Noise Sphere Guidance Document

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SAE A-21 Committee

Aircraft Noise Measurement and Aircraft Noise/Aviation Emission Modeling

Outline

- Source Noise Data Utilization
- Source Noise Data Generation
  - Prediction-Based
    - Fixed-Wing
    - Rotary-Wing
  - Measurement-Based
- Noise Propagation
- Auralization

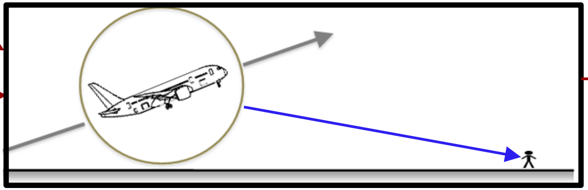
Source Noise Data Utilization

- Source noise data support many types of aircraft acoustic analyses
  - Source noise reduction technology development
  - Prediction of noise certification (Part 36) metrics
  - Assessments of community noise (Part 150)
  - Calculation of noise-power-distance data
  - Input to auralization
- Regardless of vehicle type, similar noise generation process
  - Source noise data on hemisphere centered on each source or on full vehicle
    - Data are acquired at emission angles and are a function of time
    - Data can be from source noise predictions or from noise measurements
  - Source is propagated to observers on the ground and metrics are calculated

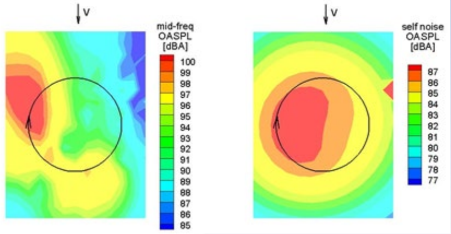
Source Noise Prediction

Source Noise Measurements

Propagation Algorithm



Noise Metrics May Be Computed for Few Observers (Part 36) or for Many Observers (Part 150)



Fixed Wing System Noise Prediction

ANOPP2

Aircraft Flight Definition

Source Noise (ANOPP)

Jet: Stone (ST2JET + *AOA correction)*

Core: SAE (GECOR)

Fan: modified Heidmann (HDNFAN-Krejsa), ACD(GTF-measured)

Landing gear (nose & main): GuoLG

Flap-side-edge: BAF-Flap

Leading edge (Krueger): estimated using BAF-Slat

Trailing edge: Fink (FNKAFM)

PAA Effects: engine noise installation effects (shielding, reflections) (GENSUP)

ITD noise technology: reduction through suppression of specific source noise (fan, gear, flap, slat) (GENSUP)

Propagation

Noise Metrics

EPNL predicted at locations defined by Code of Federal Regulations (CFR) Title 14 Part 36

Flight profiles that meet CFR 36 Aircraft geometries ← **FLOPS MVL-aero** ←

- Low speed aero (ITD 51A)
- Engine operating limits
- Airframe geometric definition
- Aircraft weights

Engine states and geometric parameters ← **NPSS**

ITD 35A: Soft Vane fan noise reduction
GTF source fan noise and 'effects' data for cut-off, bifurcation, sweep & lean, rotor-stator-spacing

ITD 50A: Flap side edge treatment noise suppression data for RJ & 3.0 dB suppression for all other vehicles
Partial main gear fairing noise suppression data for all vehicles

Propulsion/Airframe Aeroacoustic (PAA) Effects:
14x22 HWB data (Phase I)
LSAF T+W and HWB data (Phase I)

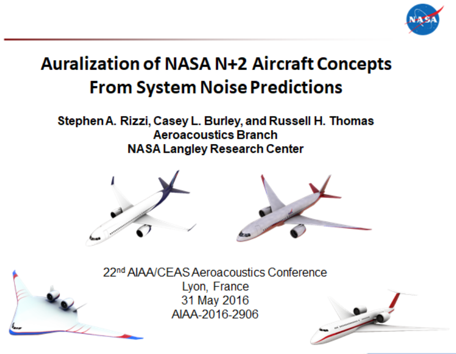
Auralization

NAF (Synthesis)

