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

MDAO Environment

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

- ANOPP2
- ANOPP
- 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

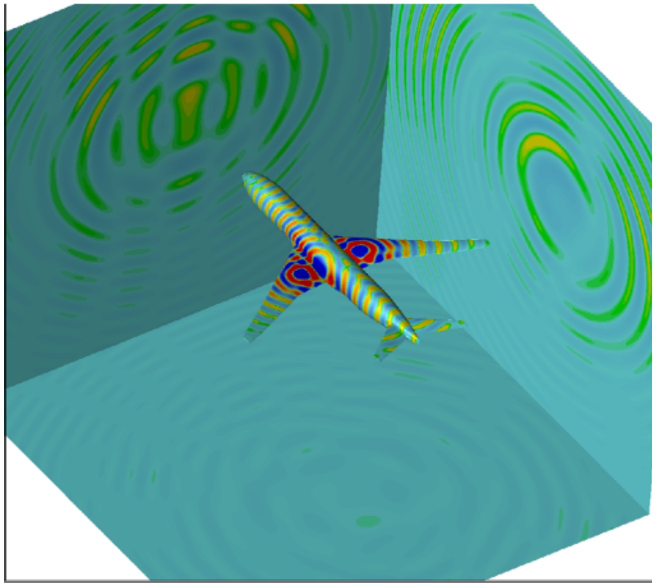
AS/T³ enabled	AS/T³	Environmentally Responsible Aviation	Fixed Wing	Rotary Wing	High Speed
Propulsion Airframe Aeroacoustics	TD-FAST	• Data • Diffraction Integral Method (DIM3)	Fast Scattering Code (FSC)		
Engine source		• Soft vane • Engine fan data	• Core models/data • Fan models/data • Soft vane data		• 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

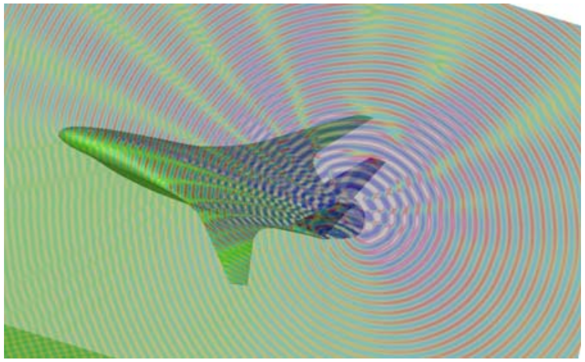
Develop, implement and validate a fast, efficient, high-fidelity time domain acoustic scattering tool for a complete aircraft configuration over a practical frequency range.

- 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

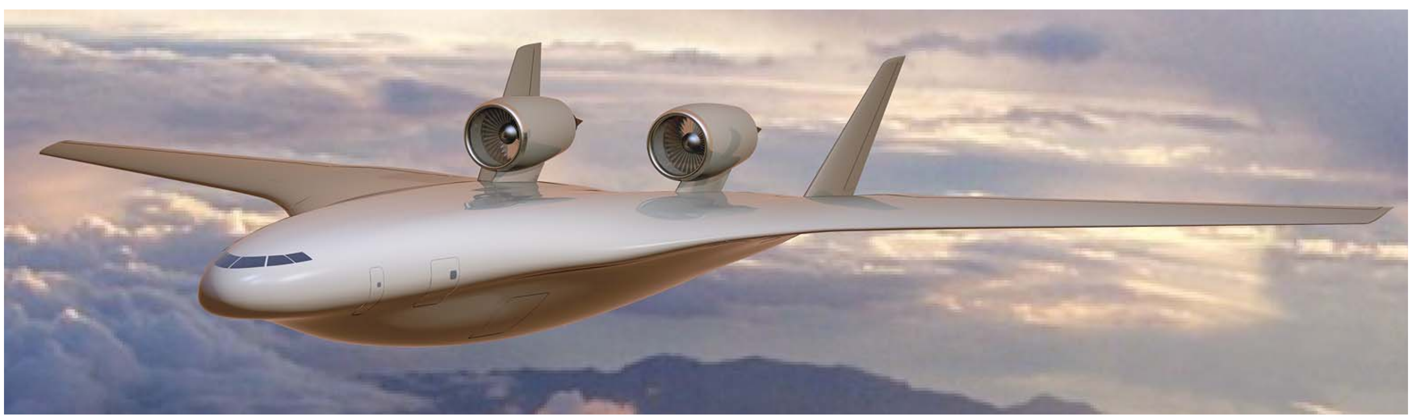
ANOPP2 Configuration Files

ANOPP2 Configuration Files	Source
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

