ASCENT Project 63

Parametric Noise Modeling For Boundary Layer Ingesting Propulsors

Georgia Tech

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Cost Share Partner: Georgia Tech

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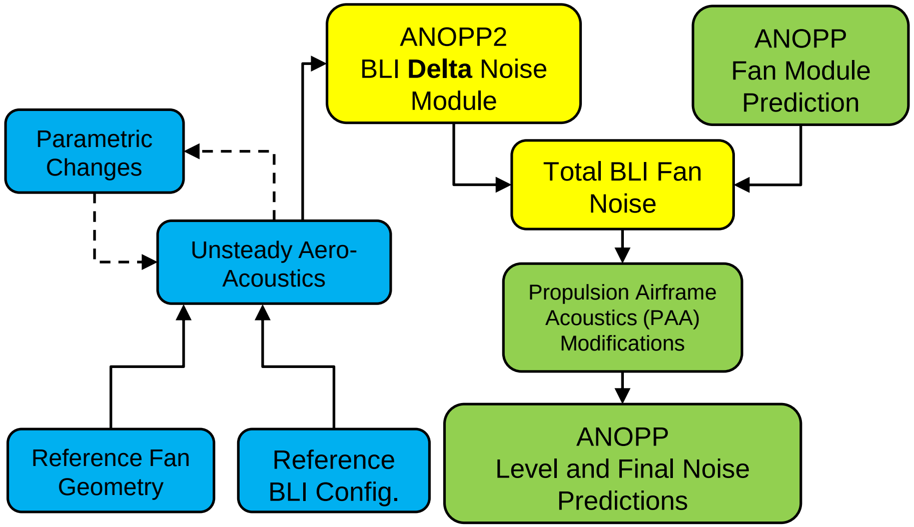
Objective:

To identify, develop, and validate a parametric fan noise module for a generic BLI propulsor based on the specifics of a configuration and design

Project Benefits:

- New capability for design engineers to determine the noise impact of new concepts
- Perform trades of fuel burn benefit versus noise at the conceptual level
- Reduce overall community noise by improving the accuracy of noise predictions for future advanced concepts
- Allowing vehicle designers to find the best opportunity for BLI technologies that offer fuel burn and noise benefits simultaneously

Research Approach: Numerical Experiments



Major Accomplishments:

- Validation of fan noise module with NASA ANOPP and experimental data.
- Creation of integrated BLI geometry and designs
- Parametric sensitivities conducted to determine cases for high fidelity CAA cases
- Successfully conducted high fidelity CAA cases for several angle of attacks and fan speeds
- Creation of python based "Delta" module to include influence of BLI distortion on distortion prediction

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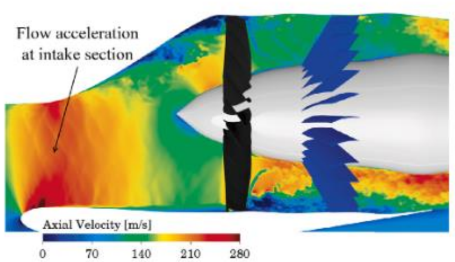
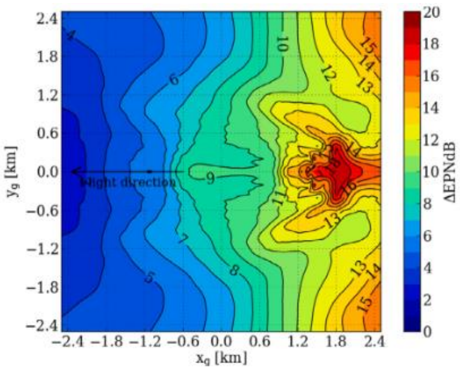
Project Motivation and Objectives

- Boundary Layer Ingestion (BLI) Concepts to **Reduce Fuel Burn**:
  - Ingest part of the boundary layer into the propulsor to improve propulsive efficiency
  - Creates distortion at the fan face
  - Problematic for operability and performance
  - **But what about the noise impact?**

- Distortion has an impact on noise:
  - Experiments have shown impact of inlet turbulence ingestion and aerodynamic distortion on noise
  - Broadband and tonal impact
  - Variability in directivity



- Some BLI noise modeling attempts have been made:
  - NASA Study Based on **Analogous Empirical Data**:
    - Clark, I. A., et al, "Aircraft System Noise Assessment of the NASA D8 Subsonic Transport Concept"
    - Found **16 dB impact** for ND8 configuration
  - TU Delft study looked at the NOVA BLI Configuration using high fidelity CAA
    - Qingqing Ye, Francesco Avallone, Daniele Ragni, Damiano Casalino, "Numerical analysis of fan noise for the NOVA boundary-layer ingestion configuration"
    - **+10 EPNdB** impact of BLI



<u>Project Purpose:</u> To identify, develop, and validate a parametric fan noise module for a generic BLI propulsor based on the specifics of a configuration and design

Project Technical Approach

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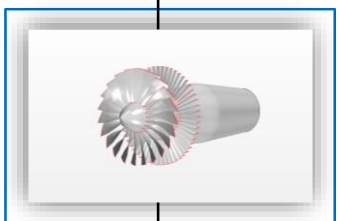
SDT Fan Inputs → NPSS Performance Model → ANOPP Inputs → ANOPP Noise Model Calibration → CAA and ANOPP Calibration

SDT Fan Inputs → Geometry Preparation in SolidWorks → SDT Mesh → PowerFlow CFD/CAA → Noise Prediction → CAA and ANOPP Calibration



Reference configuration:

- STARC-ABL aircraft
- SDT Fan Geometry (Similar to TUD study)

Project has two key paths:

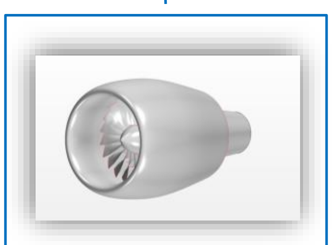
- SDT Fan Noise Performance Modeling and Calibration (top)
- BLI Design and Parametric Noise Impact Generation (bottom)

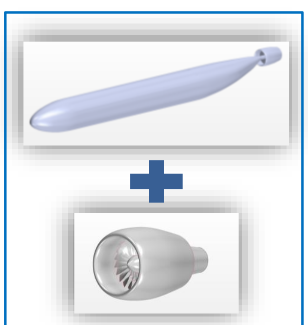
Geometry Preparation in SolidWorks → Scale SDT-A to Clean Fan → Integration STARC-ABL & SDT-A → Design Changes and RANS studies → Baseline BLI Geometry → CFD/CAA

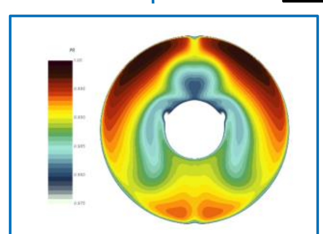
CAA and ANOPP Calibration → CFD/CAA → Parametric Changes → Design Changes and RANS studies

Parametric Changes → ANOPP2 BLI **Delta** Noise Module

CFD/CAA → ANOPP2 BLI **Delta** Noise Module



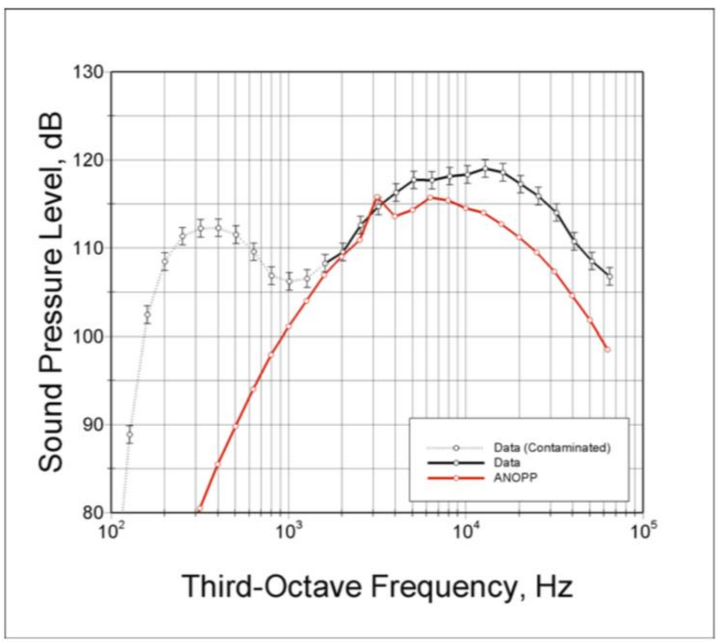




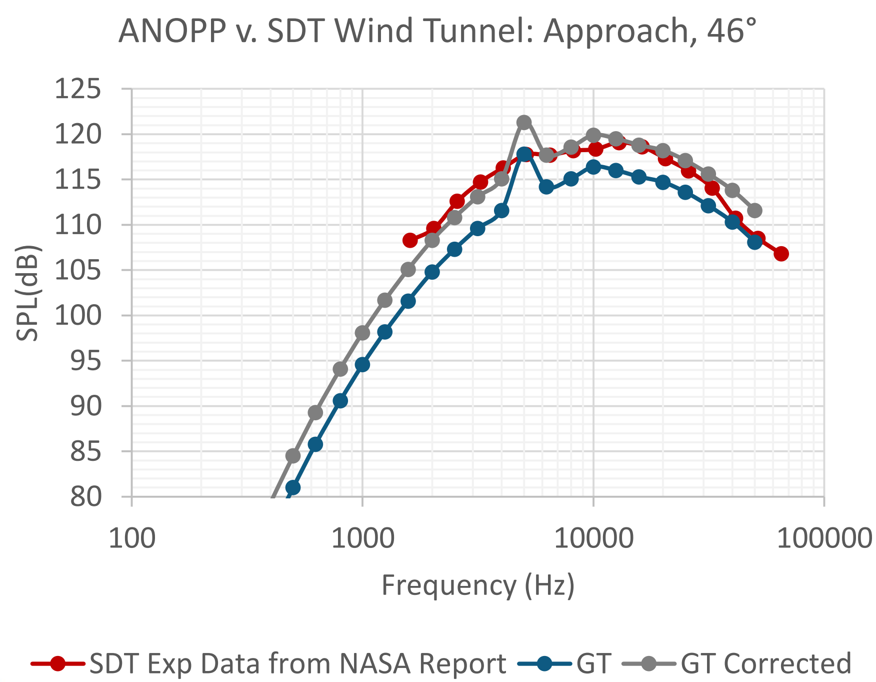
Calibration of Baseline ANOPP Model

Result Comparisons:

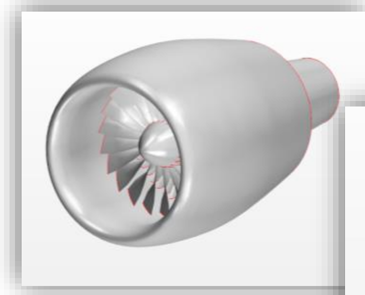
- Digitized experimental data plots from NASA report that compares SDT data to ANOPP predictions (AIAA 2008-299)
- Preliminary results show a similar difference between NASA ANOPP prediction / GT ANOPP predictions and experimental data
- Shift of +3.5dB (GT Corrected / Grey Curve) helps to better align data

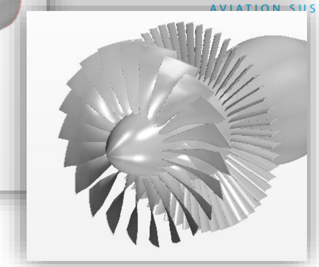


Comparison of predicted (ANOPP) and measured SPL for SDT at 7,809 RPM. Results for a position in the inlet quadrant are shown (emission angle of 46° at Mach 0.1).



