An Overview of the NASA Auralization Framework (NAF)

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Outline

- Auralization 101
- The NASA Auralization Framework (NAF) and Advanced Plugin Libraries (NAF APL)
- Research Driven Enhancements in Releases 1.2 and 1.2.1
  - Multiple pure tones (buzzsaw tones)
  - Narrowband synthesis
  - Rotor self noise (modulated broadband)
  - Unsteady blade loading and thickness noise (F1A synthesis)
  - Psychoacoustic analysis library (NAFPAL)
- Software Availability

Auralization 101

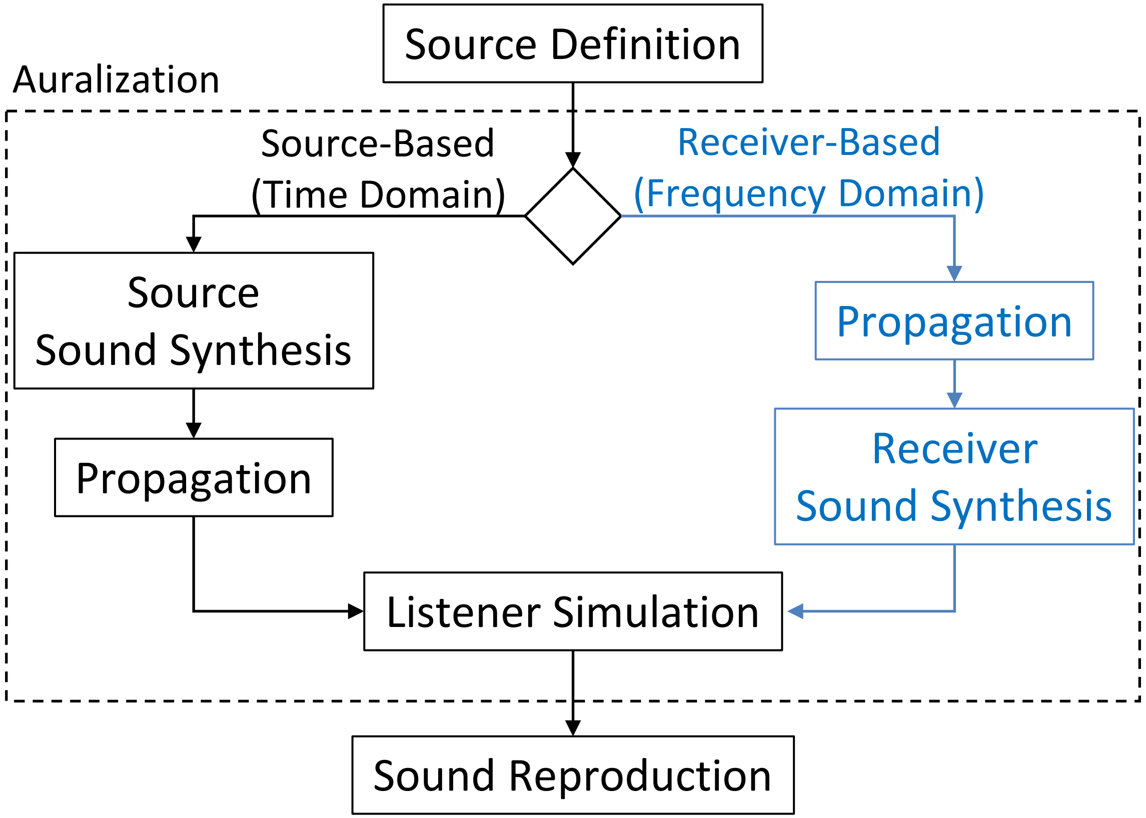
- Auralization of aircraft flyover noise is the process by which numerical data, from predictions or tests, are converted into audible sounds

- Auralization can serve several purposes:
  - Provides a means of communicating input to stakeholders in a natural form
  - Provides feedback to the noise analyst regarding the system under design
  - Serves as an integral element of perception-influenced design of new air vehicles

- Elements of auralization include sound synthesis, sound propagation, and listener simulation
  - Sound synthesis converts the noise description to a pressure time history
  - Propagation conveys the sound from the source to the observer
  - Listener simulation prepares the signal for reproduction as monaural, binaural, or multichannel

- Two approaches to aircraft flyover noise auralization
  - Source-based (most common) and receiver-based (less common)