CNoTE (Propagation)

Psychoacoustic Metrics

Rizzi, Stephens, Berton, Van Zante, Wojno, Goerig, "Auralization of Flyover Noise from Open Rotor Engines Using Model Scale Test Data," AIAA Journal of Aircraft, V53, No.1, 2016


Auralization of NASA N+2 Aircraft Concepts From System Noise Predictions

Stephen A. Rizzi, Casey L. Burley, and Russell H. Thomas
Aeroacoustics Branch
NASA Langley Research Center

22nd AIAA/CEAS Aeroacoustics Conference
Lyon, France
31 May 2016
AIAA-2016-2906

Rotary Wing Comprehensive Noise Analysis

Source Definition

Vehicle Definition
Airfoil Tables
Flight Condition

↓

Comprehensive Analysis
- CAMRAD II
- CHARM

↓ extract

Blade loads and motion
- f(radius, azimuth)
- V_{ind}, α_{eff} (for Self Noise)

→ (to AARON)

Acoustic Calculation

Source Observer (hemisphere)
Ground Observers (Mic. Locations)
Flight Path

↓

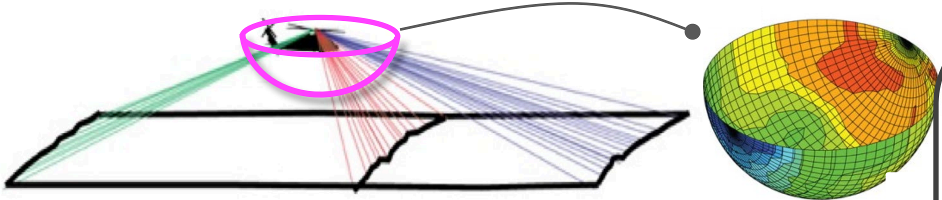
AARON
- F1A
- Self Noise
- Far Field Propagation

↓

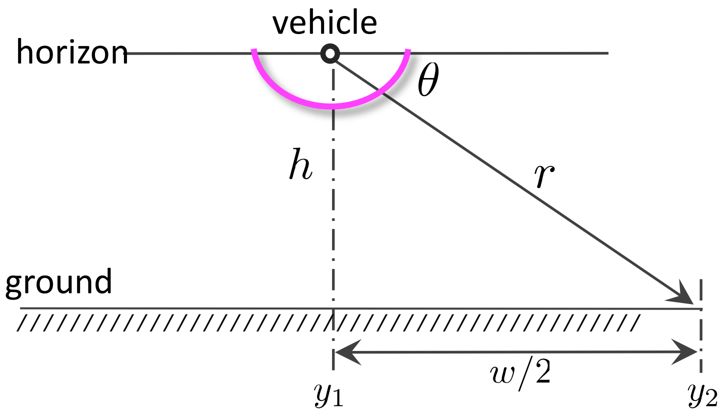
Metrics at Ground Observer(s)