Flight effects applied to measured data

Propagation & Noise Metrics

EPNL predicted at FAR 36 locations

Flight profiles that meet FAR 36 & low noise

Engine state for FPR=1.6, BPR~10

FLOPS

NPSS

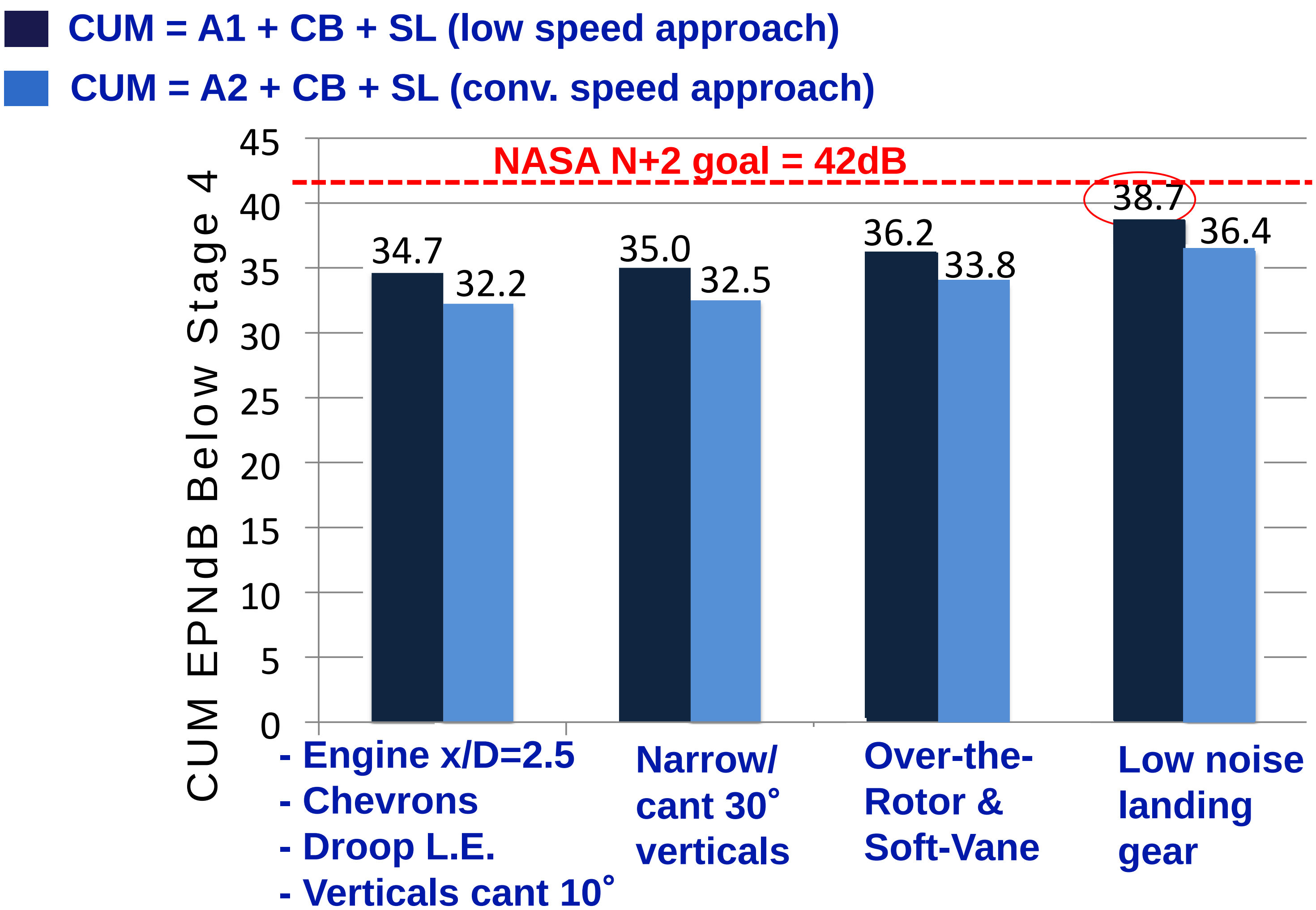
- **Low speed aero from HWB aero test**
- Elevon settings defined by stability & control considerations
- Airframe geometry definition from design
- Aircraft weights from design

