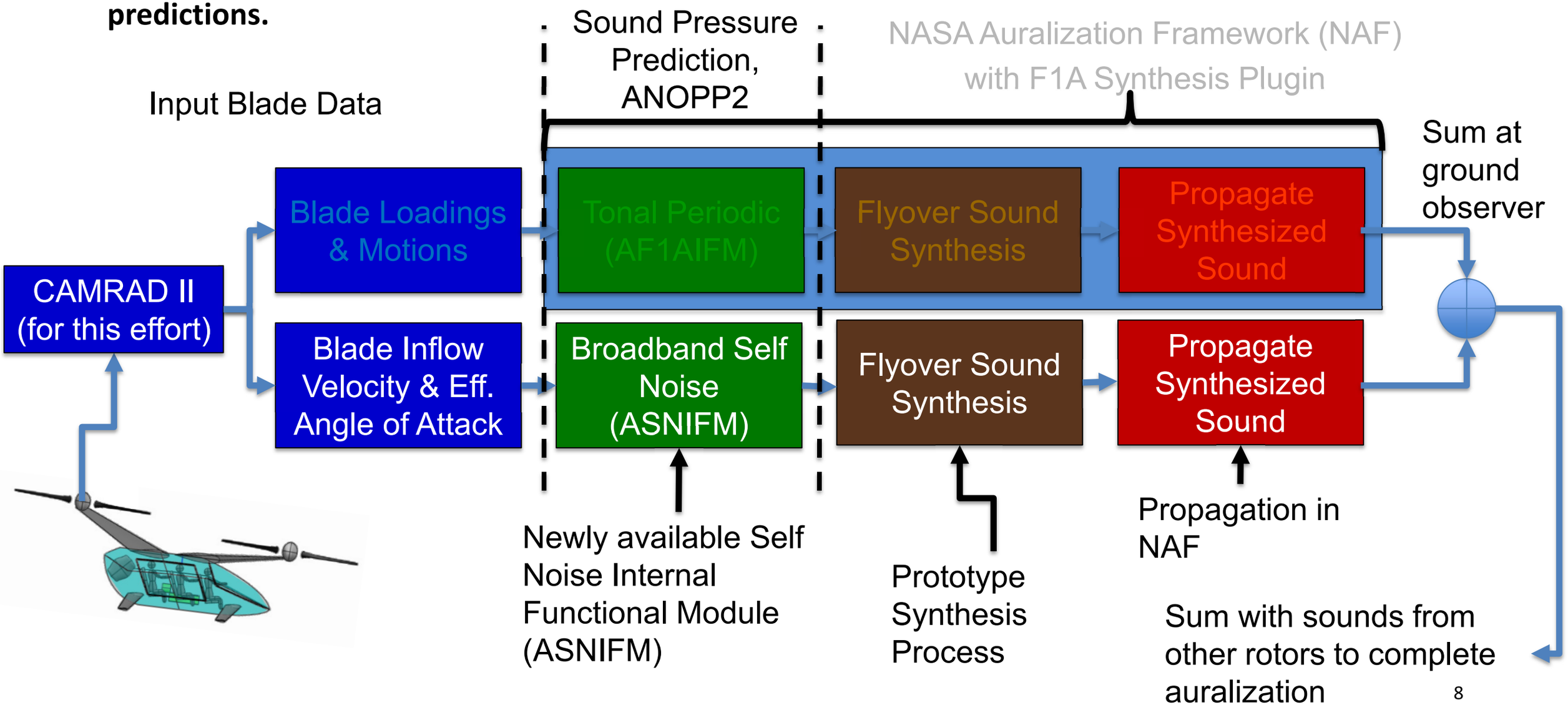
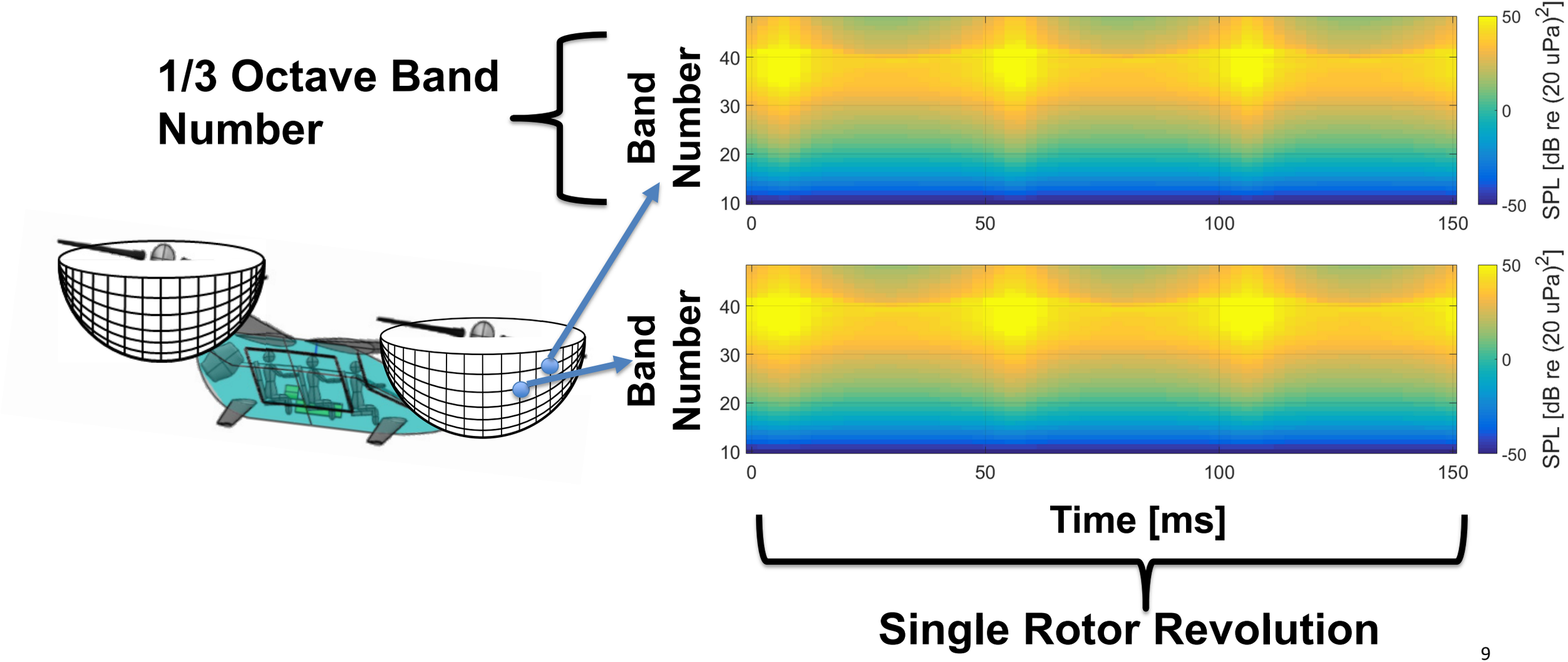