Auralization 101



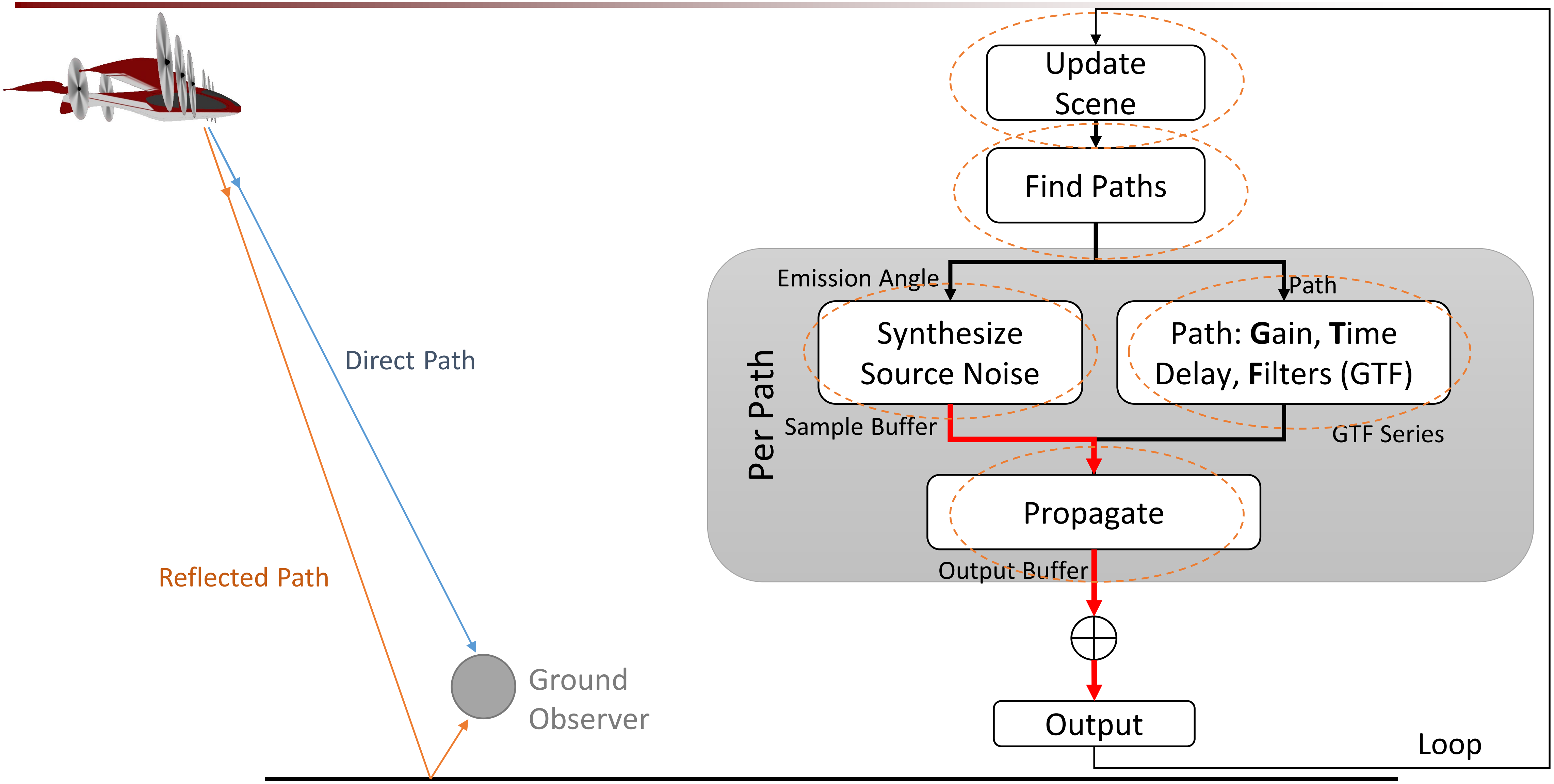
Time Domain Advantages

- Introduction of source noise unsteadiness during synthesis
- Introduction of turbulent atmosphere during propagation
- Phase retained in time domain propagation, lost in freq. domain

