Recent Aeroacoustic Tools and Methods Developments for Analysis and Design of Advanced Aviation Systems

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Outline

• Aeroacoustic Tools and Methods Development

• Aeroacoustics Tools and Methods – Use Cases
  – System Noise
  – CFD/CAA Based Design
  – Time Dependent Configurations

• Perception-Influenced Design
  – NASA Auralization Framework
  – Open Rotor and Distributed Electric Propulsion Auralizations

• Concluding Remarks
Aeroacoustic Tools and Methods

Validated Aeroacoustic Tools & Methods for Low Noise

- Source Noise Models & Reduction
- Propulsion Airframe Aeroacoustics
- Multiple Fidelity System Noise Prediction

- Engine & Airframe
- Noise Reduction Technology
- Measurement Methods
- Installed Sources
- Scattering Methods
- Installed Effectiveness
- ANOPP
- ANOPP2
- Propagation Models
# Aeroacoustic Tool and Methods – Development

**NASA Projects: Push** capabilities to AS/T³ for advancing tools and methods
- cross-cutting source noise models and data
- validation data

**NASA Projects + Other Government Agencies + Industry: Pull** of AS/T³ Tools and Methods
- Capabilities to perform system noise prediction and MDAO analysis

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NRA: Fast Efficient Computation of Acoustic Scattering for Aircraft Noise Prediction (Old Dominion University)

APPROACH
Develop, implement and validate a fast, efficient, high-fidelity time domain acoustic scattering tool for a complete aircraft configuration over a practical frequency range.

• Implement a boundary element computation on unstructured triangular and quadrilateral surface elements
• Validate results with known time and frequency domain benchmark solutions
• Demonstrate the validity and efficiency of the method for full conventional and unconventional aircraft configurations
• Develop interface for integration with the ANOPP2 multi-fidelity framework

SIGNIFICANCE
The validated time domain acoustic scattering tool (TD-FAST) provides higher-fidelity acoustic shielding/scattering predictions for incorporation into system noise assessments of current and future aircraft configurations.

POSSIBLE FUTURE WORK
• Incorporation of external incident source descriptions
• Incorporation of impedance boundary condition on scattering surfaces
• Implementation and validation of a CPU-only version

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Aeroacoustic Tools and Methods – Use Cases

- System Noise
- CFD/CAA Based Design
- Time-Dependent Configurations including Flow and Acoustics
System Noise

Outline of Program using ANOPP2

Aircraft Definition and Mission
- Atmosphere Data Structure
- Flight Path Data Structure
- Engine System Data Structure
- Geometry Data Structure
- Observer Data Structure

Select ‘Functional Modules’ (partial list)
- ANOPP
- Flight Effects, Propagation
- PAA Effects
- Surrogate Model
- Farassat’s Formulations
- Wind Tunnel Measurements

Predict Noise for Mission
- User defines computational settings
- Results stored on Observer Data Str.

Results: noise, mission, aircraft state

ANOPP2 Configuration Files

- Flight Path Configuration
- Engine State Data
- Measurement Data
- Flow Data
- Plugin Configuration

External Functional Noise Module

Externally Computed Flight Path Definition (ex: FLOPS)
NPSS: Engine State
Measured/Predicted Noise
Externally Computed Flow Properties

Acoustics
- Time histories, 1/3rd-Octaves, Narrowband
- PNL, PNLT vs. emission angle
- EPNL, SEL (certification point, contour)
- Sensitivity Matrices (Adjoint Solutions)

Aircraft/Prediction Information and Metadata
- Flight Trajectory (Throttle, Mach, Altitude, etc.)
- Engine State
- Source Geometric and Flow Properties
Noise Assessment of HWB Aircraft

• **Evaluate closed HWB design (N2A-EXTE)**
  – Boeing redesign of the CMI SAX 40 via NASA Research Announcement award (2007-2011)
  – Simultaneously meet NASA N+2 goals for noise (42 EPNdB below Stage 4) and fuel burn (>25% reduction rel. B737/767 technology)
  – Fabricate and deliver a full-span, 5.8% scale model for aerodynamic and acoustic testing

• **NASA Langley conducted aerodynamic (2011) and acoustic (2012-2013) tests**

• **Noise assessment process developed to utilize latest data and prediction methods**
  – Measured aerodynamic performance for aircraft configuration & flight path definition
  – Measured acoustic data for source noise and propulsion airframe aeroacoustic effects
  – ANOPP2/ANOPP prediction for source noise, propagation, certification noise metrics
EPNL predicted at FAR 36 locations