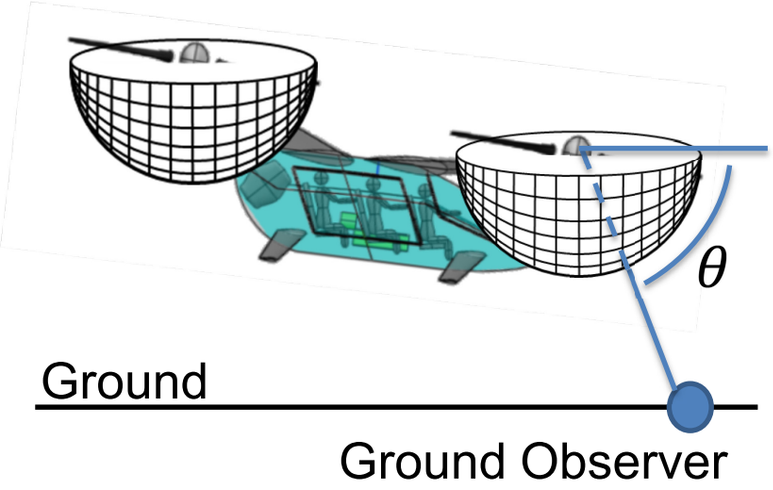
Broadband Self Noise Sound Pressure Predictions

- **Self noise sound pressure predictions from ANOPP2 are sound pressure levels in each 1/3 octave band as a function of time over a single rotor revolution.**