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

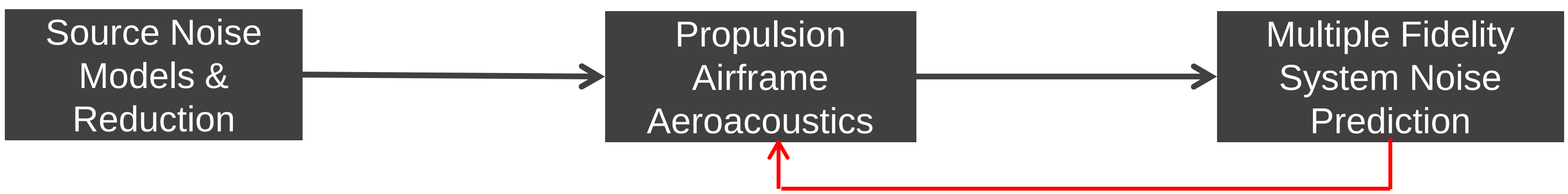
Cumulative System Noise Results



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

Aeroacoustic Tools and Methods

Validated Aeroacoustic Tools & Methods for Low Noise



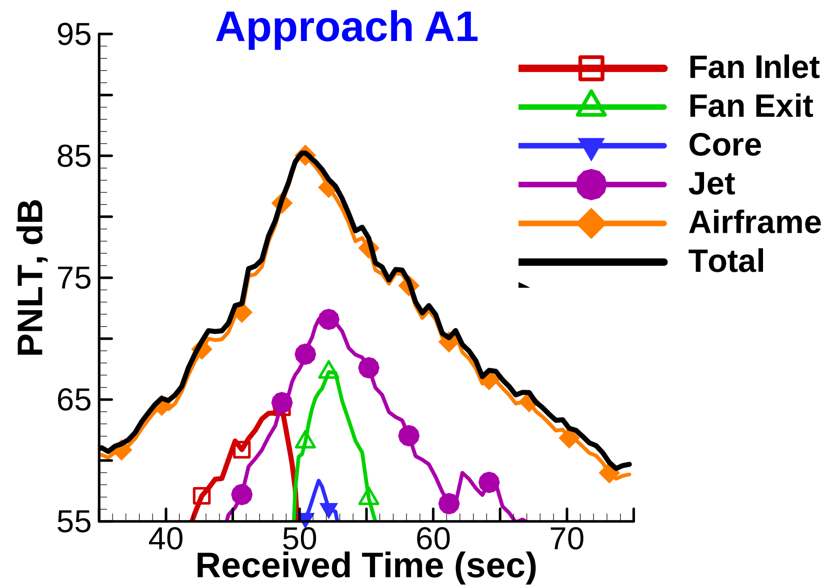
- **Installed Sources**
- **Scattering Methods**
- **Installed Effectiveness**

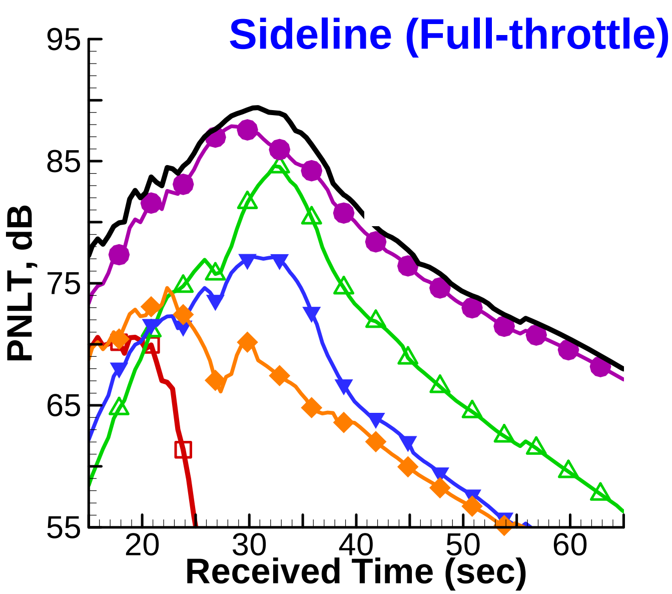
- **ANOPP2**
- **ANOPP**
- **Propagation Models**

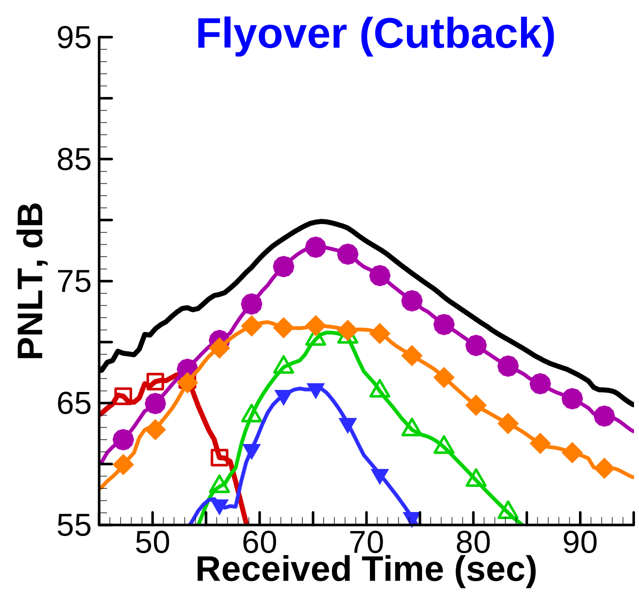
Component PNLT for "Best" Configuration

"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







Aeroacoustic Tools and Methods

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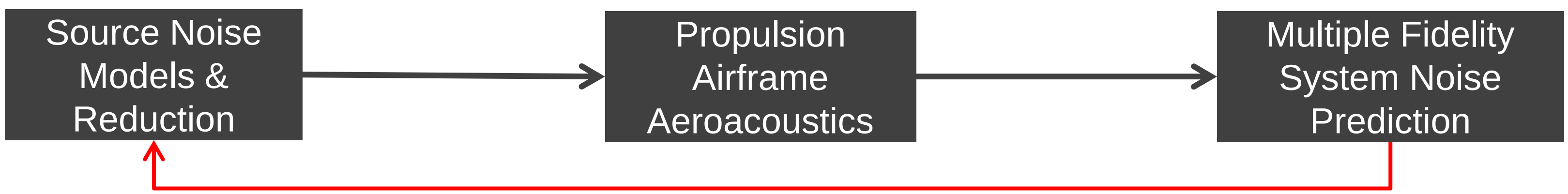


- **Engine & Airframe**
- **Noise Reduction Technology**
- **Measurement Methods**

- **ANOPP2**
- **ANOPP**
- **Propagation Models**

System Noise in MDAO Environment

2014 (complete):