ANOPP2

Aircraft Flight Definition (trajectory, configuration, operating state)

ANOPP
Jet: CJES data
Core: GECOR (SAE876)
Fan: Heidmann (Krejsa)
Airframe: measured

ANOPP Jet: CJES data
Core: GECOR (SAE876)
Fan: Heidmann (Krejsa)
Airframe: measured

PAA Effects
Fan + BENS-shielding
Core + BENS-shielding

Flight profiles that meet FAR 36 & low noise
Engine state for FPR=1.6, BPR~10

FLOPS

NPSS

• Low speed aero from HWB aero test
• Elevon settings defined by stability & control considerations
• Airframe geometry definition from design
• Aircraft weights from design

Measured source noise (lossless)
- Jet noise (CJES)
- Airframe noise:
  LG: (nose and main), drooped LE trailing edge

Measured noise suppression (BENS): turbomachinery exit and inlet

Blue indicates measured data
FLOPS = Flight Optimization System
NPSS = Numerical Propulsion Simulation System
ANOPP = Aircraft Noise Prediction Program
BENS = Broadband Engine Noise Simulator
CJES = Compact Jet Engine Simulator

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Cumulative System Noise Results

- Engine x/D=2.5
- Chevrons
- Droop L.E.
- Verticals cant 10°
- Narrow/cant 30° verticals
- Over-the-Rotor & Soft-Vane
- Low noise landing gear

NASA N+2 goal = 42dB

38.7 dB is reached with technology assumptions for fan and gear noise

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Aeroacoustic Tools and Methods

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Source Noise Models & Reduction → Propulsion Airframe Aeroacoustics → Multiple Fidelity System Noise Prediction

- Installed Sources
- Scattering Methods
- Installed Effectiveness

- ANOPP2
- ANOPP
- Propagation Models

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Component PNLT for “Best” Configuration

“Best” Configuration
- Engine at x/D=2.5
- Optimized Chevrons
- Drooped leading edge
- Narrow/cant30 verticals
- Low noise landing gear
- Over-the-Rotor liner & Soft-Vane fan noise technologies

Approach A1

Sideline (Full-throttle)

Flyover (Cutback)
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System Noise in MDAO Environment

2014 (complete):
• Initial coupling ANOPP2 with Model Center for conventional 737 aircraft

2015:
• Coupling ANOPP2 with Model Center for unconventional aircraft utilizing scattering method
• Initial coupling ANOPP2 with OpenMDAO for conventional 737 aircraft

2016:
• Coupling ANOPP2 with OpenMDAO for unconventional aircraft utilizing scattering method
• Initial coupling using adjoint methodology of ANOPP2 within OpenMDAO
Aeroacoustic Tools and Methods – Use Cases

- System Noise
- CFD/CAA Based Design
- Time-Dependent Configurations including Flow and Acoustics
CFD/CAA Based Design

- CFD
- Aero

ANOPP2 Framework
- Farassat’s Formulations
- Scattering Metric Calculations
- Acoustic Interpolation
- Scaling to Flight (Adjoint Capability)

OpenMDAO/Model Center
- Optimal Performance
- Optimal Noise

Optimal Design
Open Rotor Noise Prediction

- Development of an open rotor noise prediction methodology
- Comparison with CRPFAN (not shown) will provide further confidence in NASA’s suite of open rotor prediction tools
  - Multi-fidelity source modeling capability within ANOPP2
- Mixture of prediction methods leads to better understanding of noise characteristics
- More accurate N+2, N+3 system assessments based on predicted source levels as opposed to measurement
Aeroacoustic Tools and Methods – Use Cases

- System Noise
- CFD/CAA Based Design
- Time-Dependent Configurations including Flow and Acoustics
Time Dependent Configurations – Rotorcraft Noise Prediction and Propagation

Step 1: CFD / CSD Coupling
- CAMRAD-II
- Blade motions
- OverFLOW2
- Inputs for CFD

Step 2: Post Processing and ANOPP2 Usage
- Blade Motions and Surface Pressures
- Inputs for ANOPP2

ANOPP2 User Code:
- Uses ANOPP2 APIs
- Obtain F1A for results on hemisphere
- Duplicate results at flyover start and end
- “Fly” hemisphere with ANOPP
- Compute and export results at observer.

