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
Validated Aeroacoustic Tools & Methods for Low Noise

- Engine & Airframe
- Noise Reduction Technology
- Measurement Methods

- Installed Sources
- Scattering Methods
- Installed Effectiveness

Multiple Fidelity System Noise Prediction

- ANOPP2
- ANOPP
- Propagation Models

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### 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

<table>
<thead>
<tr>
<th>AS/T³ enabled</th>
<th>AS/T³</th>
<th>Environmentally Resistant Aviation</th>
<th>Fixed Wing</th>
<th>Rotary Wing</th>
<th>High Speed</th>
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</table>
| Propulsion Airframe Aeroacoustics | TD-FAST | • Data  
  • Diffraction Integral Method (DIM3) | Fast Scattering Code (FSC) |             |            |
| Engine source |             | • Soft vane  
  • Engine fan data | • Core models/data  
  • Fan models/data  
  • Soft vane data |             | • Surrogate models for jet noise |
| Airframe source |             | • LG data  
  • Flap-side edge data | • LG models  
  • Flap-side edge models |             |            |
| Source to receiver effects |             |             |                     |             | • Propagation models/data  
  • Terrain effects |
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
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
- Externally Computed Flight Path Definition (ex: FLOPS)

Engine State Data
- NPSS: Engine State

Measurement Data
- Measured/Predicted Noise

Flow Data
- Externally Computed Flow Properties

Plugin Configuration
- External Functional Noise Module

- 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
N2A-EXTE Noise Assessment Process

ANOPP2

Aircraft Flight Definition
(trajectory, configuration, operating state)

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

Airframe: measured

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

Propagation & Noise Metrics

Flight profiles that meet FAR 36 & low noise

Engine state for FPR=1.6, BPR~10

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

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

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

CUM = A1 + CB + SL (low speed approach)
CUM = A2 + CB + SL (conv. speed approach)

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

Validated Aeroacoustic Tools & Methods for Low Noise

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

- Installed Sources
- Scattering Methods
- Installed Effectiveness

- ANOPP2
- ANOPP
- Propagation Models
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)
Aeroacoustic Tools and Methods

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- Measurement Methods

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- Propagation Models

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

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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
- 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

- ANOPP2
- ANOPP
- Propagation Models

MDAO Environment

Auralization

Human Perception

- NAF
- CNoTE

Psychoacoustic Labs
- EER
- IER
- Boom Simulator

• Engine & Airframe
• Noise Reduction Technology
• Measurement Methods

• Installed Sources
• Scattering Methods
• Installed Effectiveness
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
Open Rotor Propulsor – Effect of Blade Set

Historical Blade Set (RDG 361)

- PNLT - Aural
- PNLT - ANOPP
- SPL\textsubscript{A} - Aural
- SPL\textsubscript{A} - ANOPP

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

Gen-2 Blade Set

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

Solo
- (flush receiver)

Interleaved with RDG 361
- (flush receiver)

Solo
- (elevated receiver)

Interleaved with RDG 361
- (elevated receiver)

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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)

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

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

Coherent
Props phased by 10Hz
Props phased by 0.5Hz
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