PAA and Aircraft System Noise Team
Overview of Research for the AATT Project

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Acoustics Technical Working Group
NASA Glenn Research Center
Outline

- Team Technical Strategy Overview and Acknowledgments
- ANOPP Status
- System Noise Assessment Process
- Prediction Method Update
  - Guo Airframe Methods
  - PAA Scattering Prediction (PAASSyN)
- Past year’s studies
  - ND8 and TW160
  - TW301
- This year’s studies
  - NASA 737MAX
  - TTBW
- PAA and Aircraft System Noise Flight Test Overview
- Summary
Team Technical Strategy Overview and Acknowledgments

SA&I Team of AATT
PSAB of GRC
ASAB of LaRC

CAB of LaRC
Industry Partners

PSAB of GRC
ASAB of LaRC

QFF

Current/active collaborations and connections are indicated but not intended to be exclusive

PAA and Aircraft System Noise Team

Aircraft Noise Assessments

ANOPP-Research
ANOPP-Release

Noise Reduction Technology Roadmaps

PAA and Aircraft System Level Prediction Method Development

Noise Reduction Technology Development

Experimental Research

New Fan Method – GRC Fan Noise Team + Industry Partners
New Liner Method – LaRC Liner Team

Boeing – Flight Research
Boeing – PAA LSAF Series
QFF – Krueger and Shielding
N2A HWB
L31v7 (Next Planned Release)
- Windows execution time improvement

L32v1 (Future Planned Release)
- Initial release of new generation of Guo airframe noise prediction methods (for gear, slat leading edge, trailing edge high lift)

ANOPP-Research (In-House)
- Additional modeling (in ANOPP or stand alone) and data used for:
  - Wide range of noise reduction technologies
  - Propulsion airframe aeroacoustic (PAA) effects
  - PAA scattering effects
    - Mid-fidelity prediction method PAASSyN
  - Calibrations to noise prediction methods
  - Acoustic liner technology prediction
  - Full range of new generation of airframe noise prediction methods including Krueger flap and additional capabilities/features
Acoustic Element Fidelity

- Source models, PAA effects, and technology implementation retain as much dependence on frequency, polar, and azimuthal angle as possible.
- Technologies may be implemented by:
  - Changing ANOPP inputs
  - Applying noise suppression hemispheres to calculated source noise
- Noise suppression hemispheres for PAA effects and technologies may be calculated from
  - Experimental data
  - Numerical simulation
Multiple noise components contribute to total noise level.
Including Technologies and PAA Effects

Can be done with PAA effects, or with multiple technologies for multiple sources
Including Technologies and PAA Effects

Difference in total integrated EPNL with and without technology is **system-level impact**.
Overview of the 3rd Generation Guo Methods:

- Similar first principles based modeling approach as in Boeing (BAF)
- More in depth formulation enables unconventional aircraft prediction
- Scales well across wide range
- Frequency dependent power law
- Airframe geometry dependent reflection model
- Absolute amplitude without need for calibration
- Expanded, higher fidelity validation database
PAASSyN Prediction Method Update

PAASSyN = Propulsion Airframe Aeroacoustics Scattering for System Noise

- Two versions under development:
  - PAASSyN-K based on classical diffraction theory and used for shielding only – near term
  - PAASSyN based on combination of ray tracing and diffraction theory and used for general shielding and reflection – future

- Mid-fidelity method for quick turn around engineering and system noise applications

- Capabilities added recently to PAASSyN-K
  - Multiple aspects to handle increasingly complex geometries
  - Uniform mean flow effect

- Actively working with a wide range of datasets
PAASSyN Development Uses a Range of Experiments

Series of Canonical Geometries: plate, sphere and cylinder

QFF NACA 0012 Spark Shielding (part of NATO AVT-233)

Boeing/NASA Series of PAA LSAF Experiments
PAASSyN-K Prediction of N2A HWB Shielding