Frequency Domain Advantages

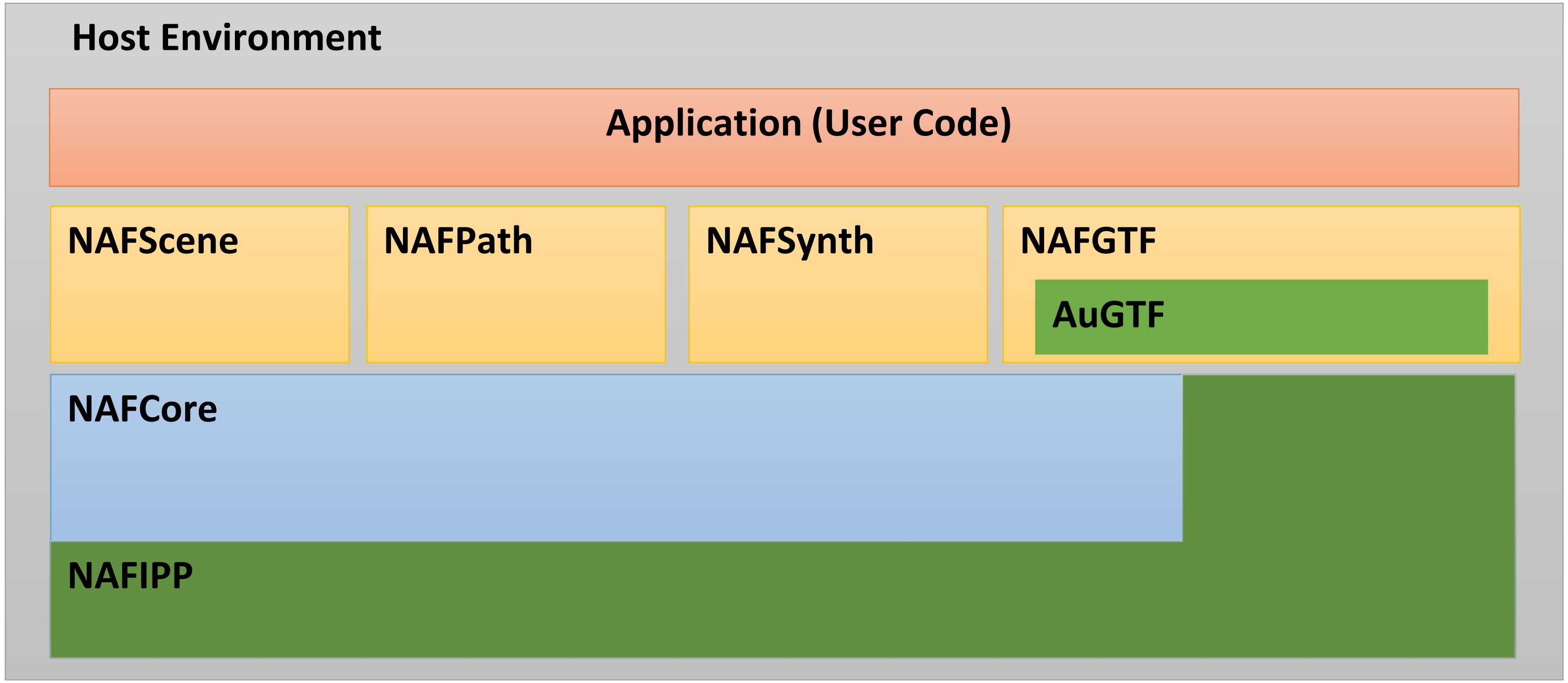
- Allows use of alternative noise prediction tools, e.g., Advanced Acoustics Model, with predefined source noise definitions or measured data.
- Allows use of alternative propagation tools, e.g., NASA Spectral Attenuation Method, Nord 2000, for advanced weather and terrain effects.

Standard Flyover Use Case



The NASA Auralization Framework (NAF)

- Provides building blocks for creating acoustic simulation applications
- Plugin architecture: interfaces are defined, straightforward to replace
  - Very basic classes provided with NAF demonstrate usage
  - Advanced auralization methods have been developed as NAF plugins



NAF and Advanced Plugin Library 1.2.1 Contents

Programs
- NAFSNAP: Source Noise and Propagation
- NAFExample
- ANOPP2 Interface Examples
  - Quickstart-modified
  - F1A Synthesis

Path Finder / Traverser
- Straight Line
- Receiver-based

Directivity Loaders
- NetCDF
- TXT (ASCII)
- Plot3D

Synth / Component
- Directivity Loader
- Restart Component
- 1/3 Octave Band
- **Narrowband**
- **Modulated 1/3 OB**
- Pure Tone
- Periodic
- **Multiple Pure Tone**
- **F1A Synthesis**
- Wave File
- Random

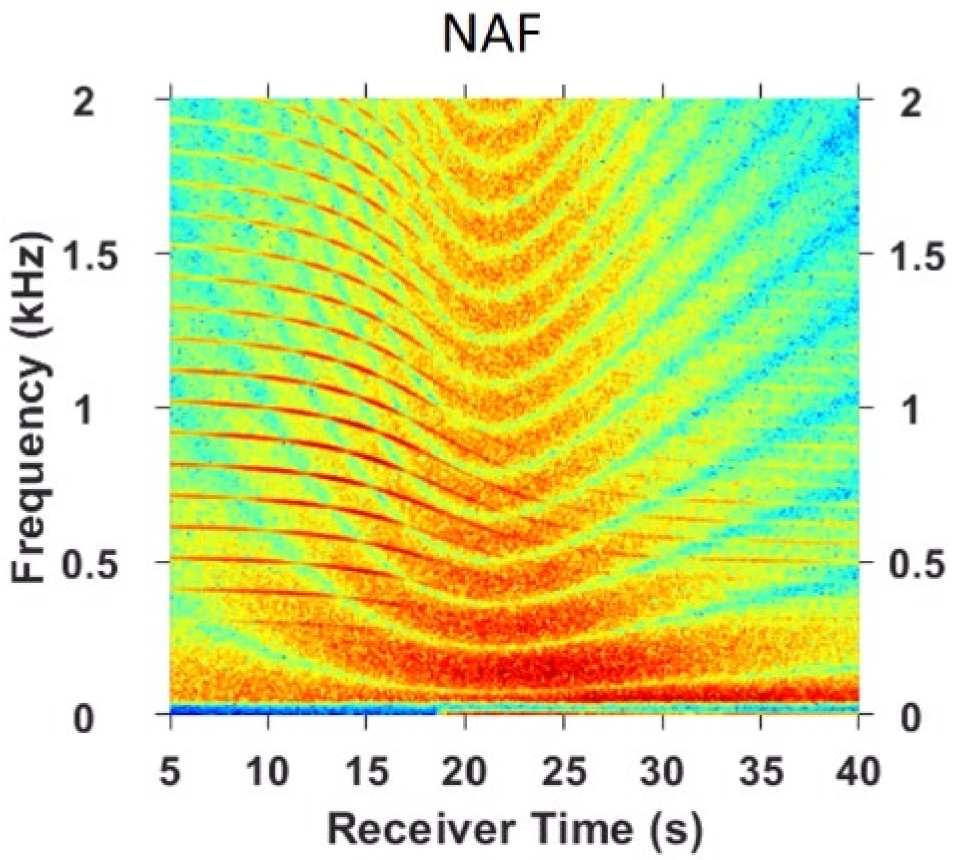
Ground Reflection
- Infinitely Hard Ground
- Delany-Bazley Impedance model