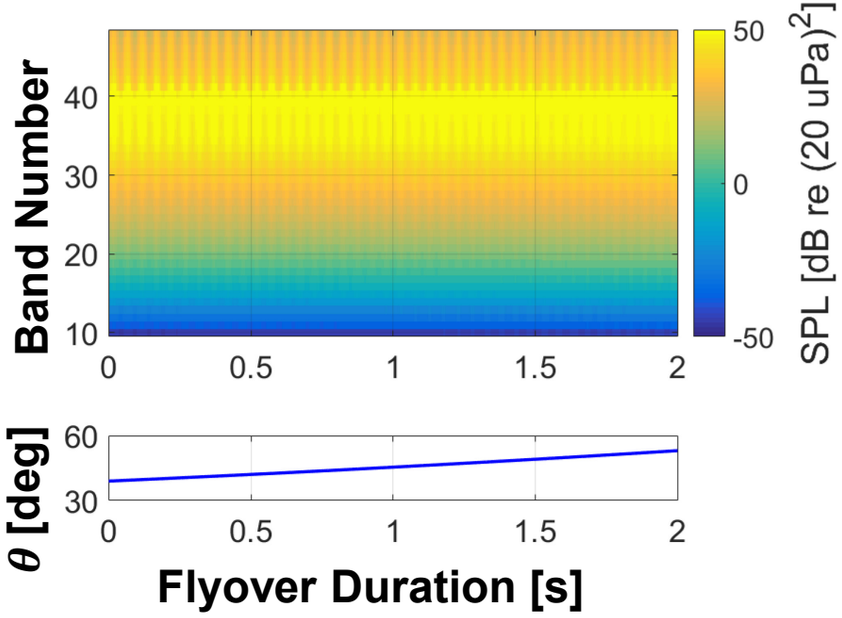


Self Noise Flyover Sound Synthesis

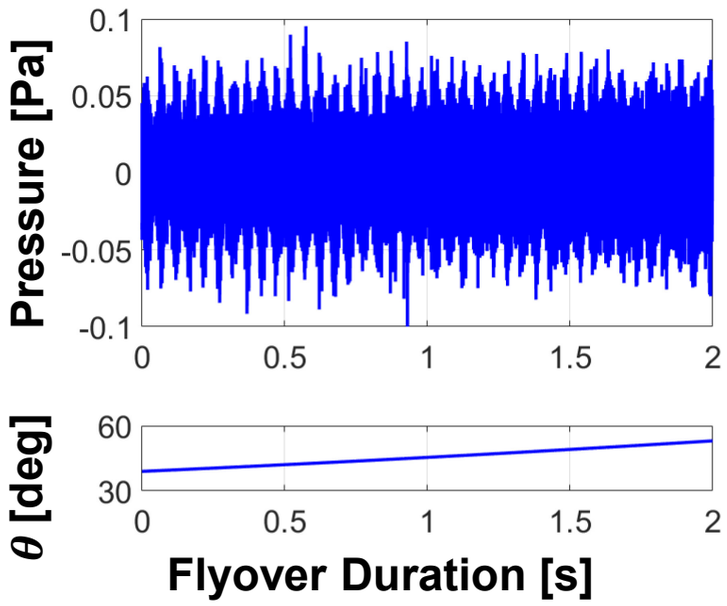
- **Generate longer sound pressure level data from many single rotor revolution predictions nodes along rotor to ground observer flyover emission angles.**
- **Modulate bandlimited stochastic signal by the longer sound pressure level prediction data to generate synthesized self noise rotor sound.**



Sound Pressure Level Prediction Data Formed by Interpolating Over Single Rotor Revolution Data