Source Noise From Measurements

To characterize **steady** flight conditions



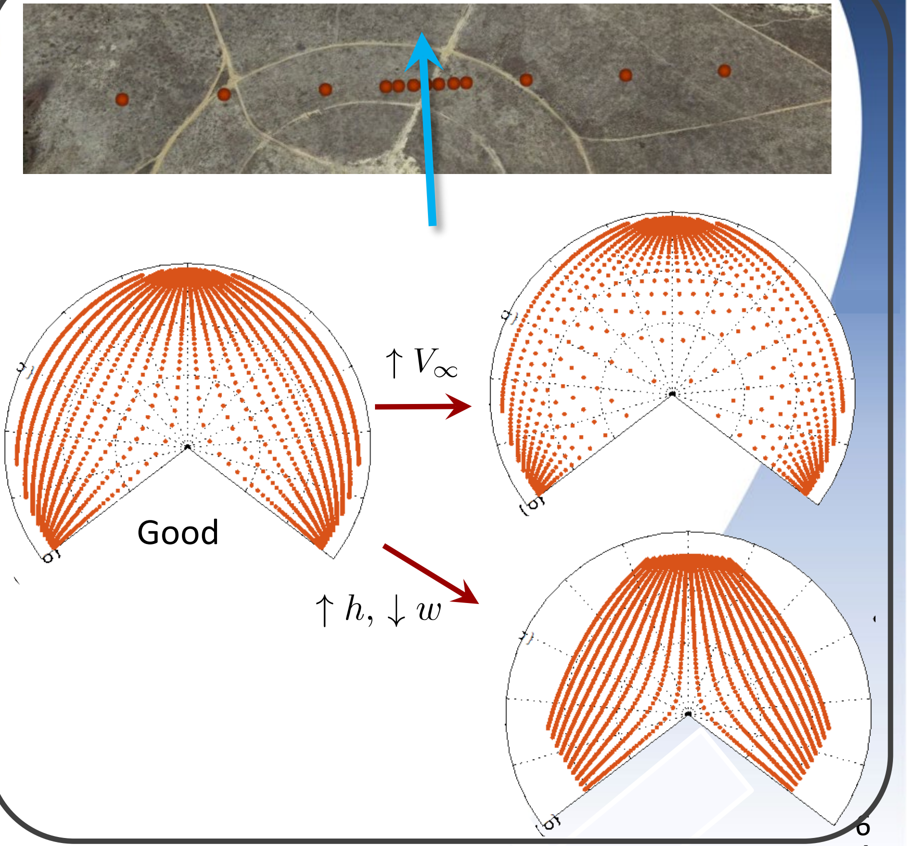
$L = f(\phi, \theta, f)$



$$SNR = 20\log_{10}\left(\frac{p_{rms}}{n_{rms}}\right) \qquad \Delta SNR_{y_1,y_2} = 20\log 10(\sin\theta)$$

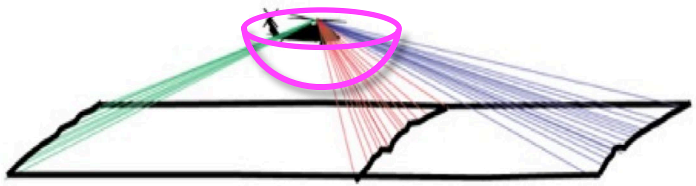
$$\text{e.g., } \theta = 10^\circ \rightarrow \Delta SNR_{y_1,y_2} = 15 \text{ dB}$$

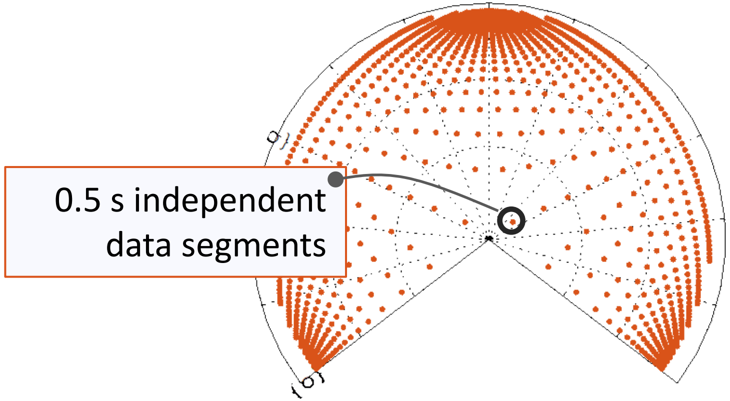
Directivity resolution depends on vehicle altitude, speed



Source Noise From Measurements

To characterize **steady** flight conditions





Signal processing considerations

- ART methodology of AAM [1]
- 0.5 s data segments (nonuniform hemisphere resolution)
- Spectra of each 0.5 s block compared to ambient levels
    - Frequency bins accepted if SNR > 3-6 dB

- Atmospheric attenuation applied - ANSI S1.26 [2]
- Angle and frequency dependent ground losses model applied
    - Chien and Soroka [3]
    - Delany & Bazley ground impedance model [4]
- Back propagation to 100 ft, spherical spreading accounted for

