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

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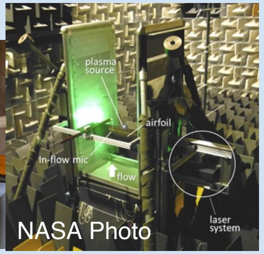
Acoustics Technical Working Group
NASA Langley Research Center

Outline

- Team Technical Strategy Overview
- PAA and Aircraft System Noise Flight Test Key Results To Date
- ANOPP Status
- Prediction Method Development Updates
  - New System Level Liner Attenuation Method
  - Guo Airframe Methods
  - PAA Scattering Prediction
- System Noise Assessment Process
- TTBW Assessment Update
- High Level Results from Recent System Noise Studies
- MBSA&E Initiative
- Summary
- Team Bibliography

Propulsion Airframe Aeroacoustics and Aircraft System Noise Team


NASA Photo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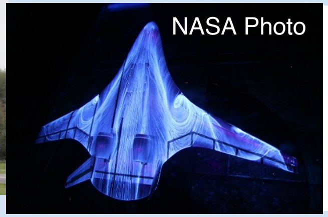
Boeing Photo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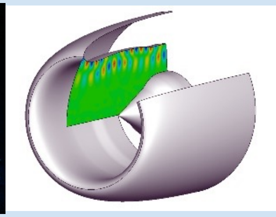
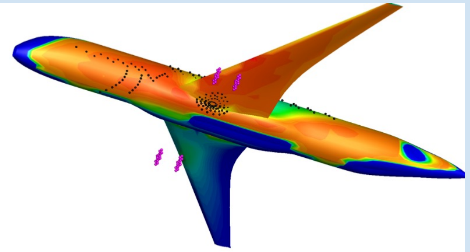


Collaboration with:

- System Analysis and Integration
- NASA Acoustics and other disciplines
- Industry
- Academia

Aircraft acoustics research including:

- Simulations
- Wind tunnel research tests
- Full-scale flight research tests




Boeing Photo

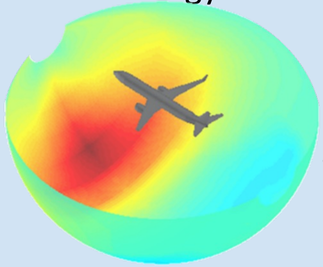

Boeing Photo

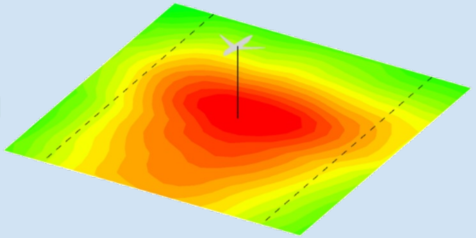
PAA & ASN Team

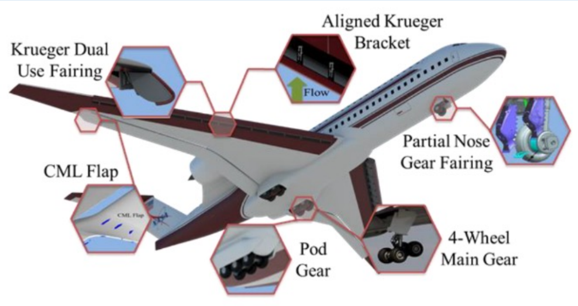
PAA are the aeroacoustic integration effects
ASN is the total aircraft system noise (e.g., certification noise)

Products:

- ANOPP (Aircraft NOise Prediction Program),
  - Research and Release Versions
- PAA and Aircraft Noise Prediction Methods
- Aircraft Concept Acoustic Assessments
- Noise Reduction Technology
- Technology Roadmaps to Guide Development