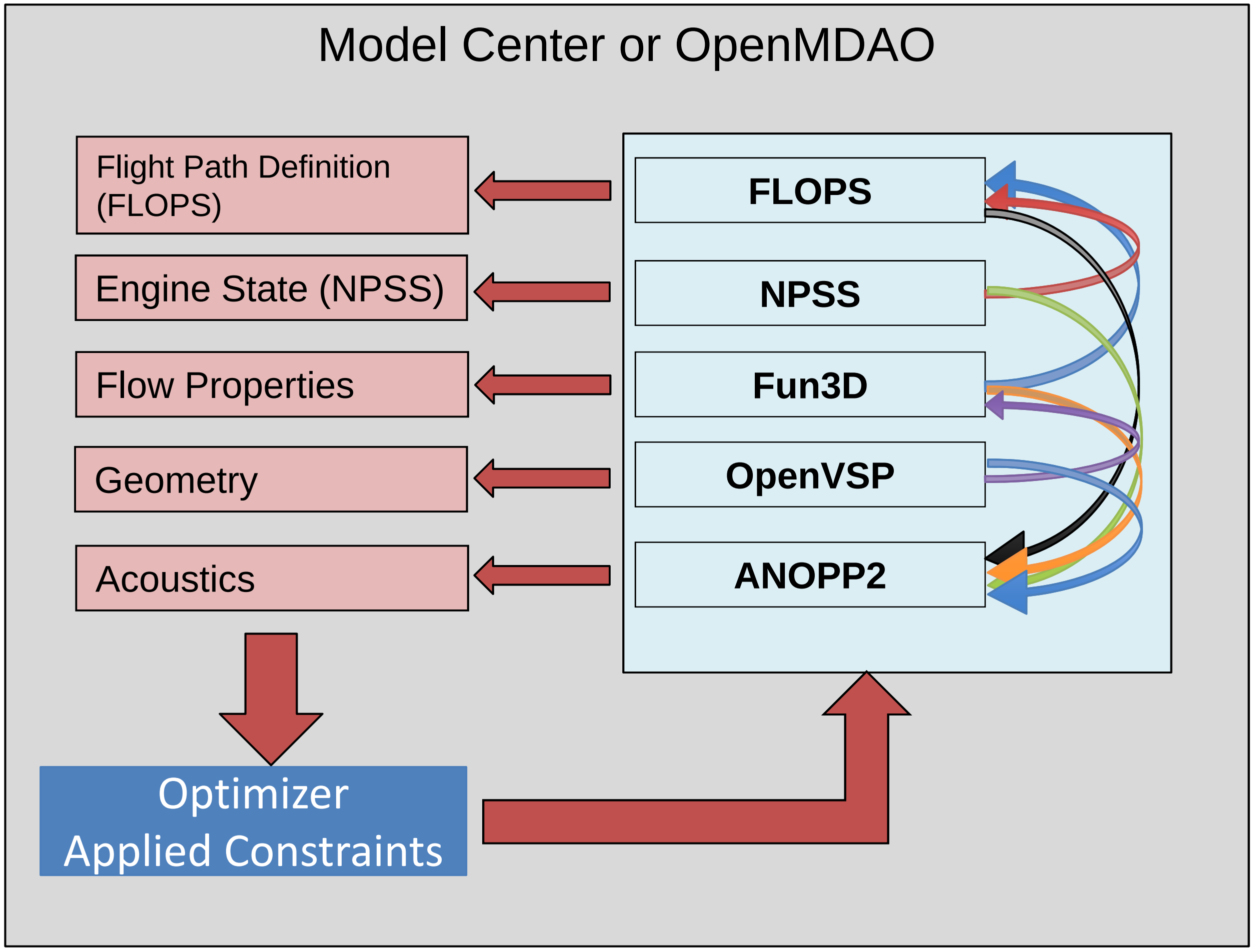
- Initial coupling ANOPP2 with Model Center for conventional 737 aircraft