Close up of vehicle

Incident field on vehicle

Source at Nozzle Exit Plane

Increasing shielding level
PAASSyN-K Prediction of QFF NACA 0012 Spark Shielding

- SPL, dB
  - PAASSyN
  - Data: Shielded
  - Data: Unshielded

- $f$ (Hz)

$M = 0.00$

Sources

Simultaneous Signal Reception

Observers

$10^3$  $10^4$  $10^5$  $10^6$  $10^3$  $10^4$  $10^5$  $10^6$
ND8 / TW160 Technology Roadmap

From AIAA-2019-2427

Continuous Moldline Link (CML)
Pod Gear
Slat Cove Filler and Sealed Slat Gap
Bifurcation Liner

Partial Nose Gear Fairing

Over-the-rotor (OTR) liner
Scarfed Nozzle
Lip Liner

Scarfed Nozzle Fan Propagation -3.3
OTR Fan -1.5
Bifi Liner Fan -0.8

Most Effective ND8 Technologies:

<table>
<thead>
<tr>
<th>Technology</th>
<th>Source</th>
<th>ΔEPNdB</th>
</tr>
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<tbody>
<tr>
<td>Scarf Nozzle</td>
<td>Fan Propagation</td>
<td>-3.3</td>
</tr>
<tr>
<td>OTR</td>
<td>Fan</td>
<td>-1.5</td>
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<tr>
<td>Bifi Liner</td>
<td>Fan</td>
<td>-0.8</td>
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Most Effective TW160 Technologies:

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<tr>
<th>Technology</th>
<th>Source</th>
<th>ΔEPNdB</th>
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<tr>
<td>OTR</td>
<td>Fan</td>
<td>-1.5</td>
</tr>
<tr>
<td>Scarf Inlet</td>
<td>Fan Directivity</td>
<td>-1.3</td>
</tr>
<tr>
<td>Krueger DUF</td>
<td>Leading Edge</td>
<td>-1.0</td>
</tr>
</tbody>
</table>
ND8 / TW160 Roadmap Results

- These configurations do not meet NASA’s noise goals, proving need for:
  - Improved aircraft configurations to take advantage of favorable PAA effects.
  - Further maturation and development of new noise reduction technologies.

**Table:**

<table>
<thead>
<tr>
<th></th>
<th>Approach</th>
<th>Sideline</th>
<th>Cutback</th>
<th>Total</th>
</tr>
</thead>
<tbody>
<tr>
<td>Pre-Roadmap BLI Penalty (EPNdB)</td>
<td>3.0</td>
<td>5.6</td>
<td>5.5</td>
<td>14.1</td>
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<tr>
<td>Far Term BLI Penalty (EPNdB)</td>
<td>3.0</td>
<td>5.0</td>
<td>4.9</td>
<td>12.9</td>
</tr>
</tbody>
</table>

From AIAA-2019-2427
Concluded a multi-year study on a set of closely matched advanced concepts – the noise reduction value of configuration change.

- PAA largest share of the **16.1 EPNdB** difference between TW and HWB at Mid Term level.
- Targeted technologies improve shielding effectiveness of HWB and MFN. Increases difference to **20.9 EPNdB** cumulative at Far Term Technology level.
Boeing 737 MAX 8 set to become new reference aircraft in AATT for fuel burn, emissions, and noise.

Modeling of LEAP-1B engine undertaken at Glenn (Propulsion Systems Analysis Branch).

Modeling of airframe and flight path done at Langley (Aeronautics Systems Analysis Branch).