ANOPP-Research vs. ANOPP-Release

- L31v7 Current Release

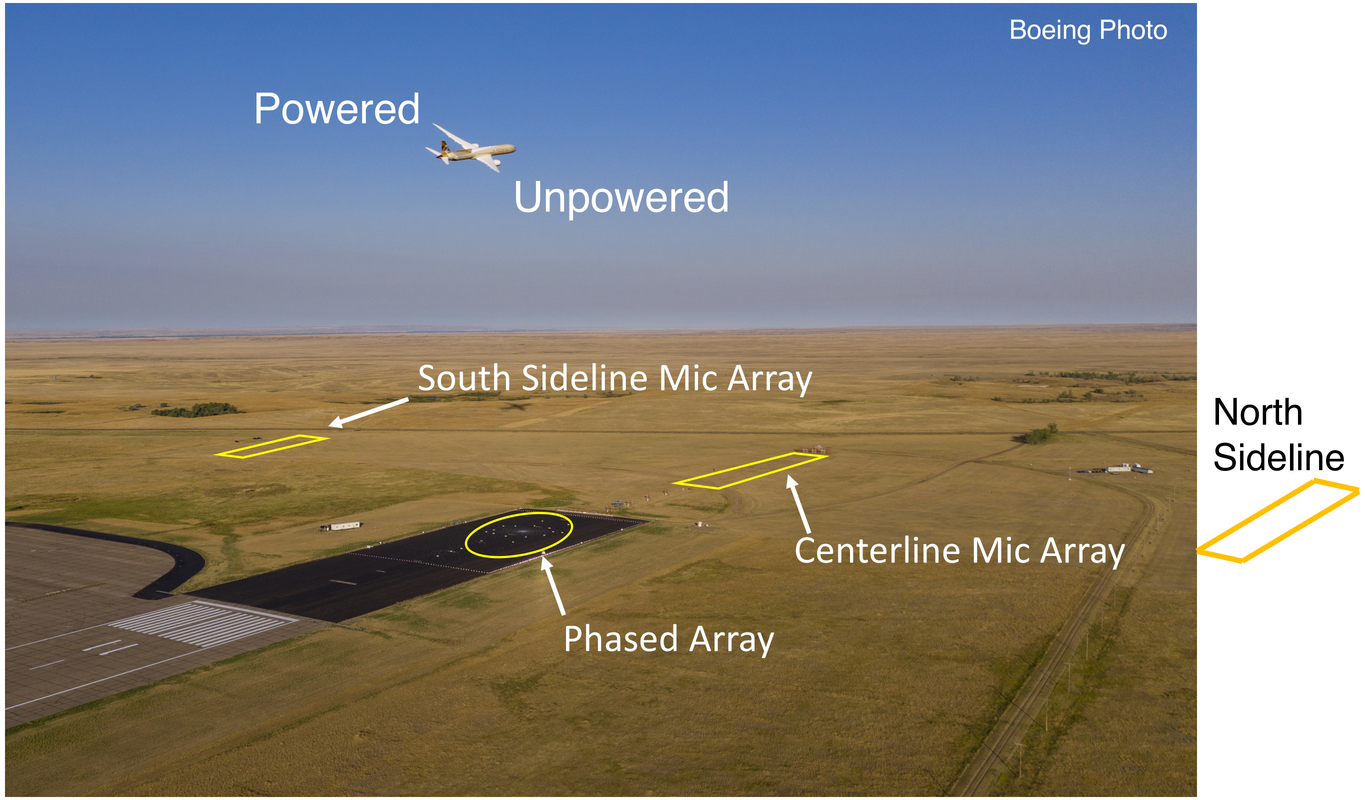
- L32v1 (Future Planned Release)
  - Initial release of the 3rd generation of airframe noise prediction methods, the Guo methods for gear, slat, and flap
  - Removal of the Fink methods for gear, slat, and flap

- ANOPP-Research (In-House)
  - Additional data and modeling (in ANOPP or stand-alone predictions) used for:
    - Wide range of noise reduction technologies
    - Propulsion airframe aeroacoustic (PAA) effects from data
    - PAA scattering effects from physics based, midcomplexity prediction methods
      - PAAShA for shielding
      - PAASc for general scattering
    - Calibrations to noise prediction methods
    - Acoustic liner technology prediction
    - Full range of the 3rd generation of airframe noise prediction methods including Krueger flap and additional capabilities/features

Propulsion Airframe Aeroacoustics and Aircraft System Noise Flight Test on the Boeing 787 ecoDemonstrator 2020