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



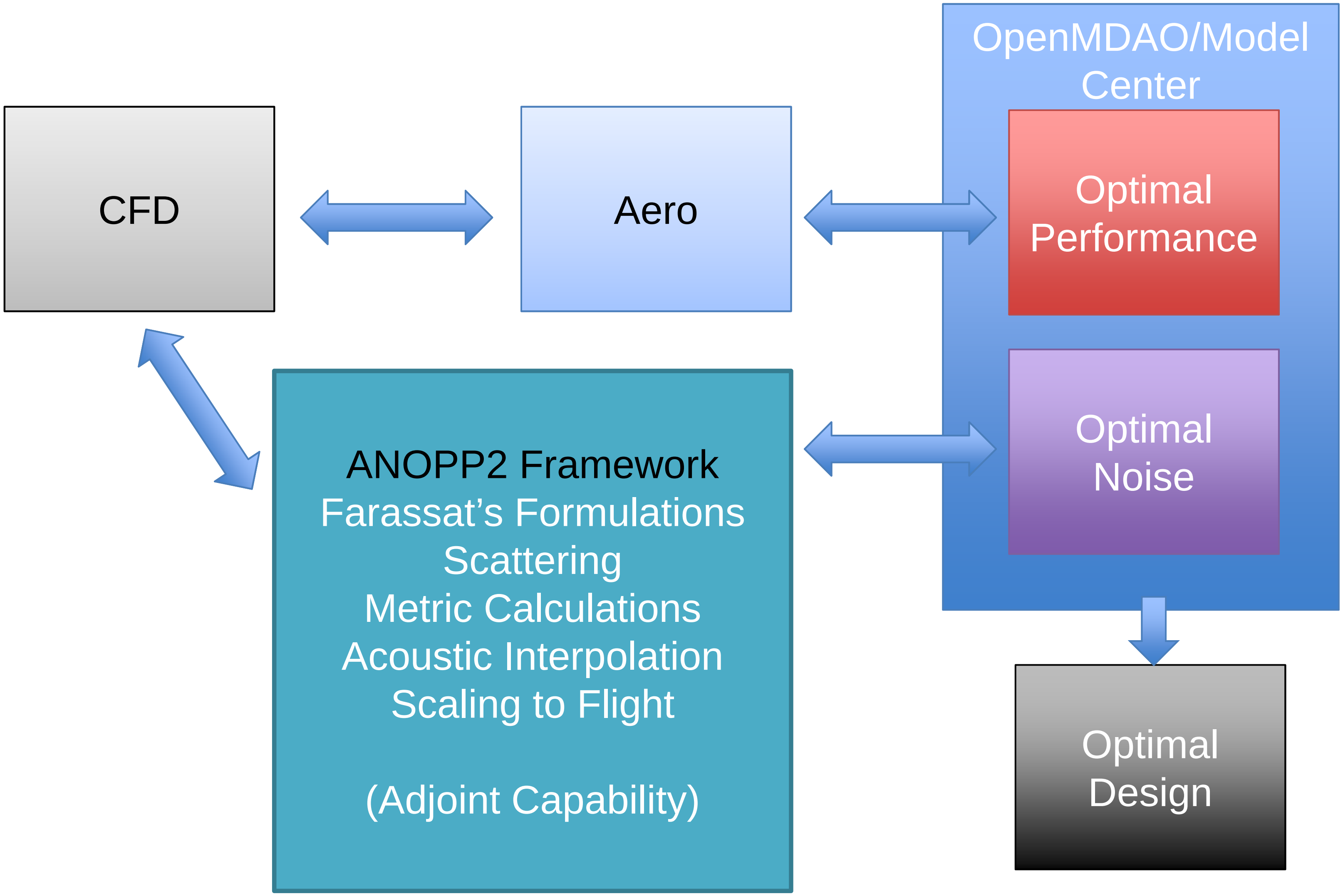
Aeroacoustic Tools and Methods – Use Cases

System Noise

CFD/CAA Based Design

Time-Dependent Configurations including Flow and Acoustics

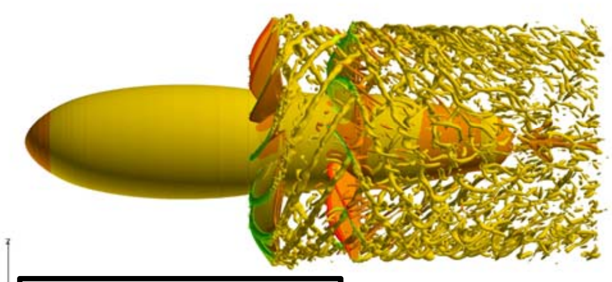
CFD/CAA Based Design



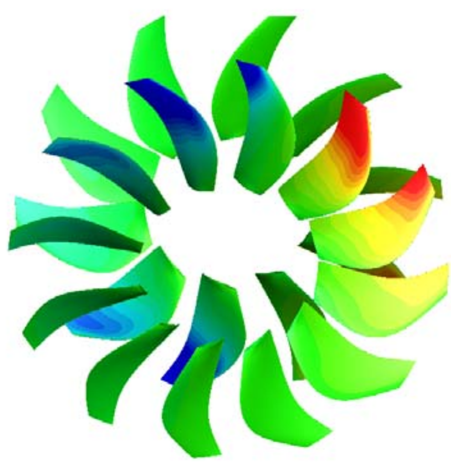
Open Rotor Noise Prediction

- **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**

Overflow Solution



ANOPP2-F1A Metadata



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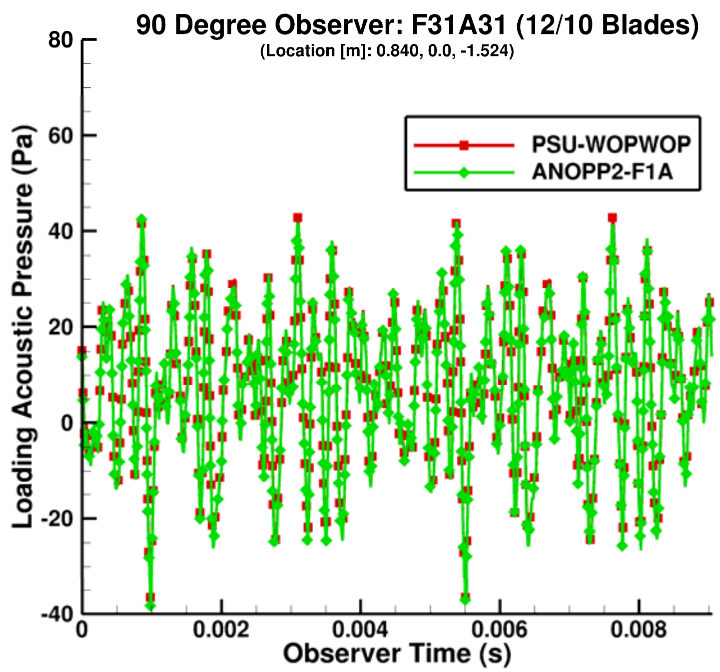