Other
- Postprocessors
  - ANOPP2 Metrics
  - **Psychoacoustic Analysis**
  - Normalization
- **Preprocessor**
  - **F1A Synth**
- Trajectory
  - CSV file - track
  - Higher order motion file

Atmosphere
- Parameter definitions
  - Uniform
  - Isothermal
  - Lapse
  - Balloon File
- Absorption Standard
  - ANSI
  - **SAE ARP 866A**

Multiple Pure Tone Synthesis

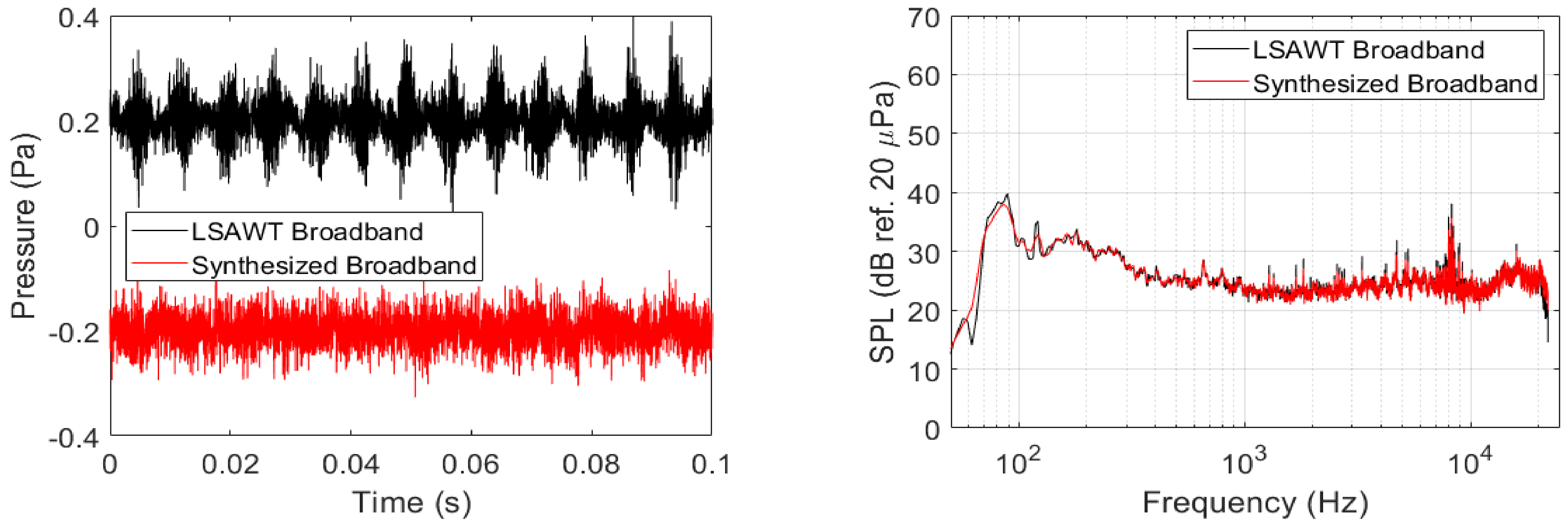
- aka Buzzsaw or Combination Tones
- Prediction is 1/3 octave band as predicted by ANOPP's modified Heidmann fan
- Generate shaft order harmonic series, matching band energies
- Was part of pre-NAF Synthesis code, now available in NAF



"A Comparison of Aircraft Flyover Auralizations by the Aircraft Noise Simulation Working Group", Stephen A. Rizzi, Ingrid LeGriffon, Reto Pieren, and Lothar Bertsch, AIAA AVIATION 2020, AIAA-2020-2582, Virtual Event, 15-19 June 2020. https://doi.org/10.2514/6.2020-2582

Narrowband Synthesis

- Empirical data with magnitude and phase
- Could also have prediction in narrowband
- Was part of pre-NAF Synthesis code, now available in NAF



(a) Pressure time history.

(b) Narrowband SPL.