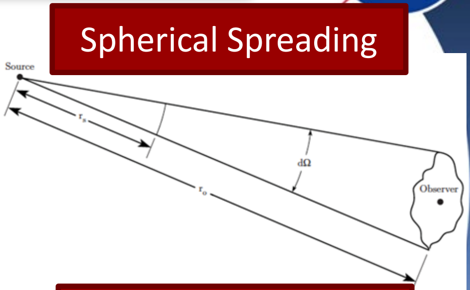
- If uniform elevation/azimuthal angle desired:
    - Implement Shepard's inverse distance weighting [5] interpolation scheme applied

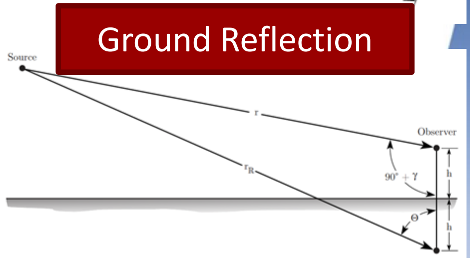
- Can choose processing parameters post-flight test

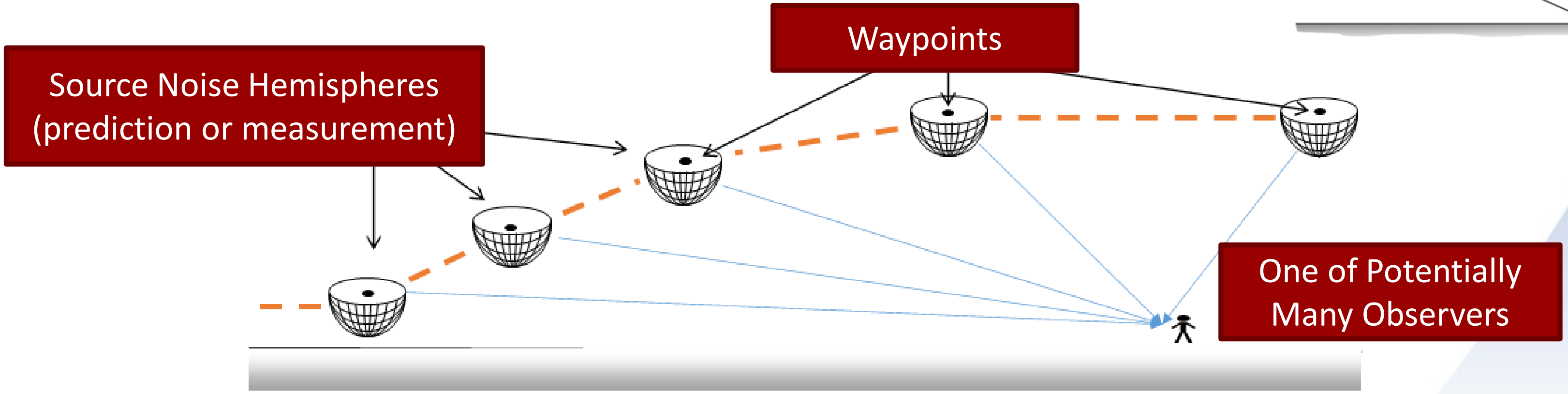
[1] Page et al., "Advanced Acoustic Model Technical Reference and User Manual," 2009.
[2] "Method for the Calculation of the Absorption of Sound by the Atmosphere," Standard ANSI S1.26-1995, 2004.
[3] Chien, C., and Soroka, W., *JSV*, Vol. 43, (1), 1975, pp. 9–20.
[4] Delany, M., and Bazley, E., *Applied acoustics*, Vol. 3, (2), 1970, pp. 105–116.
[5] Shepard, D., "A Two-Dimensional Interpolation Function for Irregularly-Spaced Data," 23rd ACM National Conference, 1968.