Dr. Doug Nark
Dr. Doug Boyd
Dr. Nik Zawodny

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

Dr. Doug Boyd

Step 1: CFD / CSD Coupling

CAMRAD-II

Inputs for CSD

Blade motions

Modified Airloads

Inputs for CFD

OVERFLOW2

Step 2: Post Processing and ANOPP2 Usage

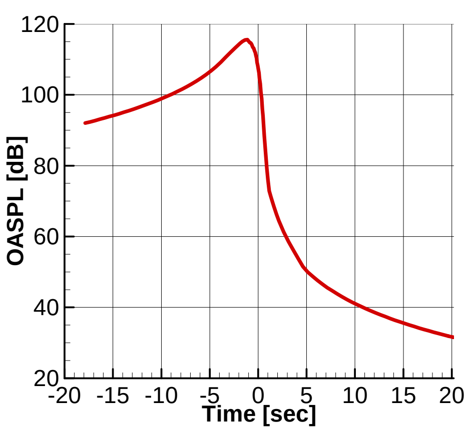
Blade Motions and Surface Pressures

Inputs for ANOPP2

<u>ANOPP2 User Code:</u>

- 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.

Flyover Results



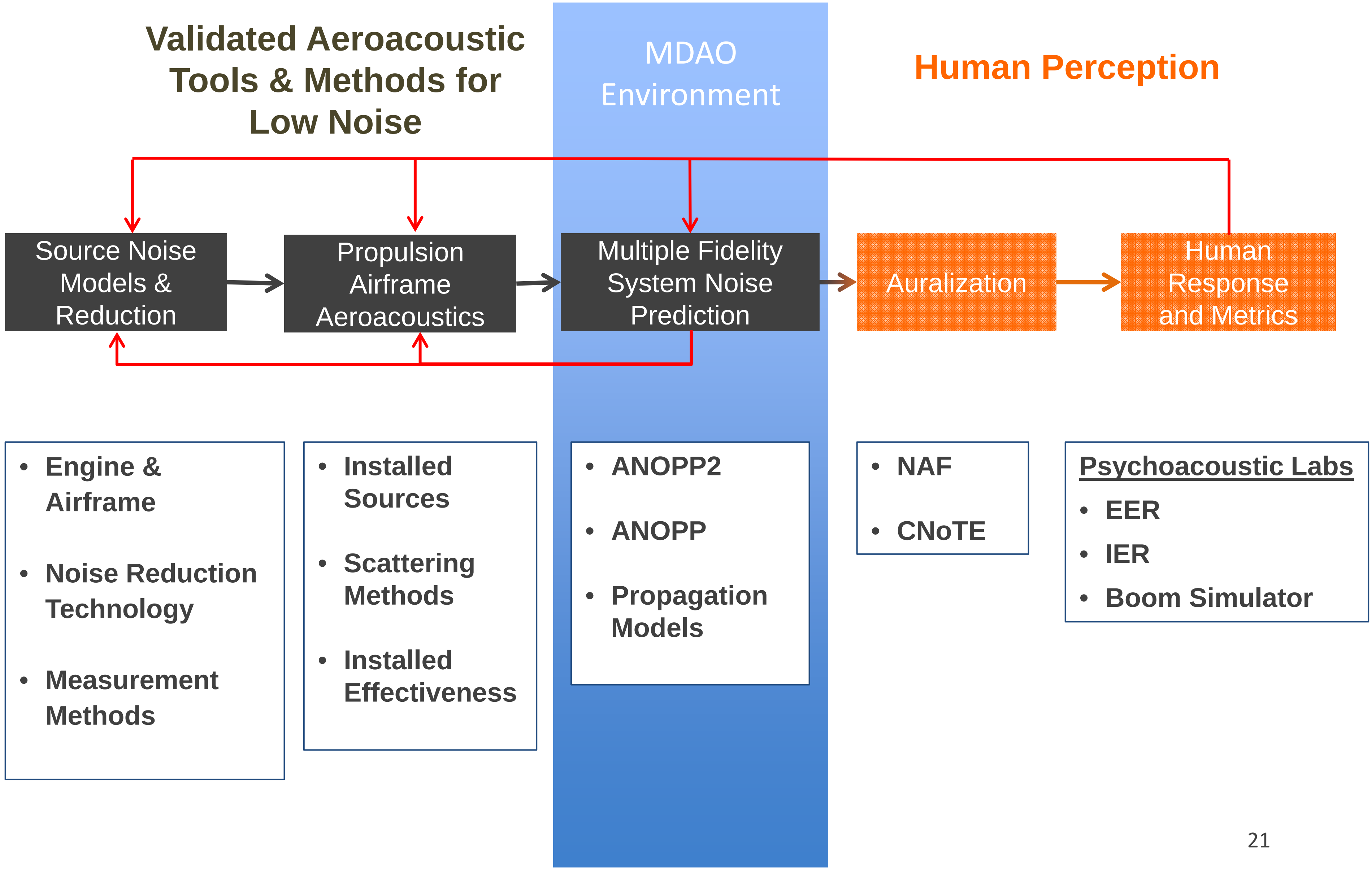
What do these transformative systems have in common?