Collaboration between NASA and Boeing

For a Straight Flight Test Point



Thomas, Guo, Clark, and June, AIAA 2022-2993
Czech et al., AIAA 2022-2994

Relative EPNdB

	High Power		
	Prediction		Measured
	PAA	No PAA	
Unpowered	-1.9	-3.1	-7.3
Centerline	+5.0	+3.2	0.0
Powered	-0.9	-3.1	-6.2

- Measured data are another quantification of PAA effects in flight
- With PAA, ANOPP-Research predicts correct trend and magnitude
- Airframe components well predicted
- Confirmed need for new ANOPP fan source noise and new liner methods

New System Level Liner Prediction Method In Development

Collaboration of the PAA & ASN and the Liner Physics Teams

Recent system noise assessments indicate high importance of fan noise (source, liner, & propulsion-airframe aeroacoustics) on overall prediction accuracy

Develop a *system-noise-compatible* acoustic liner prediction method applicable to *current and future aircraft nacelles*, *improving physical fidelity* and *accuracy* over available methods.

system-noise-compatible
- low-cost model evaluation
- compact feature space
- large design domain

current and future aircraft
- realistic geometry
- liner design flexibility
- constrained to computational approach

improving physical fidelity
- narrowband
- azimuthal dependence
- fan source specific modeling

improving … accuracy
- out-of-sample
- flight validation

Limit scope to inlet for initial modeling iteration

Airframe Prediction Method Generations in ANOPP-Research

- ANOPP-Fink (~1977)
  - Landing gear model based on simple, small scale, isolated gear test
  - Flap, slat and trailing edge models all based on flat plate trailing edge theory
- ANOPP-BAF (~2005)
  - More physics-based source mechanism modeling
  - Large scale and flight test data calibration
- ANOPP-Research Guo Methods (started 2015)
  - Physics-based modeling building on ANOPP-BAF
  - New subcomponents
  - Extended functionality
  - Completely new Krueger flap noise model
  - More applicable to future unconventional aircraft

In the timeframe of BAF also a New Trailing Edge Model – not in ANOPP yet and uses CFD data…

Still using Fink for Trailing Edge in ANOPP

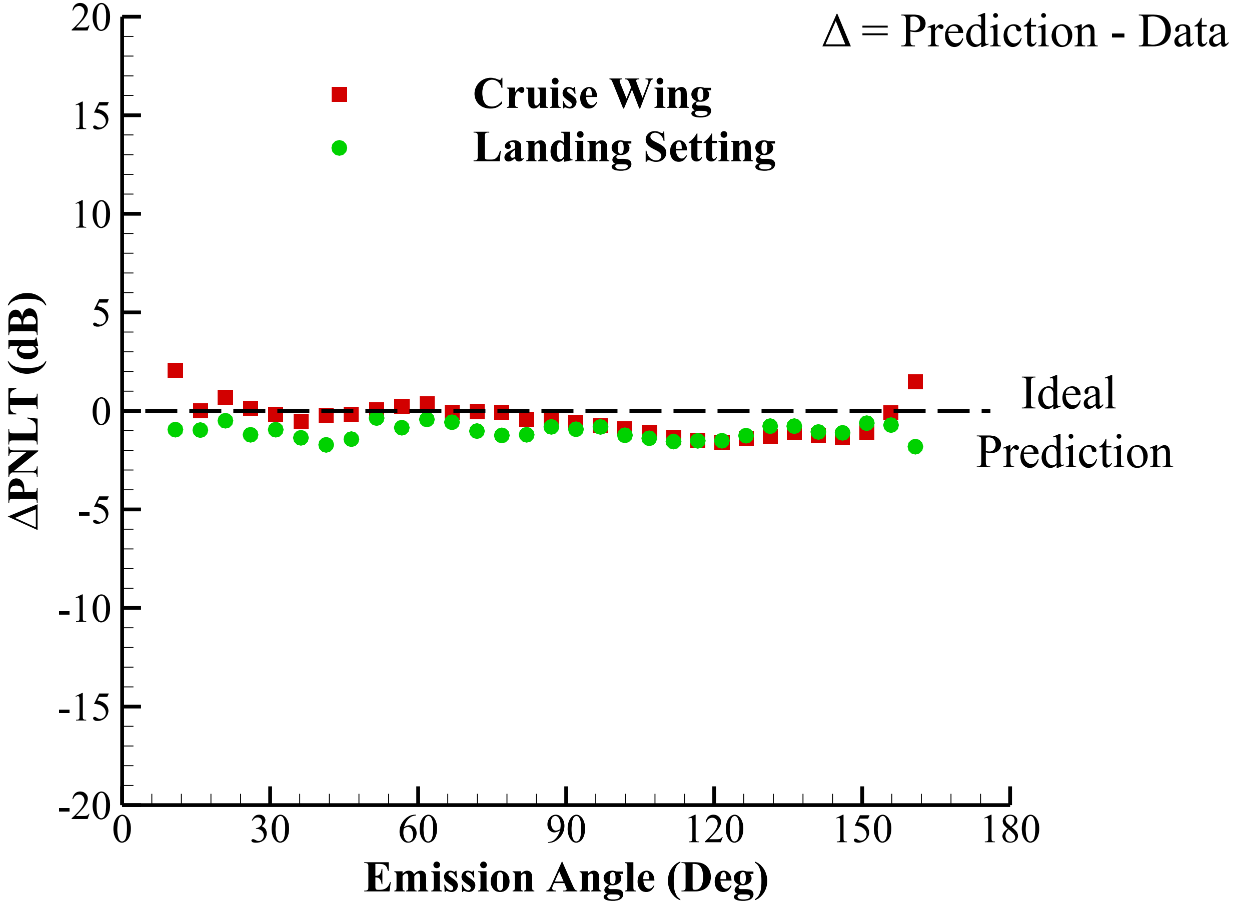
3rd Generation Airframe Noise Prediction Compared to NASA/Boeing PAA & ASN 787 Flight Test Data