SDT Fan CAA Approach





High Fidelity Simulation

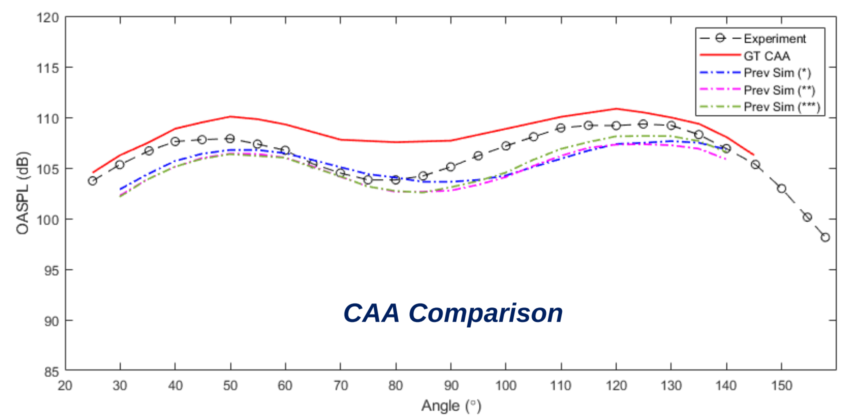
Purpose: Validating simulation approach

- Geometry: Baseline Source Diagnostic Test (SDT)
  - 22 Blades, 54 vane baseline radial OGV
- Condition: Approach $(M_\infty = 0.10,\ AoA_\infty = 0\,°, RPM = 7809)$
- High fidelity simulation via Hybrid CAA approach
  - Unsteady Aerodynamics via a LBM commercial solver
  - FarField acoustics via FWH solver with permeable formulation
- Simulation:
  - Mesh: 407 million voxels, Max Freq for CAA: ~ 7.1 kHz

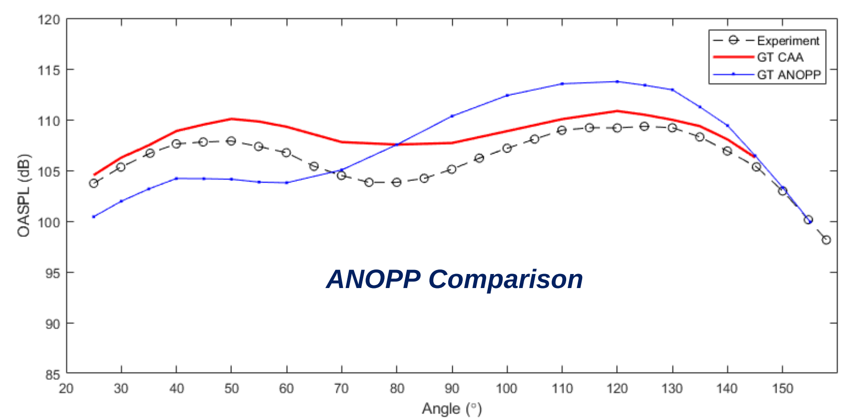
Directivity Results:

- Acoustics obtain at 21 sideline receivers (89.3 inch distance)
  - Frequencies lower than 1.6 kHZ not considered (Experimental contamination)
- CAA results shown an average discrepancy of 2.1 dB respect to experiments
  - Note previous simulations exhibit ~ 1.7 - 2.0 dB discrepancy respect to experiments
  - Note discrepancy of ANOPP ~3.6 dB respect to experiments

OASPL Directivity



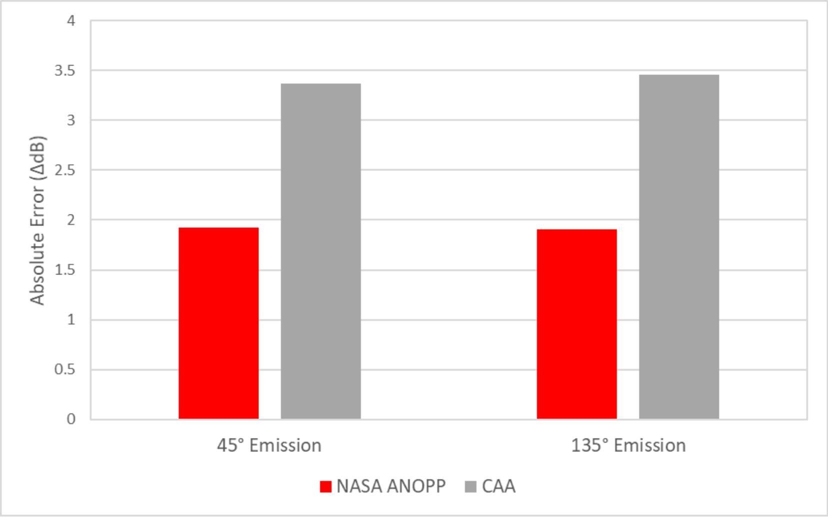
(*, **, ***) Casalino *et al*, AIAA Journal, Vol 56, No 2.