Dr. Doug Boyd

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What do these transformative systems have in common?
Perception-Influenced Design
“A synthesis of validated aeroacoustic tools and methods plus human perception”

Validated Aeroacoustic Tools & Methods for Low Noise
- Source Noise Models & Reduction
- Propulsion Airframe Aeroacoustics
- Multiple Fidelity System Noise Prediction

MDAO Environment

Auralization

Human Perception and Metrics
- NAF
- CNoTE

Psychoacoustic Labs
- EER
- IER
- Boom Simulator

- Engine & Airframe
- Noise Reduction Technology
- Measurement Methods
- Installed Sources
- Scattering Methods
- Installed Effectiveness
- ANOPP2
- ANOPP
- Propagation Models
NASA Auralization Framework (NAF)

- **Auralization of aircraft flyover noise consists of source-path-receiver modeling**
  - Source noise synthesis based on prediction (ANOPP, ANOPP2), flight-scaled wind tunnel data, flight test data
  - Propagation of synthesized noise generates pseudo-recording at ground receiver and accounts for spreading loss, atmospheric absorption, Doppler simulation, and ground plane effects
    - Pseudo-recording demonstrated to obtain same integrated metrics as those obtained from system noise prediction
  - Receiver modeling takes pseudo-recording to a subjective test environment for evaluation

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**Host Environment**

(Executable, GUI, MATLAB, LabView, etc.)

[C/C++, VisualBasic, Java, MATLAB, etc.]

**API**

Object Definitions
- Component
- Source
- SourceFrame
- Sink
- Receiver
- Envelope
- Path
- PolySampleBuf
- GTF
- GTFSeries

**SceneGen**

Defines a “simulation frame” at block boundary by traversing and interpolating trajectories, and reading live sensors

**PathFinder**

Connects sinks back in time to sources through multi-path algorithms, maintaining at least source x sink paths at each frame

**SynthEngine**

Creates new block of time pressure history from each component for each different emission angle for each frame

**GTFEngine**

Applies Gain-Time-Filter to TPH at fractional samples for each path
Open Rotor Propulsor – Effect of Blade Set

### Historical Blade Set (RDG 361)

- **SPL<sub>A</sub> - Aural**
- **SPL<sub>A</sub> - ANOPP**
- **PNLT - Aural**
- **PNLT - ANOPP**

- EPNL Cut-Off
- 111.3 (ANOPP), 111.3 (Aural) EPNdB

### Gen-2 Blade Set

- **Solo** (flush receiver)
- **Interleaved with RDG 361** (flush receiver)
- **Solo** (elevated receiver)
- **Interleaved with RDG 361** (elevated receiver)

- 100.5 (ANOPP), 100.2 (Aural) EPNdB – Flush
- 97.6 (ANOPP), 97.5 (Aural) EPNdB – Elevated

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DEP Aircraft Component and System Noise

High lift systems (LEP & T.E.)
- Motor nacelles
- Minimize turbulent edge flows

Engine/airframe integration
- Prop-prop interaction
- Prop-wing interaction

Landing gear design & placement

Propulsion/LEP System
- Propeller noise
- Electric motor noise
- Low annoyance/detection configurations
Effect of Spread Spectrum on Leading Edge Propeller Noise

State-of-the-Art General Aviation Baseline – Cirrus SR22
Average Source Power: 102.2 dB (prop only)

Distributed Electric Propulsion – LEAPTech Concept with 18 propellers
Average Source Power: 87.5 dB (props only) for all configurations below, yet sound very different

Notes
• All average source power levels taken over 1km x 1km area
• Sound sampled at ground location in middle of area, with aircraft flying 150m directly overhead

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Concluding Remarks

• NASA aeroacoustic tools span range from source noise prediction and reduction, to PAA, to systems analysis, to human perception and metrics
  – Unifying ANOPP2 and NAF frameworks allow projects to plug-in their own methods and both leverage and invest in the cross-cutting toolset that AS/T³ is continuing to develop.
  – Tools under development support all NASA aeronautics projects and those of other government agencies and industry.

• Aeroacoustic tools and methods demonstrated for system noise prediction, CFD/CAA based designs, and time-dependent configurations
  – ANOPP2 acoustic formulations provide a new path for Revolutionary Computational Aerosciences work to achieve optimized air vehicle designs

• Perception-influenced design is a means of achieving low noise conceptual and detail design for advanced configurations in a MDAO environment
  – This is an enabling capability not previously available
  – Applies to vehicle systems over a wide range of flight regimes