Guo and Thomas, AIAA 2022-2995

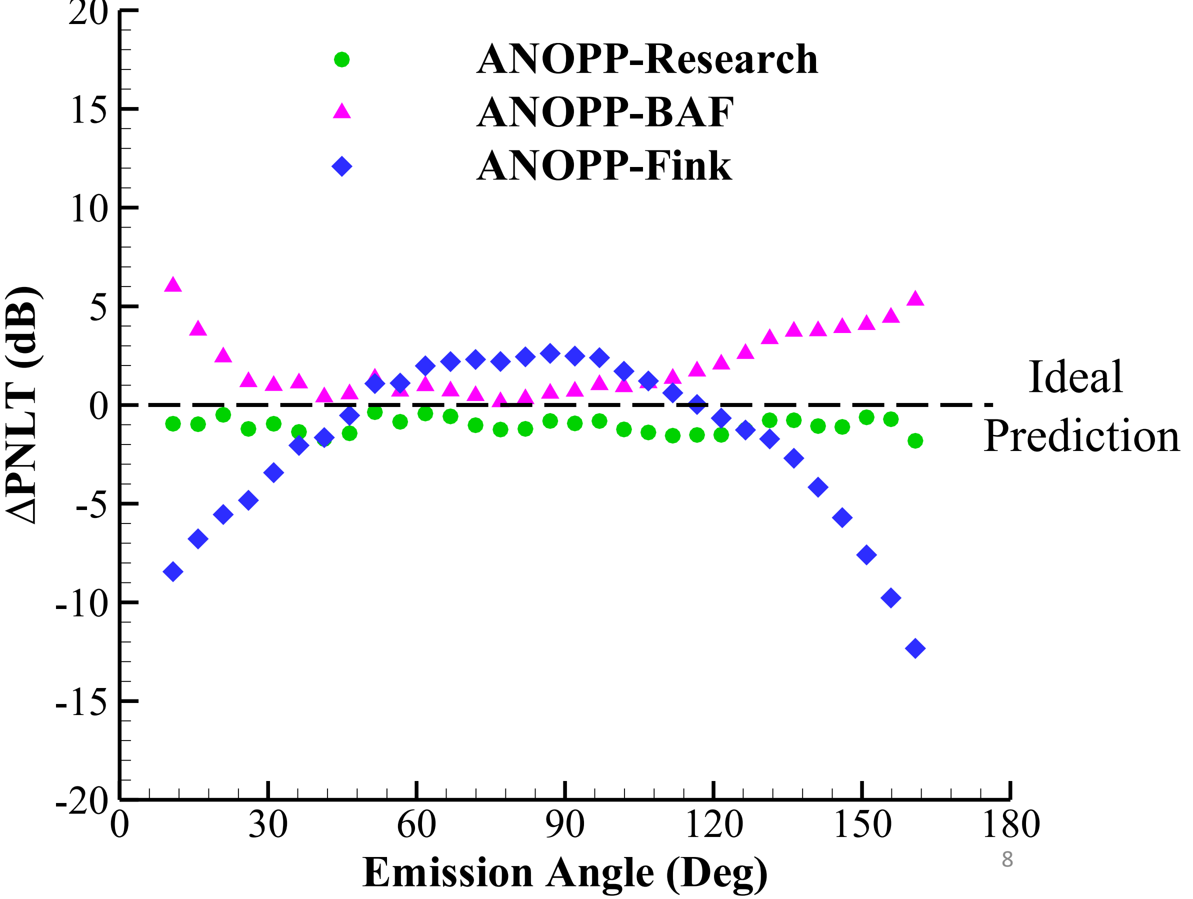
Landing Gear

Error in EPNL

- Cruise wing: ΔEPNL = -0.5 dB
- Landing setting: ΔEPNL = -1.0 dB



Landing setting



Airframe Methods Status

- **Fink methods shown to be completely inadequate – as expected**
- **ANOPP-Research Guo Airframe Methods – overall excellent performance**