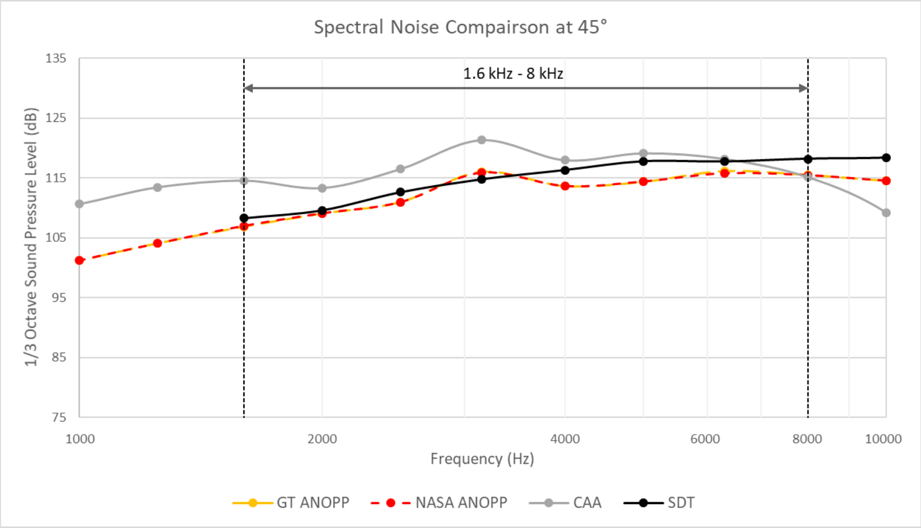


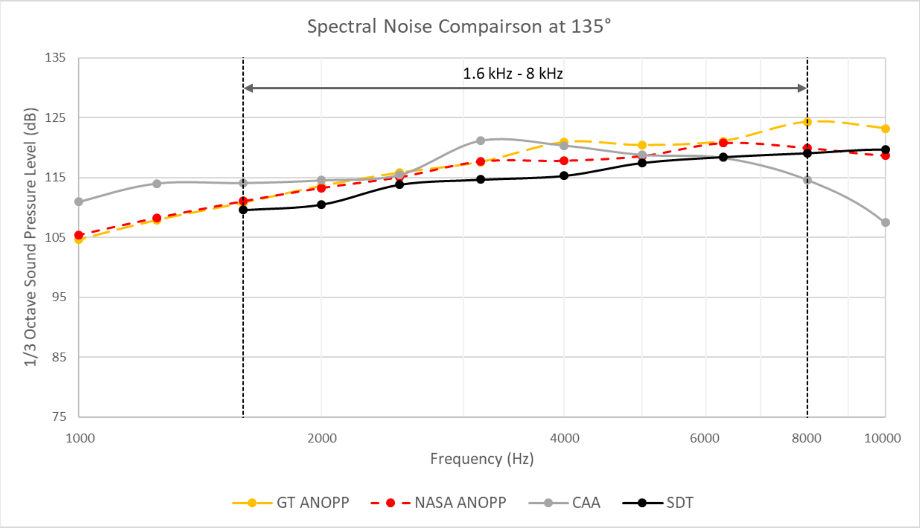
Comparison of CAA/ANOPP with Baseline SDT

Spectral Results:

- Spectral acoustics obtained at 45° and 135°,
  - Scaled to match 1-ft lossless basis used in NASA results
- Applicable frequency range between 1.6 – 8 kHz
  - Due to provided SDT data and permeable simulation limitations
- Results show an average discrepancy of ~3.5 dB
  - Comparable to ~2 dB discrepancy shown by NASA ANOPP model
- Peak discrepancy at 3150 Hz due to blade passing frequency effects at 2860 Hz

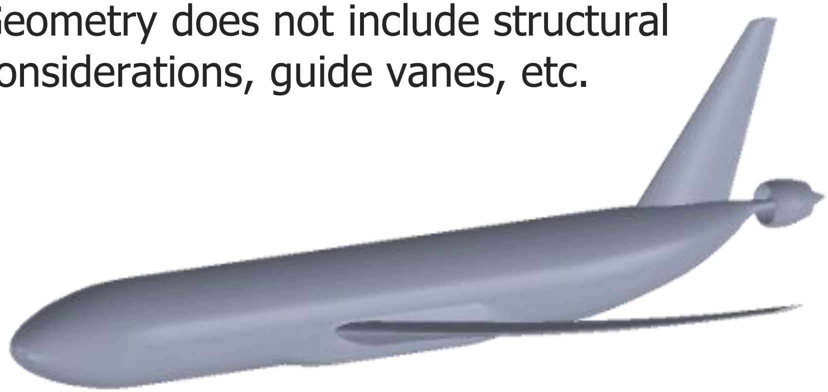


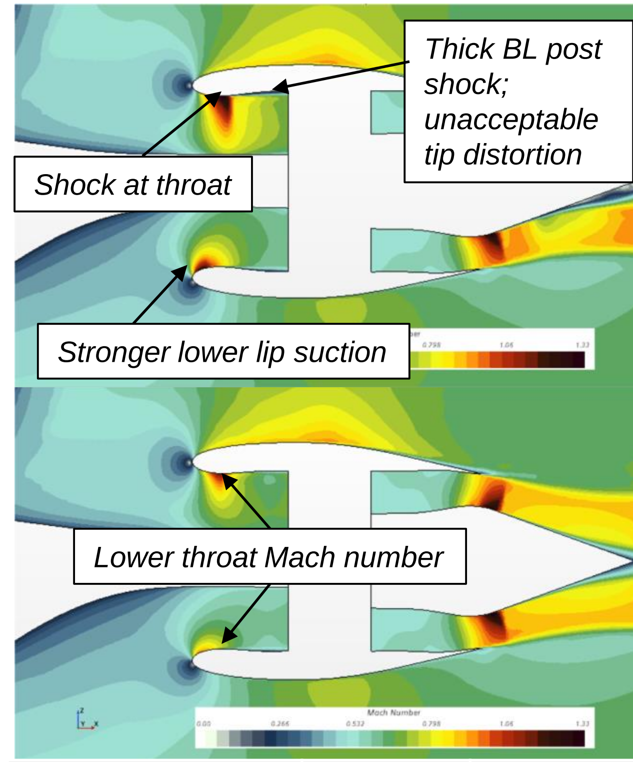




Integrated Tail-cone Thruster Design and Geometry

- Similar sized vehicle to the Boeing 737-8
- Included wing and vertical tail in geometry
  - Known from literature to affect ingested distortion
- Scaled fan based on SDT geometry:
  - Fixed tip speed and specific corrected flow (Wc / A)
  - Scaled to power of the STARC-ABL design (Welstead and Felder)
- Highlight and throat areas increased based on results from steady state RANS CFD
  - Blockage effects from ingested boundary layer caused shocks in the inlet for original design
- Aft section adapted from SDT geometry and manually tailored to provide reasonable exit flows
- Geometry does not include structural considerations, guide vanes, etc.