Source Noise Propagation

- Other factors also dictate what an observer hears
  - Atmospheric absorption (molecular vibration dampens noise as it travels)
  - Spherical spreading of acoustics waves (same power spread over larger area)
  - Ground reflection (frequency dependent interference patterns and ground absorption)
  - Curved ray propagation (temperature gradients changing local speed of sound)
  - Convective amplification and Doppler shifting of frequency domain noise sources
- Source hemispheres and flight path are fed into propagation algorithm
  - Source hemispheres can be from measurements or prediction
  - Flight path may be for a complex maneuver (below) or one of many for NPD curves

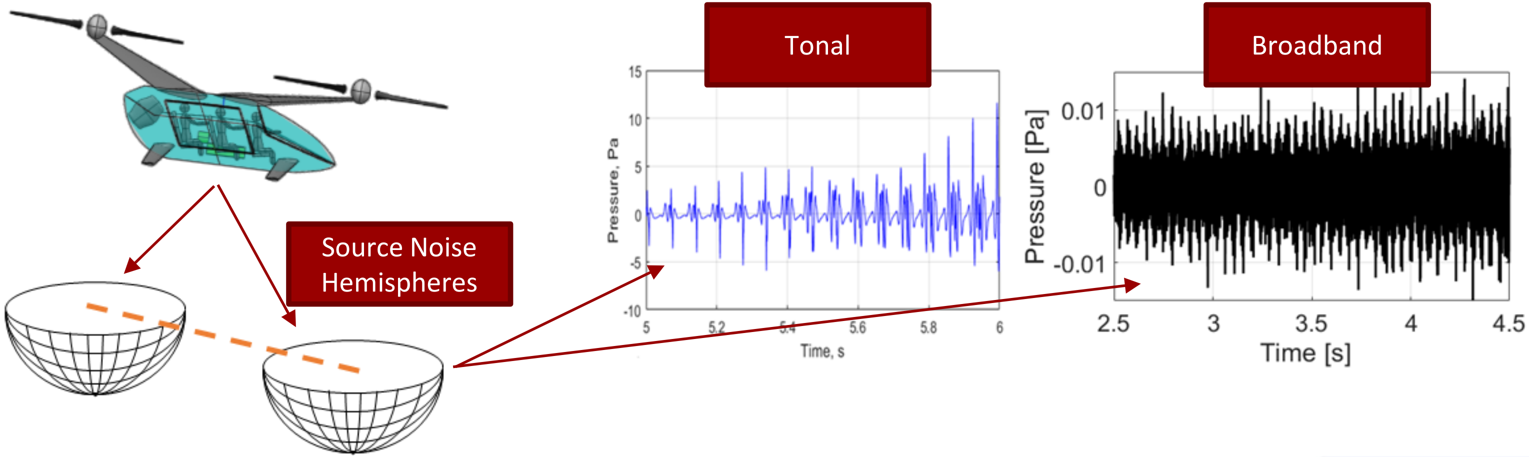






Auralization

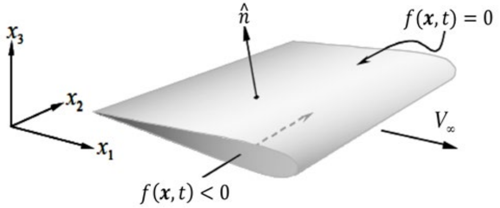
- Noise certification and community noise metrics are not ideal for assessing human response
- Auralization is typically performed using source noise data, either from predictions or measurements
  - Different noise source types require different synthesis methods, so we typically require source noise data (inclusive of installation effects) from each individual source on the vehicle.
- Audible signal can be assessed for various human response measures (e.g., annoyance, audibility)
  - New measures are being developed to better capture human response
- NASA's Auralization Frame (NAF) calculates audible signals at source and observer from hemisphere data



Backup Charts

Rotary Wing Source Noise Prediction (Tonal Noise)