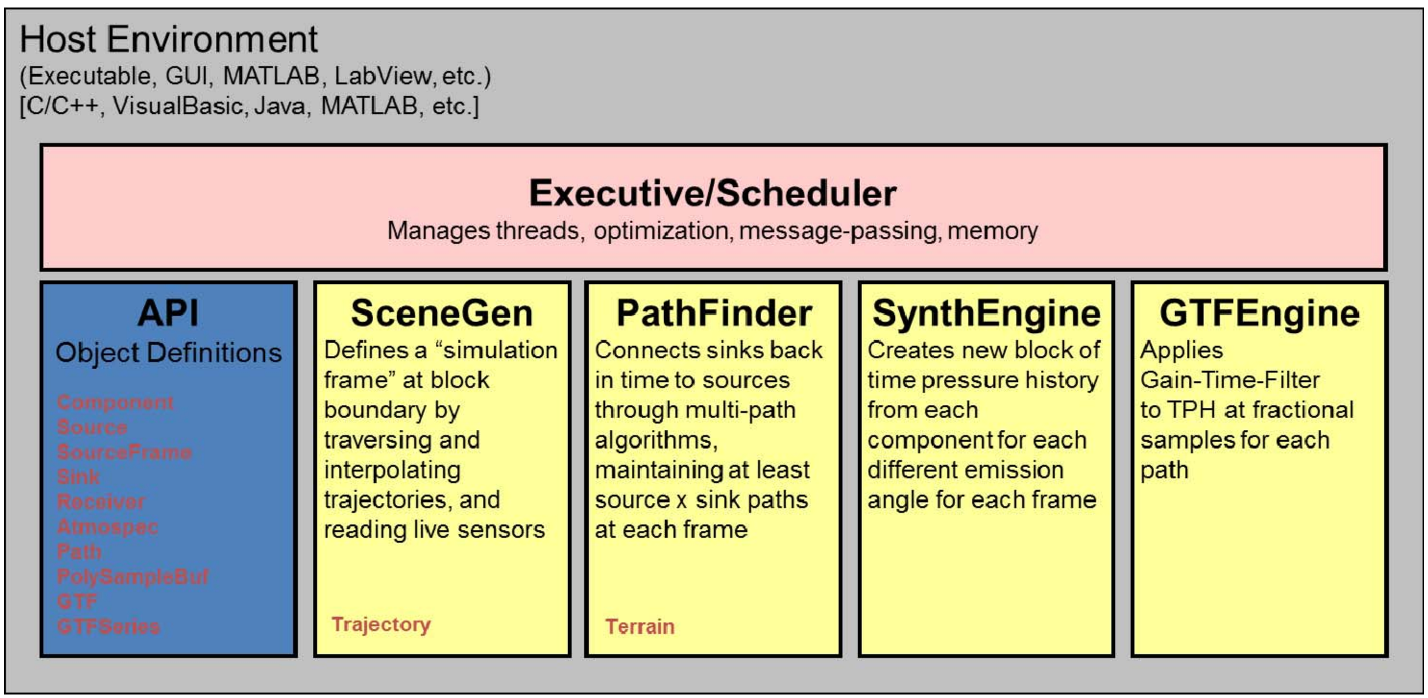

Perception-Influenced Design

“A synthesis of validated aeroacoustic tools and methods plus human perception”



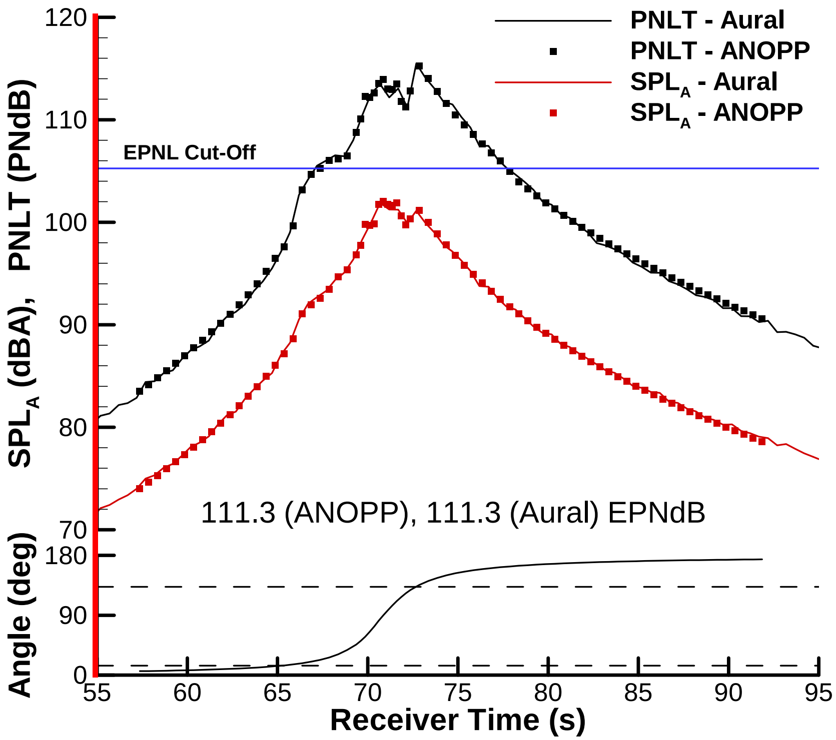
NASA Auralization Framework (NAF)

- **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



Open Rotor Propulsor – Effect of Blade Set

Historical Blade Set (RDG 361)



A-weighted SPL & PNLT
(flush receiver)

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)