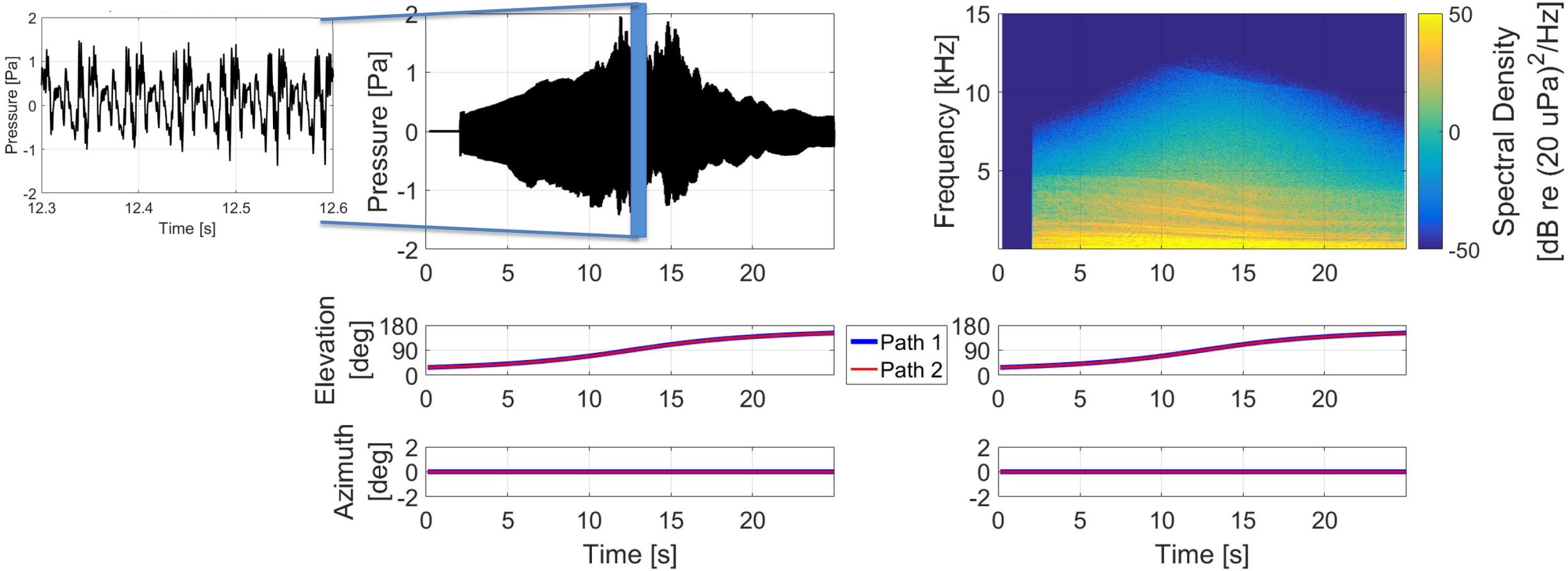


Synthesized Sound Near Rotor to Propagate to Ground Observer



Auralization of Quadrotor Flyover

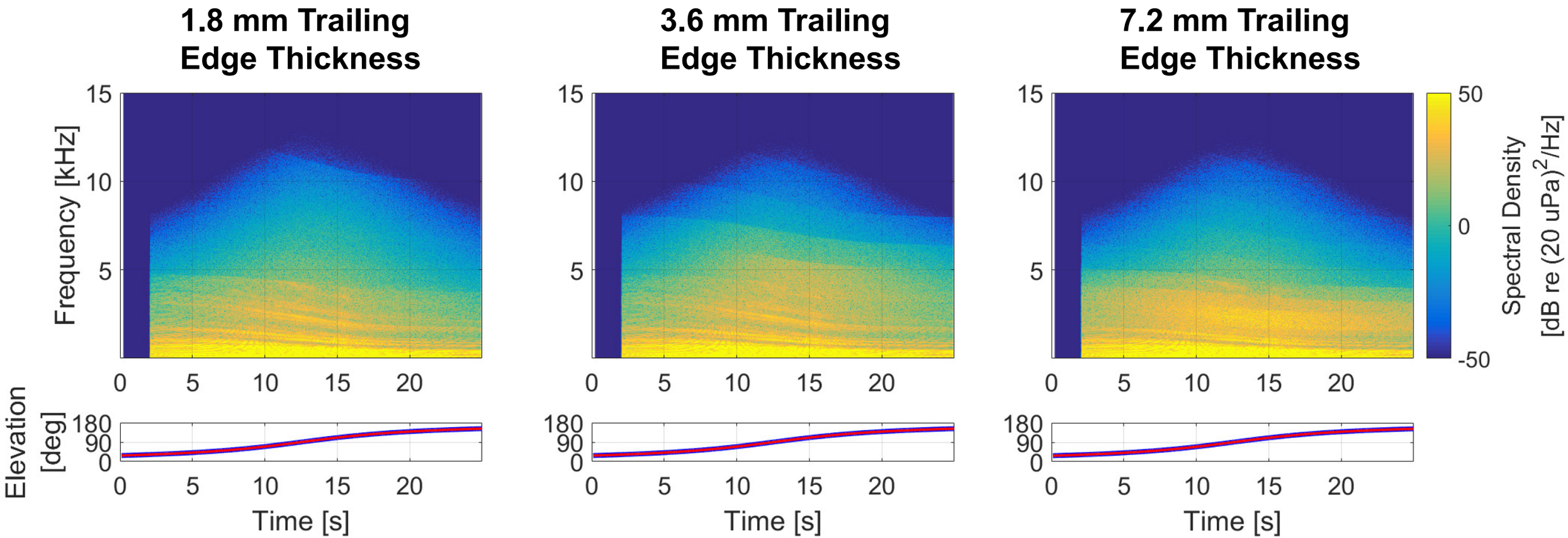
- **Quadrotor auralized by combining tonal periodic and broadband self noise sounds from all four rotors.**