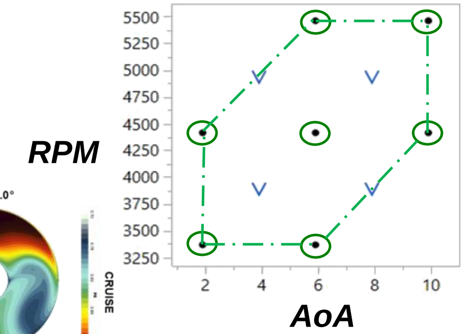


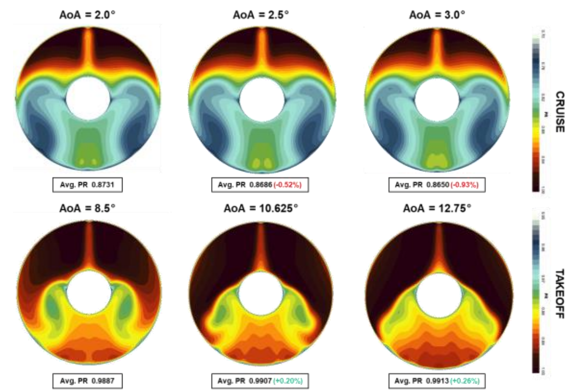
Approximate Values	Original Nacelle	Modified Nacelle
Peak upper throat Mach number	1.27	1.14
Peak lower throat Mach number	1.18	0.90

High Fidelity Simulation Progress

Design Space Analysis

- Mach number & altitude are negligibly different for certification noise points
- Fan radius perturbations explored, and no clear major change in distortion levels was observed in valid range of geometry scaling
- Fan RPM and angle of attack (AoA) had largest influence on observed distortion levels
- Sampling plan (green symbols) focus on feasible operational space of fan
- Variables and ranges reflect real world operational envelope for noise certification points

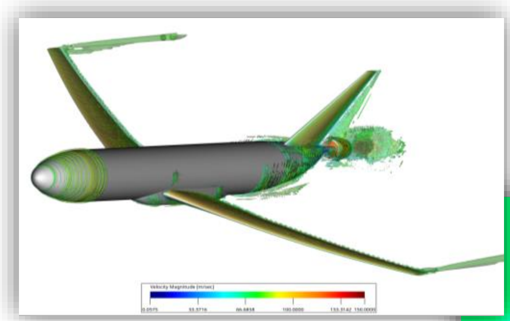




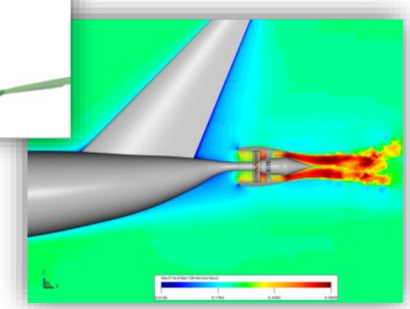
Simulation Effort: Hybrid CAA

- Unsteady Aero simulation by a LBM commercial solver
  - Mesh: 1054 millions voxels
- Far-field aeroacoustics by a FW-H solver with permeable formulation
  - Max Res Freq. ~ 5.0 kHz
  - Flow data for CAA collected over 10 rotor revolutions