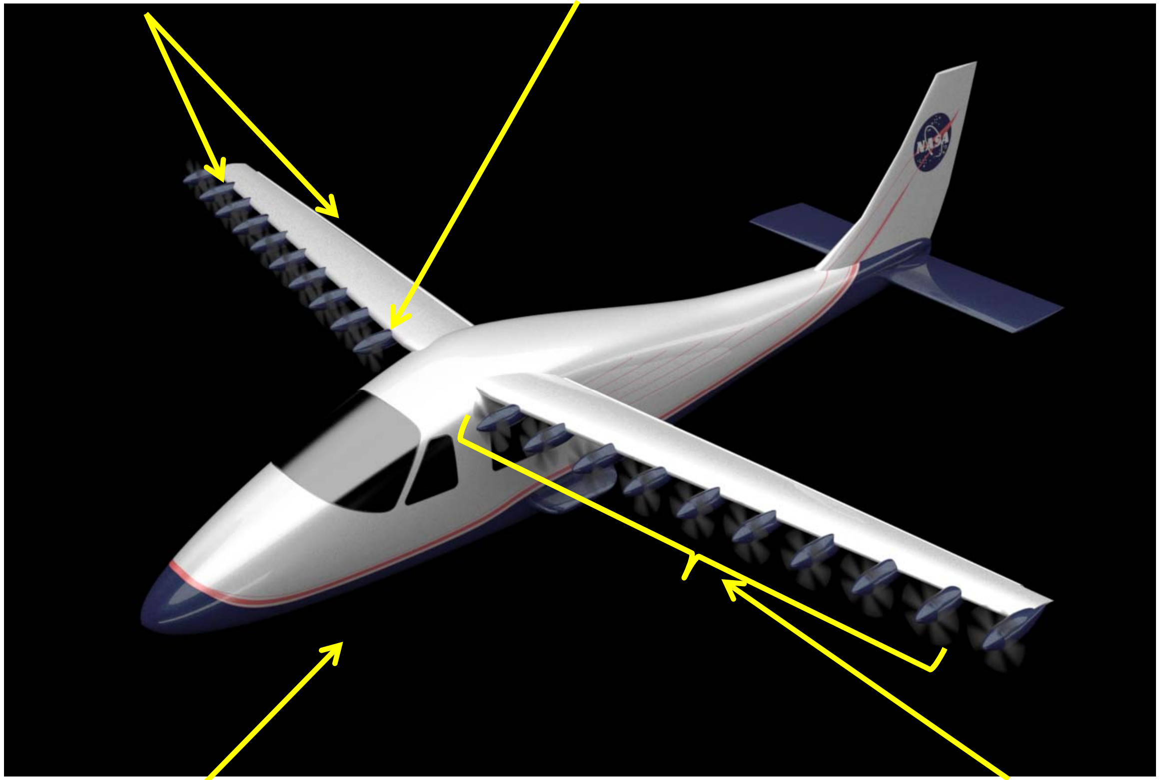
Solo
(elevated receiver)

Interleaved
with RDG 361
(elevated receiver)

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

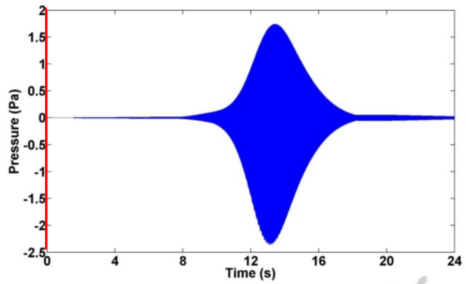


Landing gear design & placement

Propulsion/LEP System
- Propeller noise
- Electric motor noise
- Low annoyance/detection configurations

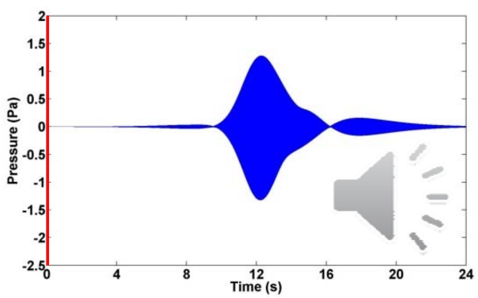
Effect of Spread Spectrum on Leading Edge Propeller Noise

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

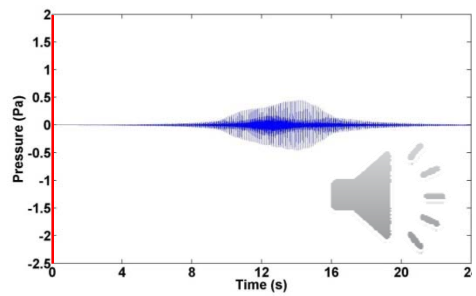


Notes
- All average source power levels taken over 1km x 1km area
- Sound sampled at ground location in middle of area, with aircraft flying 150m directly overhead

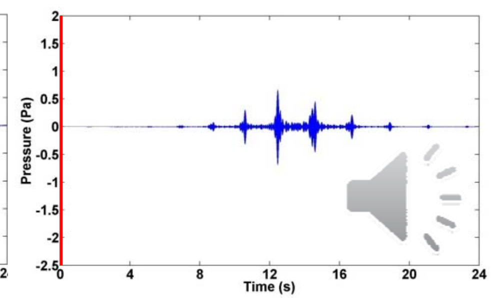
Distributed Electric Propulsion – LEAPTech Concept with 18 propellers
Average Source Power: 87.5 dB (props only) for all configurations below, yet sound very different



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/T^3 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