- **Sound file for auralization available online at https://stabserv.larc.nasa.gov/flyover/.**

Changing Trailing Edge Thickness

- **Changing blade trailing edge thickness affects self noise and produces noticeable audible differences in full Quadrotor (all four rotors, tonal periodic and self noise) auralizations.**



- **Audible sounds, including 0.9 mm Trailing Edge Thickness case, available online at https://stabserv.larc.nasa.gov/flyover/.**

Summary

- **NASA Quadrotor eVTOL concept auralized for level flyover using tonal periodic and broadband self noise sounds.**

- **Auralization would have been challenging without different components for blade data generation, acoustic prediction, sound synthesis, and sound propagation developed and working together.**
  - Key development for auralization of tonal sound synthesis: newly implemented NAF F1A Synthesis plugin, will be available in an upcoming NAF release.
  - Self noise auralization process developed as proof of concept, will be implemented as NAF plugin and eventually be available in a NAF release.

- **Changing blade trailing edge thickness can have noticeable audible effects on self noise.**

- **Upcoming publications on self noise:**
  - Krishnamurthy, S. and Rizzi, S.A., “Prediction-Based Auralization of a Multirotor Urban Air Mobility Vehicle.” AIAA SciTech Forum, 2021.
  - Will be submitting abstract to AIAA Aviation 2021 on implementing broadband self noise synthesis as a NAF plugin.

Acknowledgements and Thank You

- Quadrotor auralization was performed with support from the Transformational Tools & Technologies Project of the NASA Transformative Aeronautics Concepts Program.
- Developing the NAF F1A Synthesis plugin and self noise synthesis method were performed with support from the Revolutionary Vertical Lift Technology Project of the NASA Advanced Air Vehicles Program.

Sound files are available for download at:

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

Email: siddhartha.krishnamurthy@nasa.gov

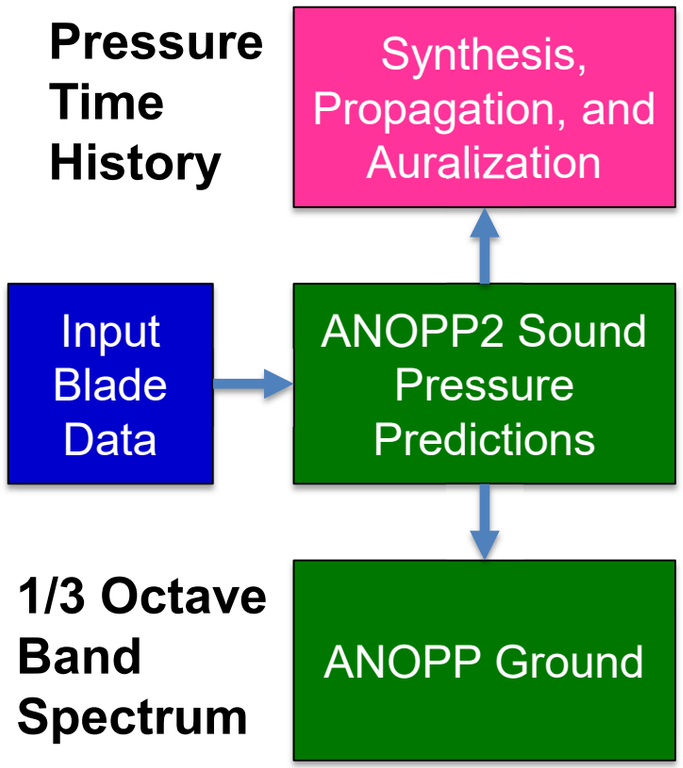
Image References

- **Slide 3:**
  - Urban Air Mobility artwork is from NASA Advanced Air Mobility National Campaign Overview website, https://www.nasa.gov/aeroresearch/aam/description/.
  - Picture of Exterior Effects room provided by Steve Rizzi, NASA Langley Research Center.
- **Slides 4-6 and 8-10:**
  - Quadrotor pictures from Silva, C., et al., "VTOL Urban Air Mobility Concept Vehicles for Technology Development." Paper 3847. 2018 Aviation Technology, Integration, and Operations Conference, Atlanta, GA, 2018.
- **All other images generated by presenter (Siddhartha Krishnamurthy).**