LSAWT

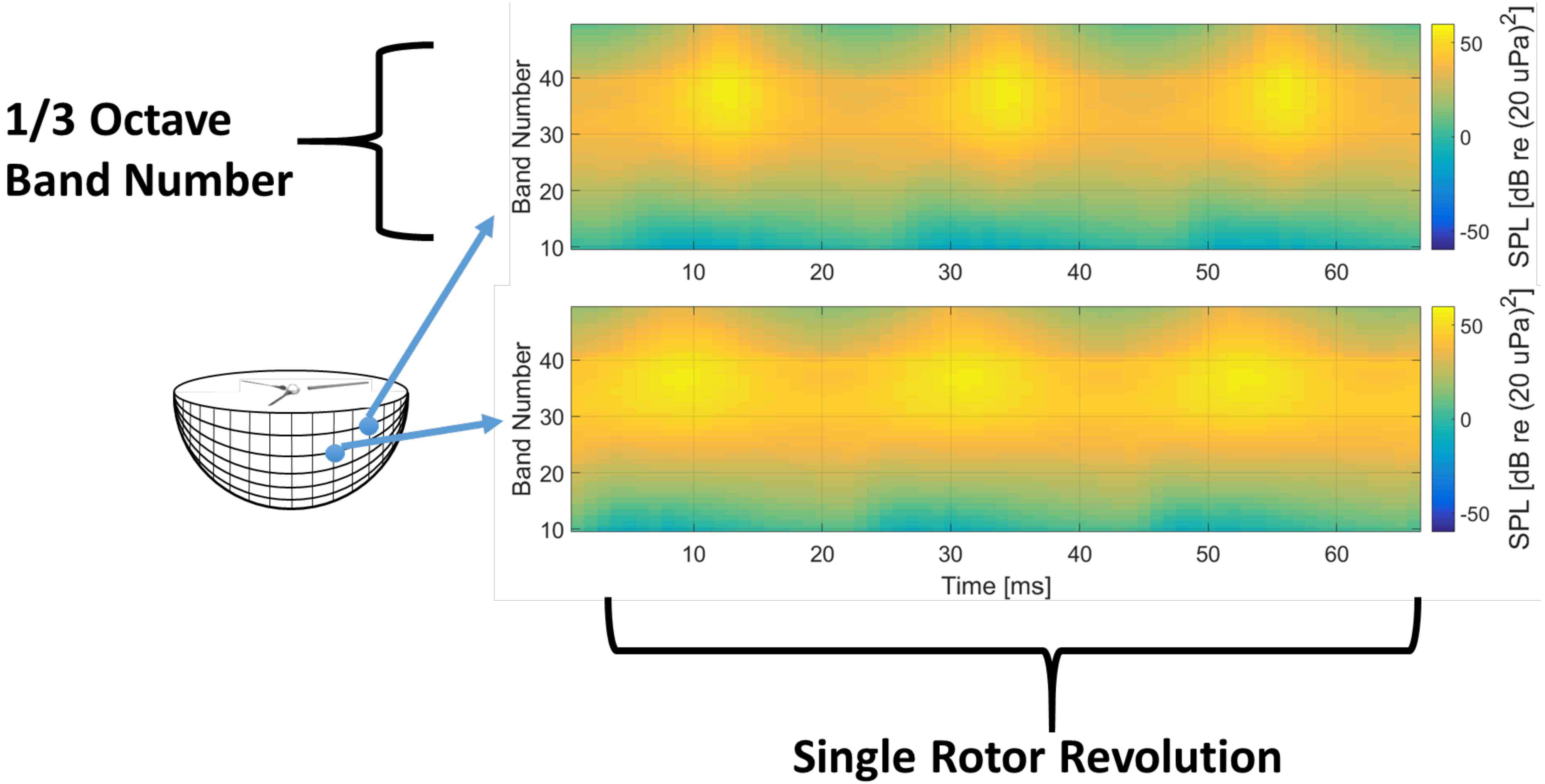
Synthesized

Audio sample levels adjusted for playback

"On the use of Acoustic Wind Tunnel Data for the Simulation of sUAS Flyover Noise", Stephen A. Rizzi, Nikolas S. Zawodny, and Nicole A. Pettingill, 25th AIAA/CEAS Aeroacoustics Conference, AIAA-2019-2630, Delft, NL, 20-23 May 2019. https://doi.org/10.2514/6.2019-2630

Broadband Self Noise Sound Pressure Predictions

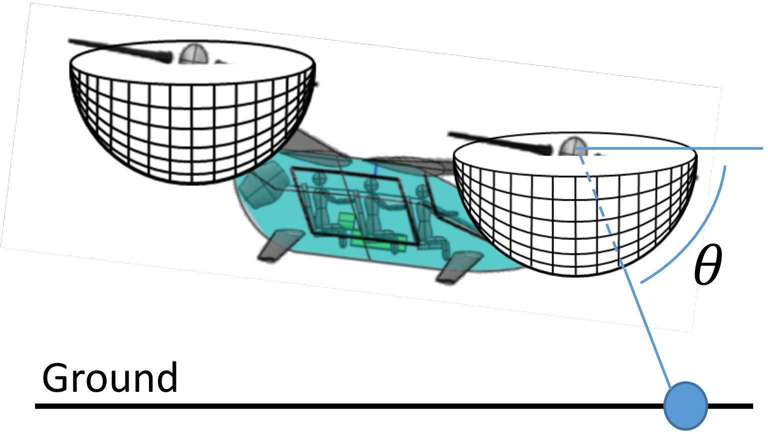
- Self noise sound pressure predictions from ANOPP2 Self Noise Internal Functional Module (ASNIFM) are sound pressure levels in each 1/3 octave band as a function of time over a single rotor revolution.