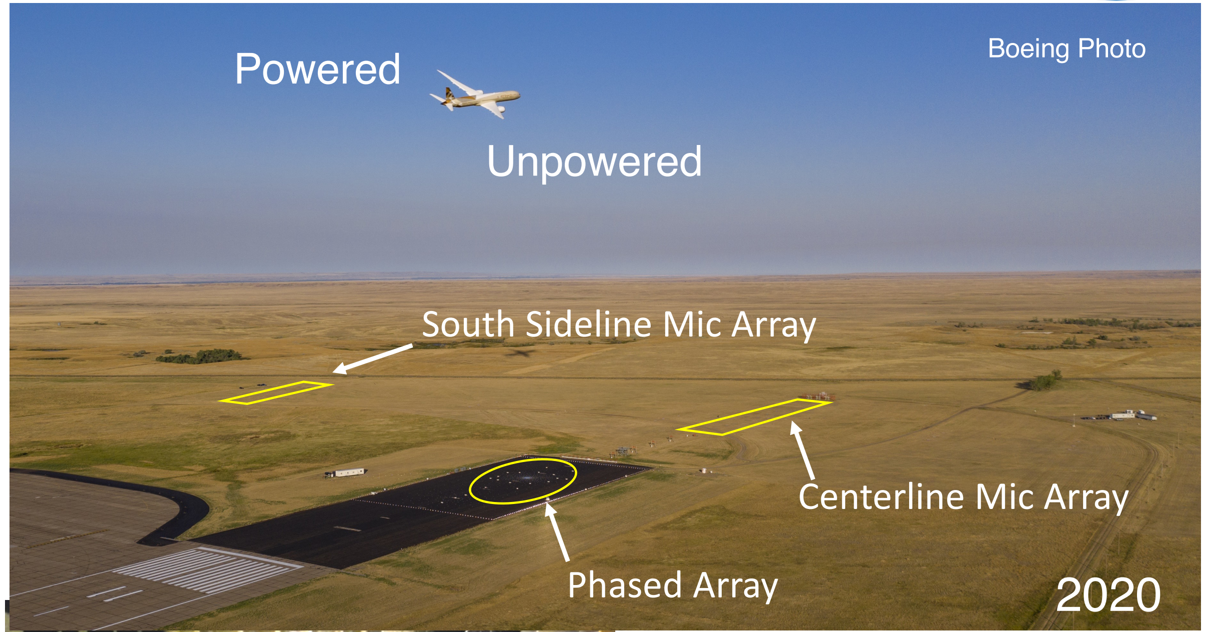
Component	Accuracy	Potential Improvement	Impact on Component EPNL
Landing Gear	Good Overall	Wake/Edge Interaction and/or Model for Small Parts	Minor
Slat	Good Overall	Gap and/or Bracket Noise Directivity	Minor
Flap	Good in Parametric Trends, Large Error in Amplitude	Model for Advanced Flap System	Major (~2 dB)