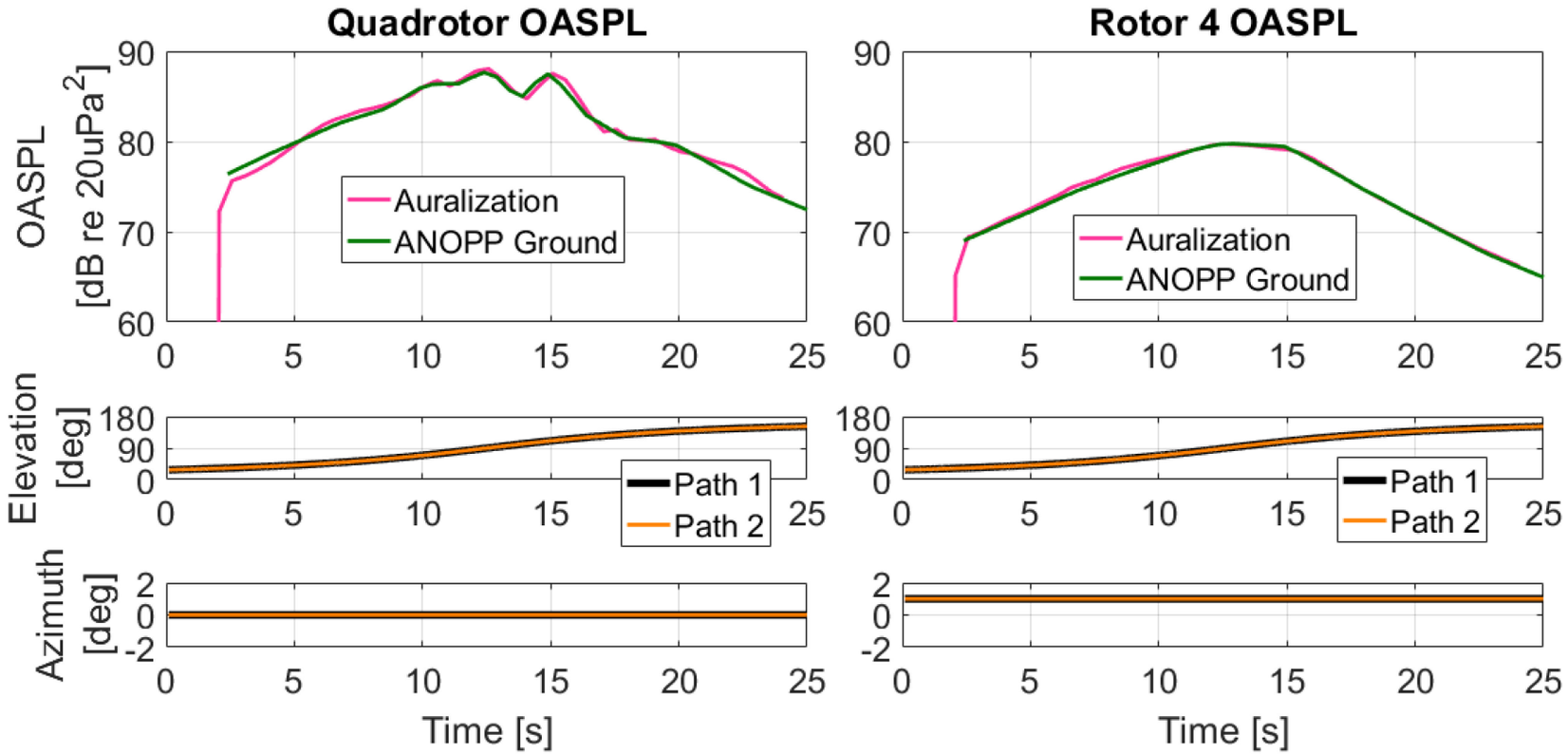
Backup Slides

Checking Auralization

- **Overall sound pressure level (OASPL), 50 Hz – 10 kHz, compared between auralization and ANOPP Ground, tonal periodic and self noise combined.**



(Contributions from all four rotors)



Similar OASPL traces for other three rotors