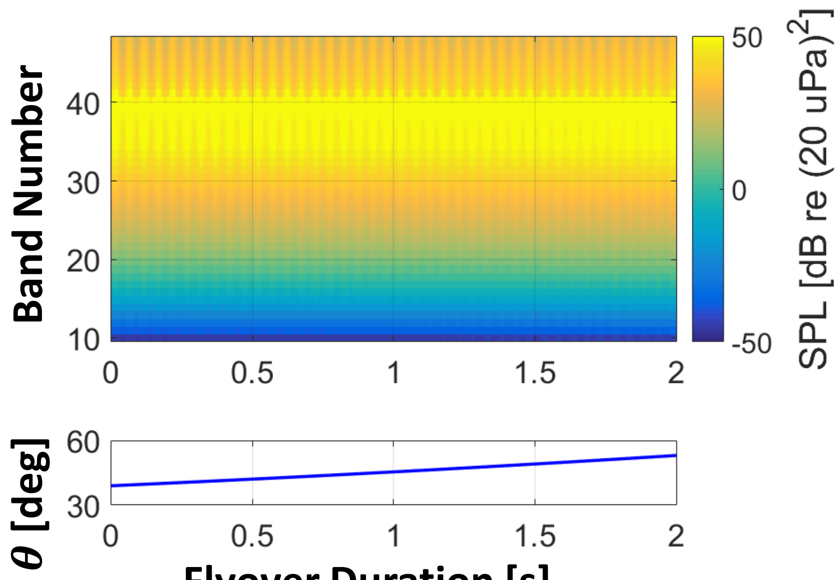
Self Noise Flyover Sound Synthesis

Primary Steps:

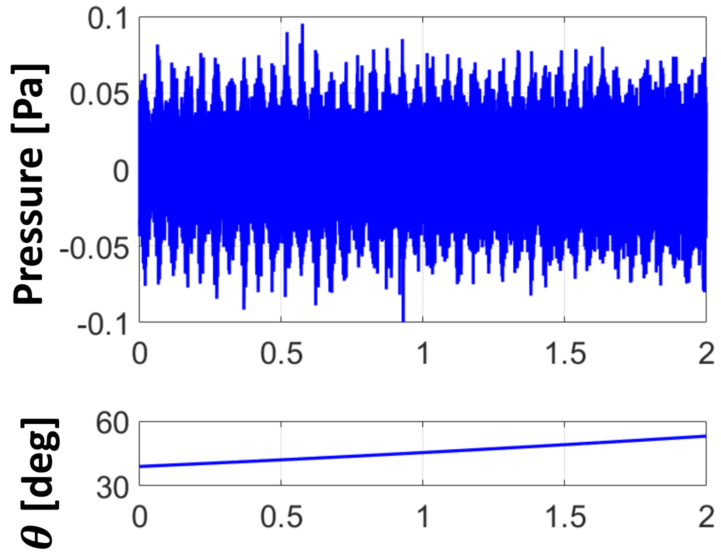
1. **Interpolate self noise data to instantaneous emission angle.**
2. **Extend or trim self noise to duration of current buffer.**
3. **Modulate stochastic signal by self noise data.**



Sound Pressure Level Prediction Data



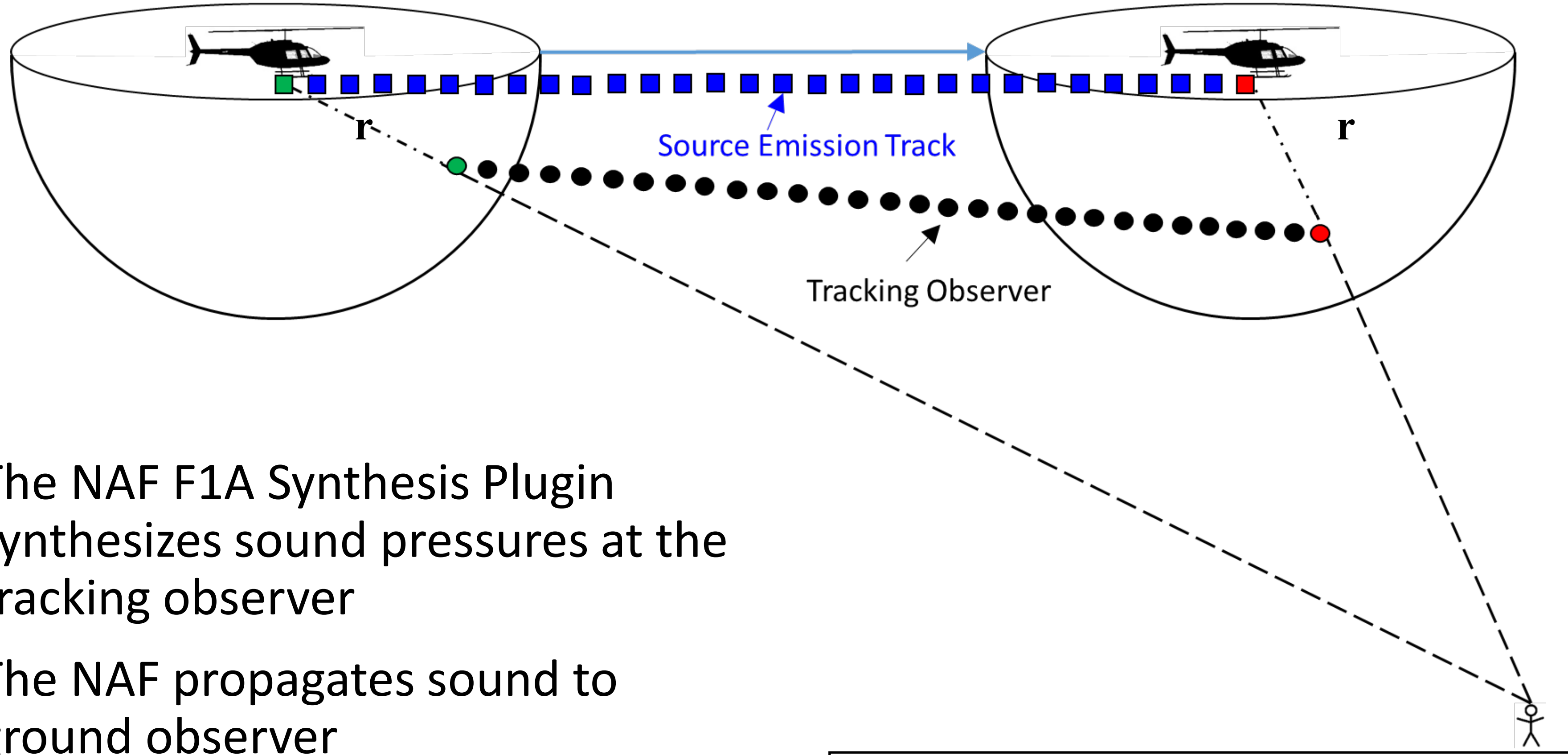
Synthesized Sound Near Rotor to Propagate to Ground Observer