- Farassat's Formulation 1A of the Ffowcs Williams and Hawkings equation
  - Includes thickness and loading (impulsive) noise
  - Can include broadband noise if very high fidelity CFD is used (Lattice Boltzman or LES+)
    - Very time consuming, often not included
    - Broadband noise is typically empirically modeled (next slide)
- Computes tonal acoustic pressure from surfaces that can:
  - be from CFD-based structured/unstructured surface (depend on flow solution)
  - be from reduced order lifting line comprehensive analysis
  - be from surface or line node-based or face-centered data (depend on flow solution)
  - be constant or deforming surfaces or lines
- Many capabilities for reduced memory footprints
  - Calculate time derivatives of flow quantities as needed
  - Read surface and fluid properties from disk as needed
- Different parallel processing options
  - MPI by observer position and/or source surface data
  - OpenMP by source surface data
- Significant metadata output crucial for debugging usage



Surface Terms | Volume Term → 0

$$\bar{\Box}^2 p' = \frac{\bar{\partial}}{\partial t}\{Q\delta(f)\} - \frac{\bar{\partial}}{\partial x_i}\{F_i\delta(f)\} + \frac{\bar{\partial}^2}{\partial x_i \partial x_j}\{T_{ij}H(f)\}$$

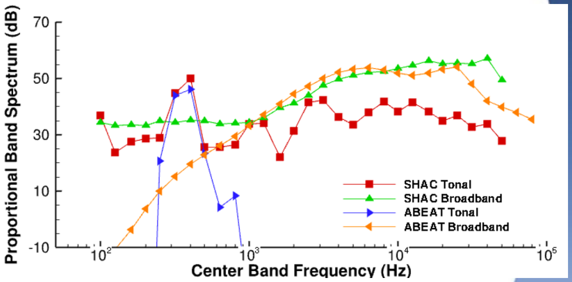
$$4\pi p'_m(\boldsymbol{x}_i,t) = \int_{f=0} \left[(\dot{Q}J + Q\dot{J})A_{1A} + QJB_{1A}\right]_{ret} du_1 du_2$$

$$4\pi c_\infty p'_d(\boldsymbol{x}_i,t) = \int_{f=0} \left[(\dot{\boldsymbol{F}}_i J + \boldsymbol{F}_i \dot{J})\boldsymbol{C}_{1A,i} + \boldsymbol{F}_i J \boldsymbol{D}_{1A,i}\right]_{ret} du_1 du_2$$

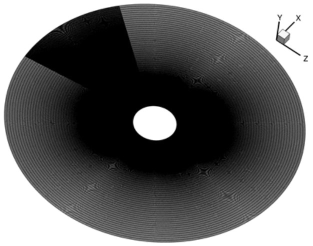
Rotary Wing Source Noise Prediction (Broadband)

- Broadband noise for UAM vehicles is still an ongoing research area
  - Significantly more important than traditional rotorcraft
  - Includes broadband self noise (from turbulence generated in blade's boundary layer)
  - Can also be from ingestion of turbulence field into rotor (rotor wake interaction)
- Numerically calculating turbulent field quickly is very challenging
  - Reduced order models based on flat plate assumption are very promising
- Physics-based empirical models are based on NACA 0012 measurements
  - Correlation between boundary layer characteristics and radiated noise

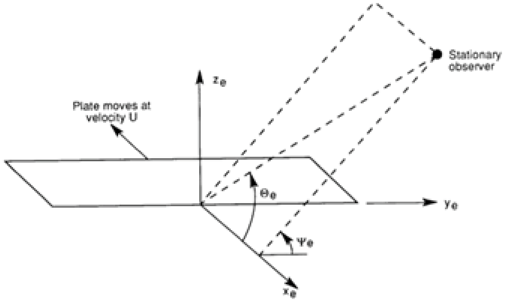
Validation by Comparing to Wind Tunnel Measurements



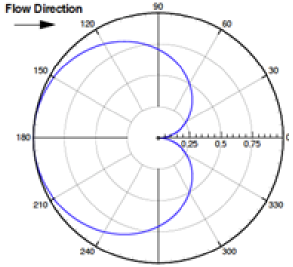
Discretize Rotor



Flat Plate Assumption for Each Segment



Empirical Noise Radiation from Each Segment



Sum Noise in Frequency and Time