ANOPP-Research currently being used to predict noise characteristics, including PAA effects.

www.boeing.com
Transonic Truss Braced Wing (TTBW)

- Originally a Boeing single aisle, high aspect ratio wing concept
- AATT Systems Analysis and Integration performing fuel burn and emissions assessment of NASA derivative
  - N+3 engine modeling (Glenn Propulsion Systems Analysis Branch)
  - Airframe modeling and flight path (Langley Aeronautics Systems Analysis Branch)
- ANOPP-Research in use to predict unique aspects of the concept
- Predictions to integrate latest results of on-going research

Flight Test Contract Awarded to Boeing, May 2019
- Dr. Michael Czech, Boeing PI
- Dr. Paul Bent, Boeing PM

- Dedicated NASA task, four days of acoustic flight testing
- Highly instrumented, both ground and aircraft
- Extensive set of additional aircraft/engine information to be provided, necessary for prediction inputs
- Test matrix includes engine power line and high lift variations, also
  - Production and hardwall bypass duct
  - Special operations for PAA effects

- Joint NASA/Boeing analysis and prediction using ANOPP
- Additional data analysis provided on flight test measurement uncertainty
Objective 1
Measure the acoustic signature of the flight test aircraft for a variety of flight conditions and aircraft configurations sufficiently to be used for multiple purposes:
  • validation of NASA’s ANOPP,
  • separation and quantification of airframe noise sources,
  • quantification of engine noise signature as a function of power,
  • hardwall aft duct to simulate higher bypass ratio fan/jet ranking,
  • quantification of flight acoustic measurement repeatability.

Objective 2
Measure, in flight, Propulsion Airframe Aeroacoustics (PAA) effects:
  • reflection (to the ground) of engine noise by the wing and fuselage and,
  • shielding of engine noise by the wing and fuselage.
Microphones above the wing are well shielded from aft fan and jet noise:
- Quantify transition from fully lit to fully shielded zones
- Together with under wing array, quantify the attenuation due to shielding
Propulsion Airframe Aeroacoustic (PAA) and Aircraft System Noise Flight Test on Boeing 787 ecoDemonstrator

Innovative On-Aircraft 200+ Sensors To Measure Reflection and Shielding

Circumferential
Over Wing Array
Linear
Shielding of Aft Fan and Jet by Wing
Partial Shielding

Scattering of Fwd Fan by Fuselage
Under Wing Array
Reflection from Wing

PAASSyN-K prediction of shielding by wing

Noise source at bypass nozzle exit

\( f = 2000 \text{ Hz} \)
Expected Impacts:

- Improved understanding of many aspects of transport aircraft noise
- Quantification of full scale PAA effects in flight
- Best evaluation of ANOPP to date with high quality, high resolution data
- Direct quantification of prediction uncertainty
- Lead to improvements in ANOPP
- Enduring dataset that will be used to improve and evaluate new ANOPP methods
Additional Team Activities

- Trailing edge noise study to prove the best practice when using Fink TE prediction
  - Used both wind tunnel data and QTD2 flight test data
  - Pointed the way to improvements needed in trailing edge noise prediction

- Successfully concluded the DLR, NASA and ONERA International SAA collaboration – Aircraft Noise Simulation Working Group (ANSWr):
  - Understanding of system noise capabilities
  - PAASSyN-K compared well with higher fidelity BEM
  - Airframe noise prediction had the largest differences between groups

- Co-leading a new NATO Applied Vehicle Technology Group 318, benefits to NASA:
  - Insight into higher fidelity PAA methods
  - DLR funded system level PAA wind tunnel experiment
  - Design/Predict/Test fundamental noise reduction concepts
Summary

- AATT is providing robust and ambitious research that is advancing the capabilities and understanding of PAA and aircraft system noise.
- NASA is continuing to develop new capabilities to improve ANOPP.
- Boeing/NASA PAA flight test on the 787 ecoDemonstrator represents a major effort with many expected impacts in the years ahead.
Recent Publications (1)

Recent Publications (2)

Noise Prediction Framework

All predictions made using ANOPP-Research within the ANOPP2 framework.
**TW301 Technology Roadmap**

**From AIAA-2019-2428**

- Continuous Moldline Link\(^1\) (CML)
- Four Wheel Bogie
- Partial Gear Fairing\(^1\)
- Krueger Dual use Fairing\(^2\) (DUF)
- PAA Liner
- Thickened Bifurcator
- Scarf Inlet
- OTR Liner
- Lip Liner

**Most Effective TW301 Technologies:**

<table>
<thead>
<tr>
<th>Technology</th>
<th>Source</th>
<th>ΔEPNdB</th>
</tr>
</thead>
<tbody>
<tr>
<td>OTR</td>
<td>Fan</td>
<td>-1.4</td>
</tr>
<tr>
<td>Four Wheel Bogie</td>
<td>Gear</td>
<td>-1.0</td>
</tr>
<tr>
<td>Krueger DUF</td>
<td>LE</td>
<td>-0.8</td>
</tr>
</tbody>
</table>

Application of 11 technologies resulted in reduction of 5.7 dB for margin of 30 dB to Stage 4 for Far Term vehicle.