"A Synthesis Plugin for Auralization of Rotor Self Noise", Siddhartha Krishnamurthy, Aric Aumann, Stephen Rizzi, AIAA AVIATION 2021, AIAA-2021-2211, Virtual Event, 2-6 August 2021. https://doi.org/10.2514/6.2021-2211

Rotor Self Noise
(2 sec)

F1A Synthesis Tracking Observer



Constant distance r maintained between source emission track and tracking observer

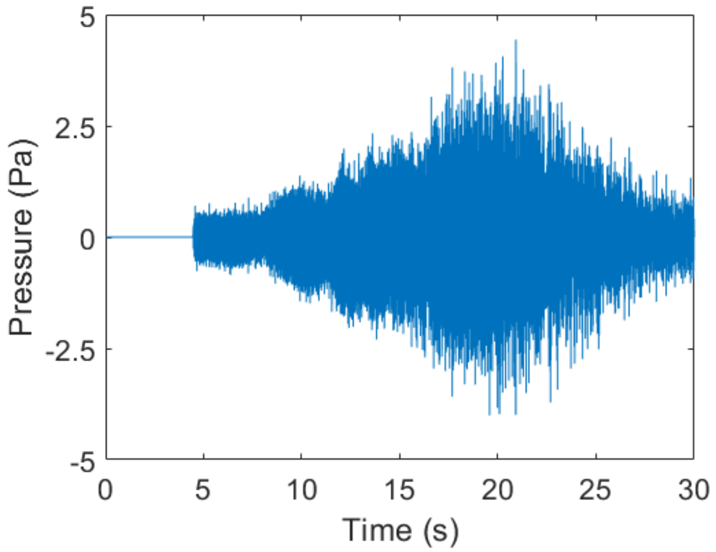
- The NAF F1A Synthesis Plugin synthesizes sound pressures at the tracking observer
- The NAF propagates sound to ground observer
- Each vehicle noise source and each propagation path require separate tracking observers

“A Synthesis Plug-in for Steady and Unsteady Loading and Thickness Noise Auralization”, Siddhartha Krishnamurthy, Brian C. Tuttle, and Stephen A. Rizzi, AIAA AVIATION 2020, AIAA-2020-2597, Virtual Event, 15-19 June 2020. https://doi.org/10.2514/6.2020-2597

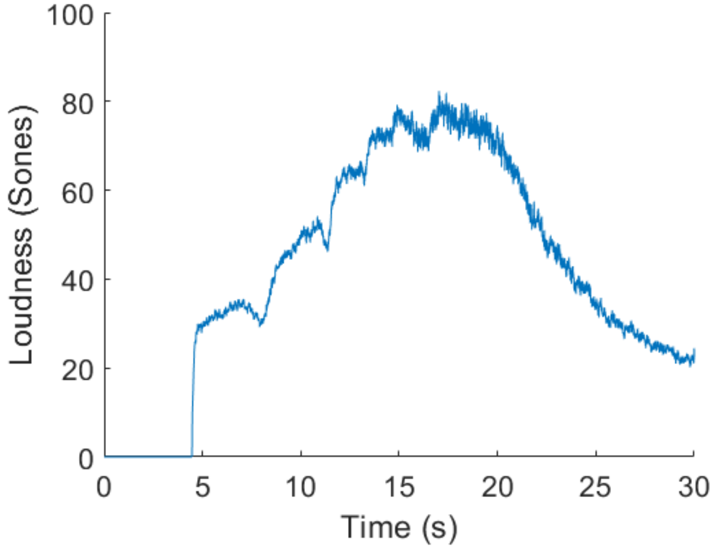
Psychoacoustic Analysis Library (NAFPAL)