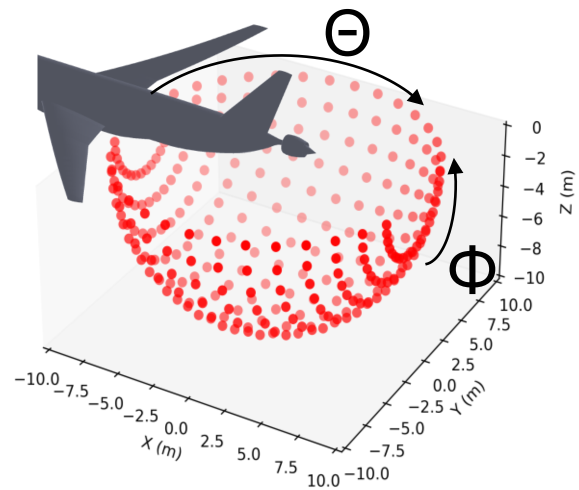
Vortical Structures



Mach Flowfield

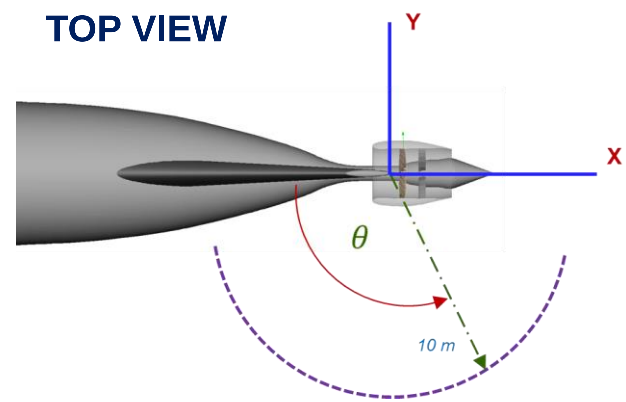


Integrated Results



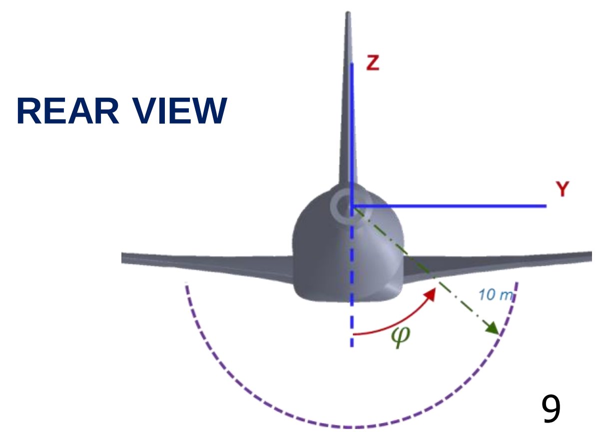
CAA Spatial Recording

- Emitted noise captured by hemispherical set of microphones
- Chosen radius, 10 m, limits effects of airframe noise
- Microphone placement centered about fan location
- Direct upstream and downstream microphones removed due to model inaccuracies in jet flow regions



ANOPP Spatial Model

- ANOPP SDT fan model recorded using same hemispherical setup
- Model integrated into ANOPP2 for rapid low-fidelity result generation, easily run series of cases at once
- Data collected over 3 RPM variations
- Identical spatial layout model allows for change in PNL level calculation between methods at each node



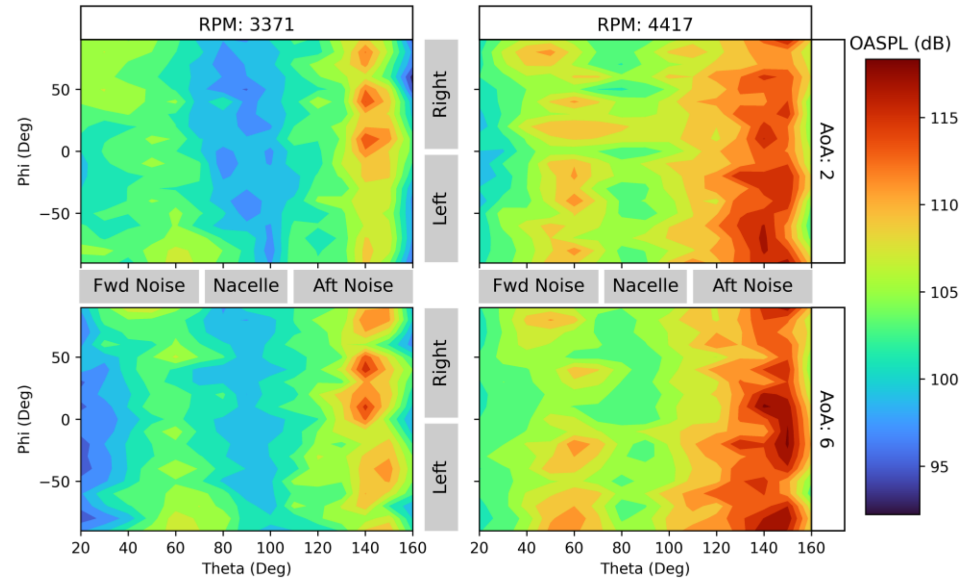
*All Results and Conclusions are Preliminary

Spatial Results

Contours at radius = 10 meters

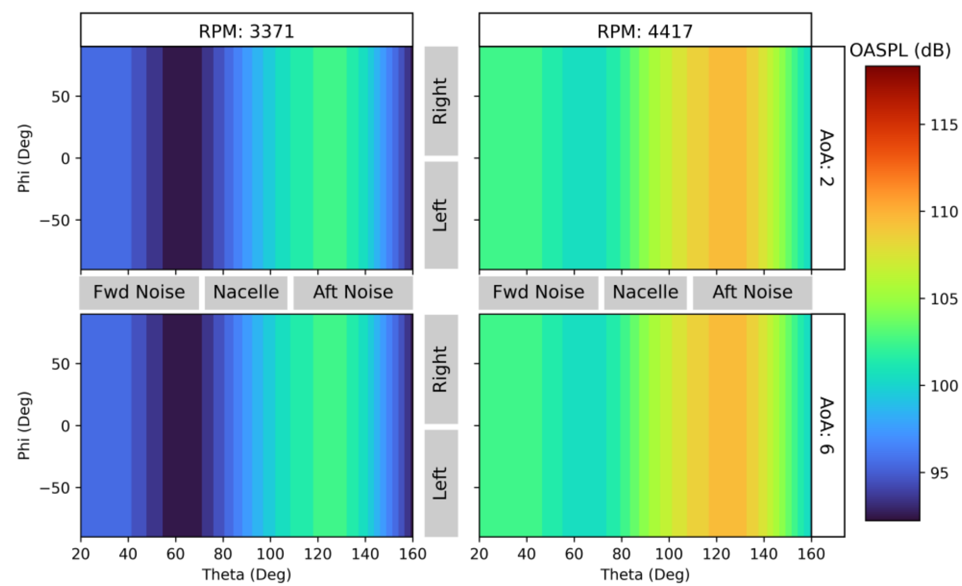
CAA Results

- Results successfully collected for 5 of the 7 cases – Highest angle of attack cases required 4-5x simulation run times (out of budget)
- 5th case data set at highest RPM still being assessed – Shows somewhat dissimilar trends to data for the 4 on this slide
- Results show regions of increased noise aft of the fan
- Clear increasing OASPL trend with rotor speed
- However, not clear OASPL trend with AoA
- Discernable regions of inlet and aft fan noises shown at higher RPM



ANOPP Results

- Results show clear regions of increased noise in the forward and aft sections of the fan
- Clear increasing OASPL trend with rotor speed
- No change in values due to AoA
  - Angle of attack does not change results as ANOPP does not calculate flow effects, therefore changes in flow orientation have no effect