Guo and Thomas, AIAA 2022-2995

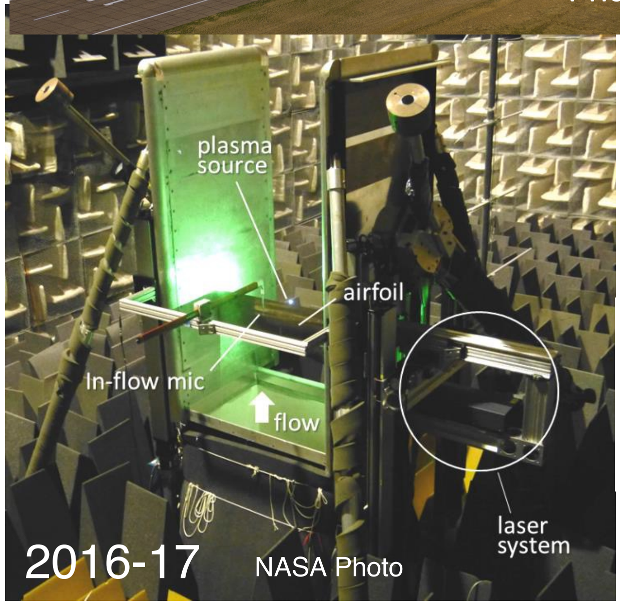
PAA Progress Has Used a Range of Experimental Research – Prediction Method Development Benefited

Series of Canonical Geometries: plate, sphere and cylinder

N2A HWB 14x22



Boeing / NASA Series of PAA LSAF Experiments

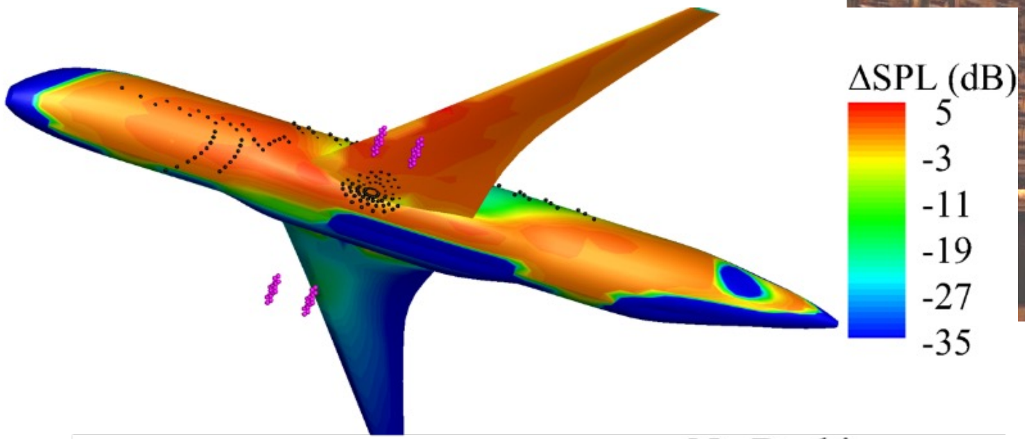


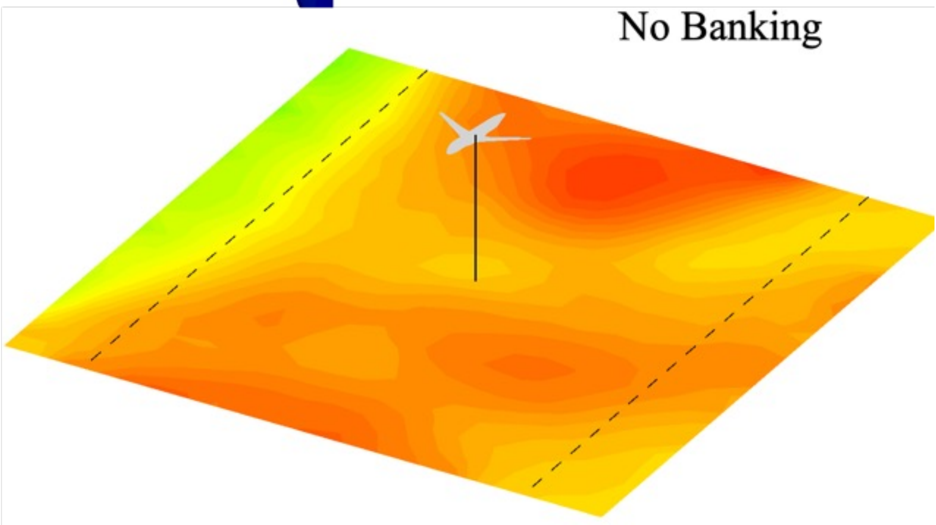
QFF NACA 0012 Spark Source (part of NATO AVT-233)