- NAFPAL is a NAF postprocessor plugin for analysis of NAF output
- NAFPAL includes:
  - Zwicker time-varying loudness (ISO 532-1).
  - DIN 45692 and Aures sharpness
  - Fluctuation strength and roughness based on Daniel and Weber
  - Tone prominence ratio based on ECMA-74
- NAFPAL uses the ISO 532-1 software library.
  - NAF user must download and build
- Future plans include implementation of sensitivities for use in perception-influenced design

Simulated flyover using NAFSNaP



Time-varying loudness using NAFPAL



Software Availability

- Request software through the NASA Software Catalog

- NAF and NAF-APL version 1.2.1
  - NAF: https://software.nasa.gov/software/LAR-18541-1
  - NAF-APL: https://software.nasa.gov/software/LAR-19278-1

- ANOPP2 version 1.3
  - ANOPP2: https://software.nasa.gov/software/LAR-19861-1

Our Team… Present and Past

Present

Aric Aumann (AS&M)

Matt Boucher (NASA)

Andrew Christian (NASA)

Siddhartha Krishnamurthy (NASA)

Menachem Rafaelof (NIA)

Stephen Rizzi (NASA)

Brian Tuttle (AMA)

Past

Matt Allen (VT)

John Faller (Post-doc)

Jonathan Hardwick (VT)

Selen Okcu (Post-doc)

Dan Palumbo (NASA ret.)

Nick Pera (VT)

Brenda Sullivan (NASA ret.)

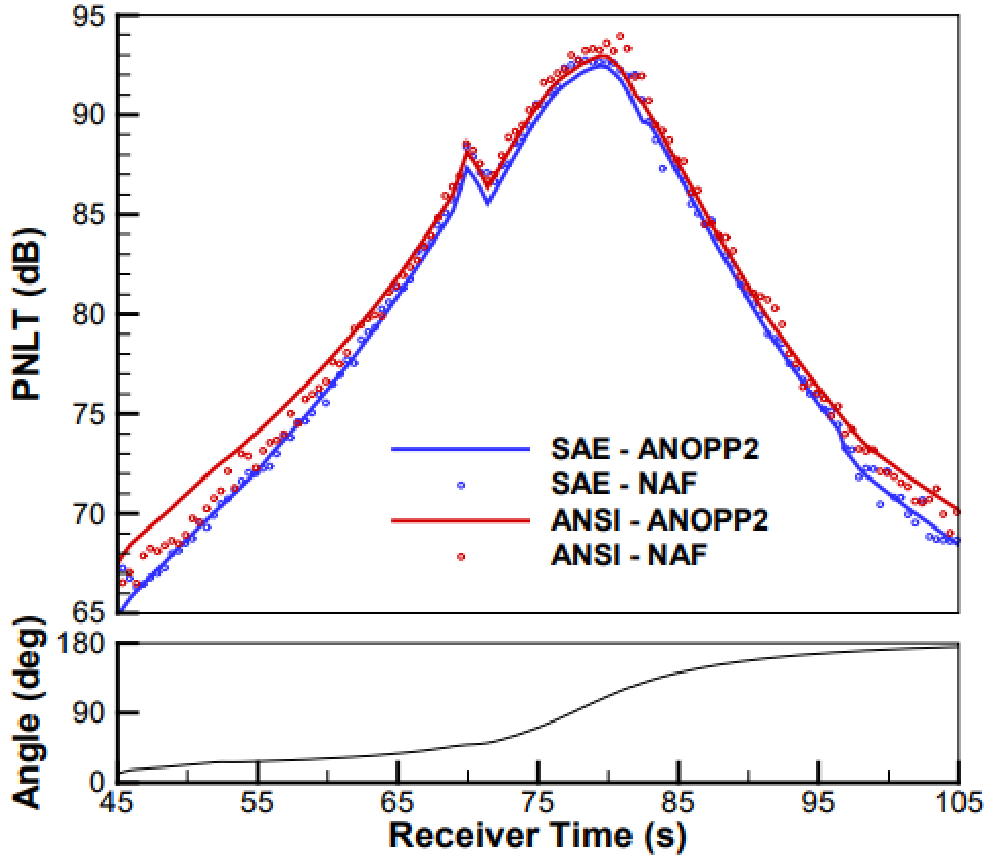
Movies and sounds are available for download at:

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

Backup Slides

SAE ARP 866A Absorption

- Added model for calculating absorption according to SAE ARP 866 Revision A
- Consistent with prediction tool chain
- NAF Advanced Plugin Library now includes ANSI as well as SAE ARP 866A absorption models



"Auralization of a Supersonic Business Jet Using Advanced Takeoff Procedures", Stephen A. Rizzi, Jeffrey J. Berton, and Brian C. Tuttle, AIAA SciTech 2020, AIAA-2020-0266, Orlando, FL, USA, 6-10 January 2020. https://doi.org/10.2514/6.2020-0266