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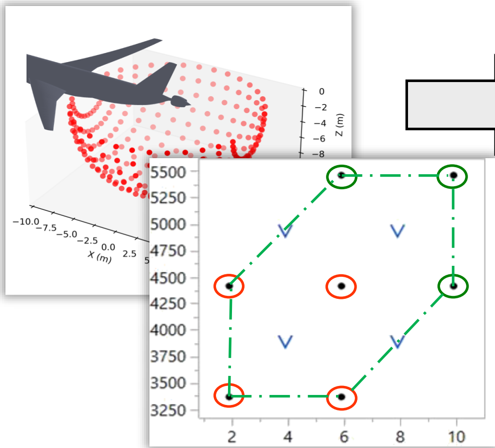
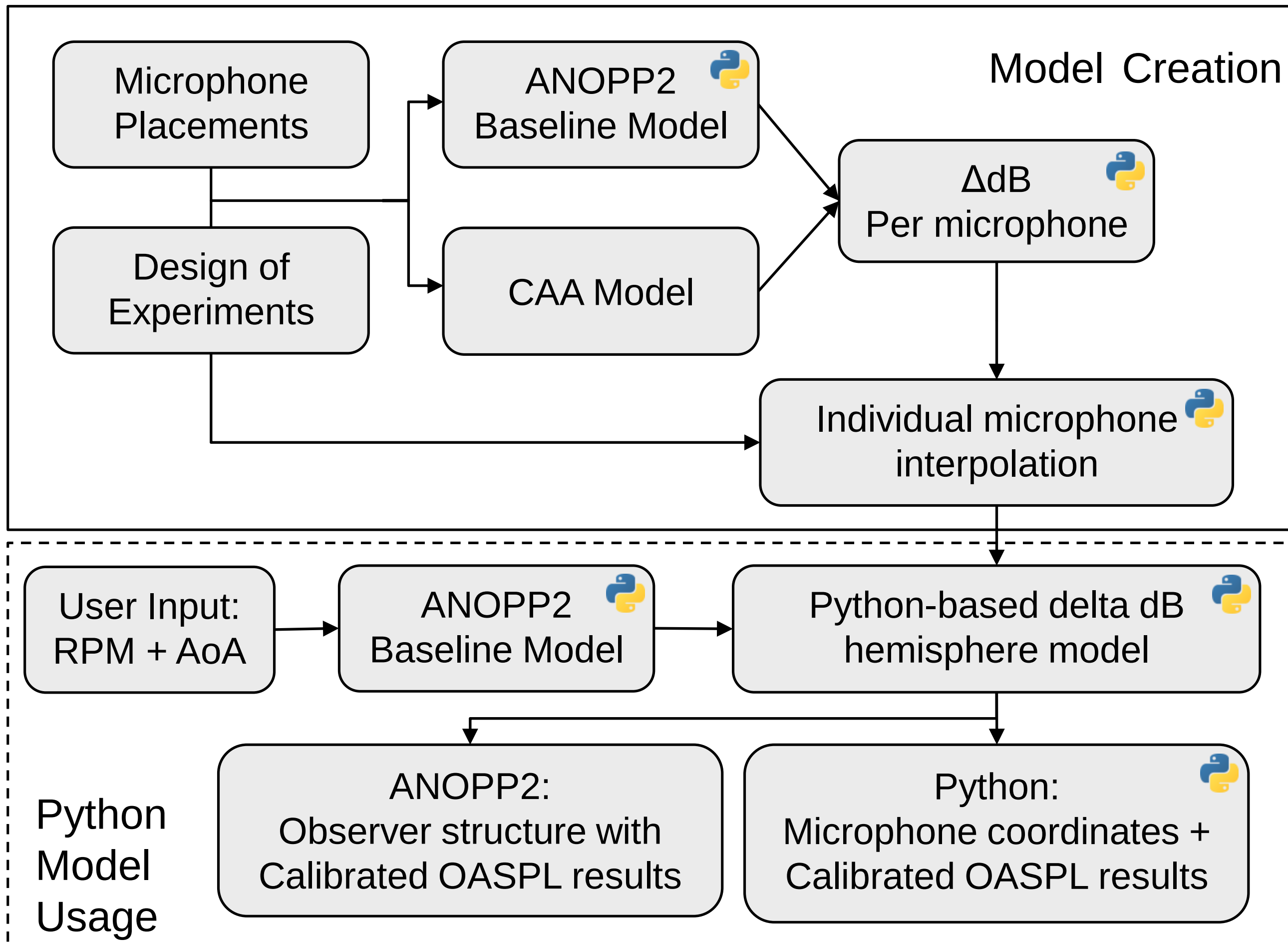
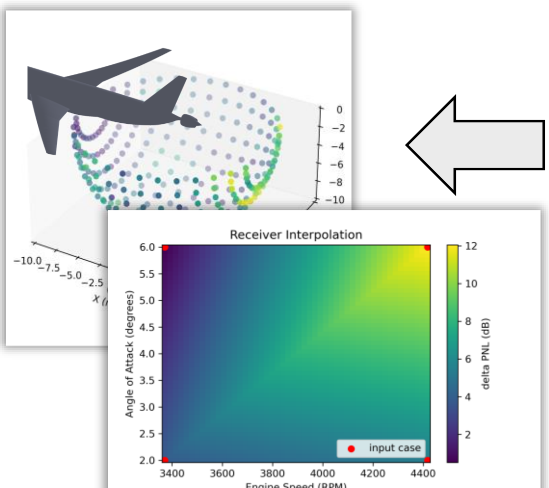
Model Creation Overview