\(^1\)AIAA 2018-2972
\(^2\)AIAA 2018-3126
TW301 Technology Roadmap

- Fan still dominant source at all certification points
- Aft fan noise with PAA effects must be directly targeted to reduce system noise any further

- Estimate a 8-10 EPNdB PAA benefit from configuration change
  - MFN presents a lower risk option that still gets most of the benefit
  - Existing Data Point: 5.6 EPNdB difference between MD-90 and A319

<table>
<thead>
<tr>
<th>Configuration</th>
<th>Margin With PAA (EPNdB)</th>
<th>Margin Without PAA (EPNdB)</th>
<th>PAA Benefit (EPNdB)</th>
<th>2016 Value¹ (EPNdB)</th>
</tr>
</thead>
<tbody>
<tr>
<td>TW</td>
<td>24.3</td>
<td>28.6</td>
<td>-4.3</td>
<td>-4.8</td>
</tr>
<tr>
<td>MFN²</td>
<td>34.4</td>
<td>30.2</td>
<td>4.2</td>
<td>–</td>
</tr>
<tr>
<td>HWB³</td>
<td>40.4</td>
<td>34.0</td>
<td>6.4</td>
<td>7.1</td>
</tr>
</tbody>
</table>

¹AIAA-2016-0863
²AIAA 2018-3126
³AIAA 2018-3125
**HWB301 Uncertainty (1/2)**

- Quantified uncertainty in certification prediction of HWB301
- Builds on results of past activities
- Improved quantification of elemental uncertainties

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**Setup**

1. Identify noise prediction elements
2. Choose prediction method
3. Choose uncertainty quantification method and supporting data
4. Generate deterministic element source prediction
5. Quantification of noise prediction element standard uncertainty
6. Generate element probability density function (PDF)

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**Monte Carlo Simulation**

1. Sample element PDF
2. Propagate source noise to observer
3. Sum source levels at observer
4. Compute system level EPNL at observer

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**Post Processing**

1. Compute statistical moments
2. Generate convergence plots of statistics
3. Generate scatter plots and histograms
4. Compute statistical moments
5. Generate convergence plots of statistics

---

*Quantified uncertainty in certification prediction of HWB301*
*Builds on results of past activities*
*Improved quantification of elemental uncertainties*
• Considerable progress reducing uncertainty
  • 2.6 EPN dB reduction from 2013-2016
  • 1.1 EPN dB reduction from 2016 to current
  • Improvements in Krueger flap prediction and jet uncertainty quantification

• Likely to reach Mid Term noise reduction goal

• Prioritized case highlights contributions of:
  • Fan with PAA effects and lining
  • Krueger flap
Twin Aisle Far Term Technology Overlap

**High System Benefit**
- Scarf Inlet
- Lip Liner
- TW
- Center Plug Liner
- OTR
- Krueger DUF
- 4 wh. Main Gear
- PAA Liner
- CML
- Pod Gear
- PAA Effects
- TW
- HWB

**Low System Benefit**
- Gap Seal
- PNGF
- Thickened Bifurcation
- CML
- Lip Liner
- HWB

**MWB**
- Thickened Bifurcation
  - Small change in total lined area
- CML
  - Continuous flap system (787-like)
  - Porous flap side edge treatment applied on Mid Term vehicle

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1 Not included in HWB roadmap
2 Partial nose gear fairing (PNGF) included in Mid Term HWB technology assumptions