Python ANOPP2 Module

- Spatial data from ANOPP + CAA provides dB deltas for series of RPM/AoA cases
- Data series used to fit interpolation model and is stored in python dictionary
- User input desired RPM and AoA into python script which uses ANOPP2 to generate baseline results
- Baseline results are corrected using the interpolation model



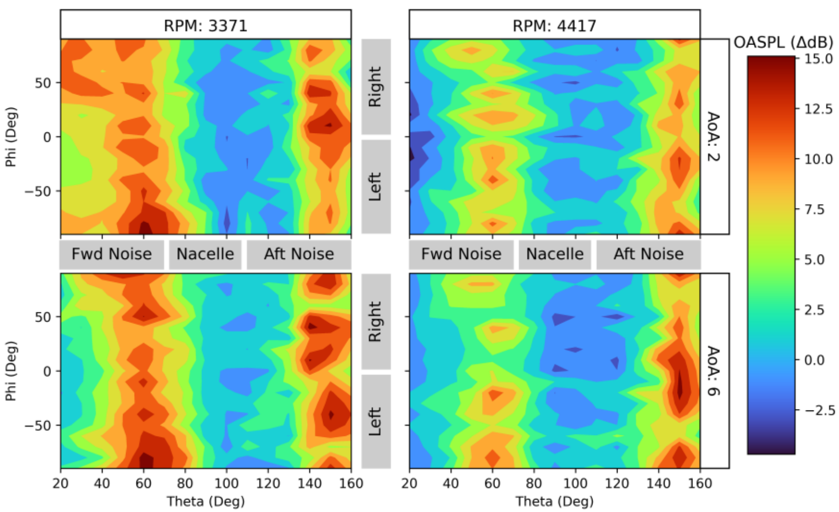


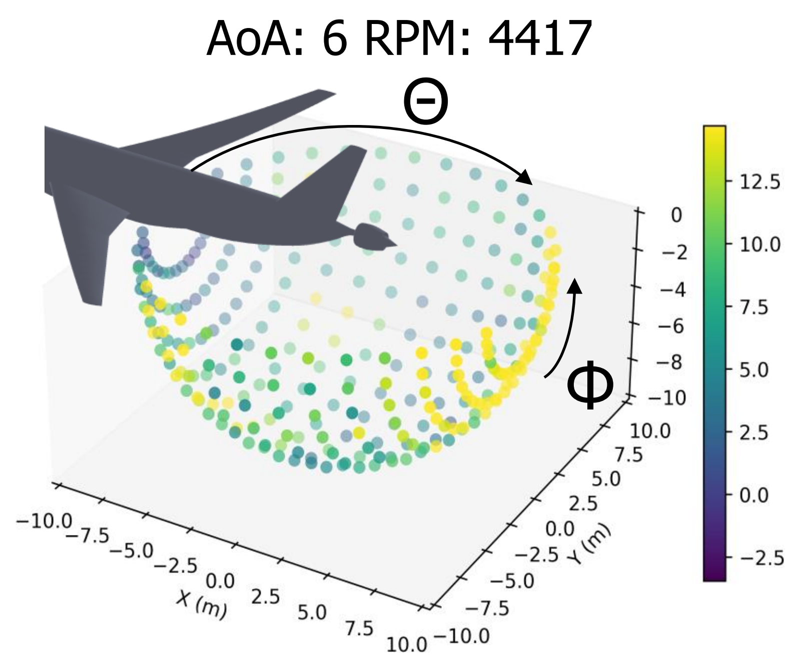


Conclusions

Results Comparison

- Observed CAA noise increase from estimated ANOPP PNL for BLI tail-cone thruster
- Impact from RPM increase stronger than that due to AoA increase
- Higher RPMs and AoAs require larger deltas
- Strongest corrections tend to happen near exhaust – Similar trend to prior TU Delft Nova BLI study
- Notable corrections for inlet fan noise around theta = 60 at lower RPM





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Next Steps and Questions

Final Steps:

- Plan to use module for sample whole aircraft noise assessment
- Documentation of module developed
- Publish findings and approach

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Contours at radius = 10 meters

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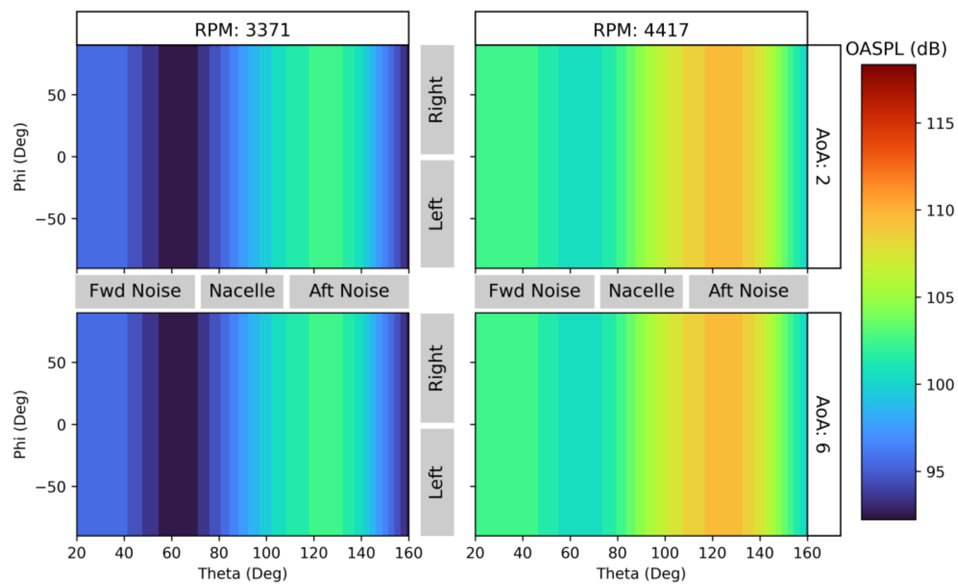

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