Two Methods for Prediction of PAA Scattering Effects

PAASc Prediction

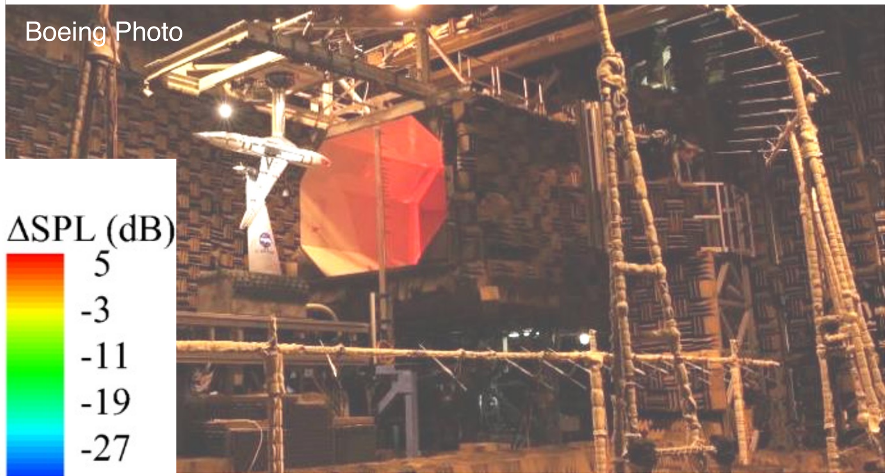
Guo and Thomas, AIAA 2022-3077





Prediction from LSAF PAA Data

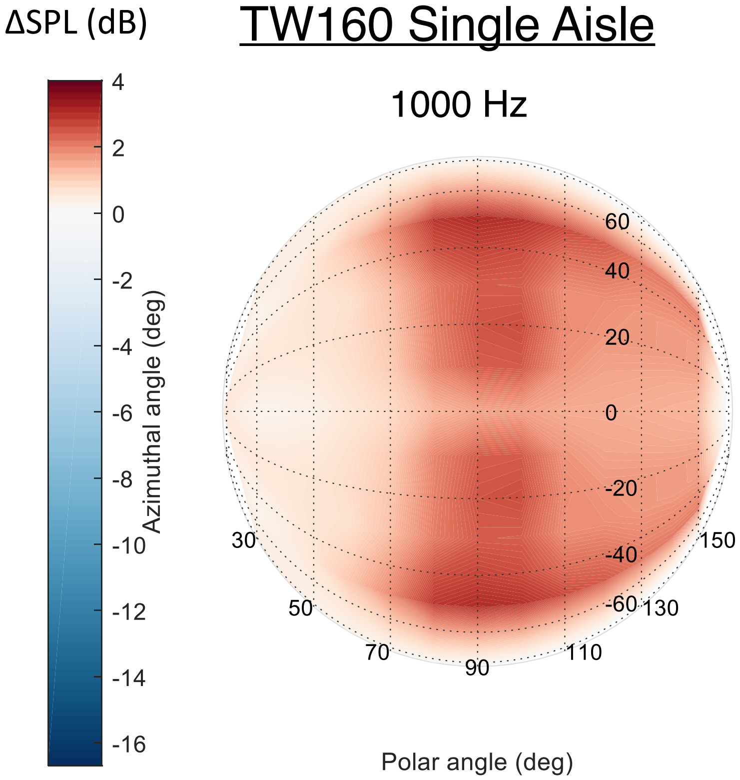
Czech and Thomas, AIAA 2013-2185



Boeing Low Speed Aeroacoustic Facility (LSAF)

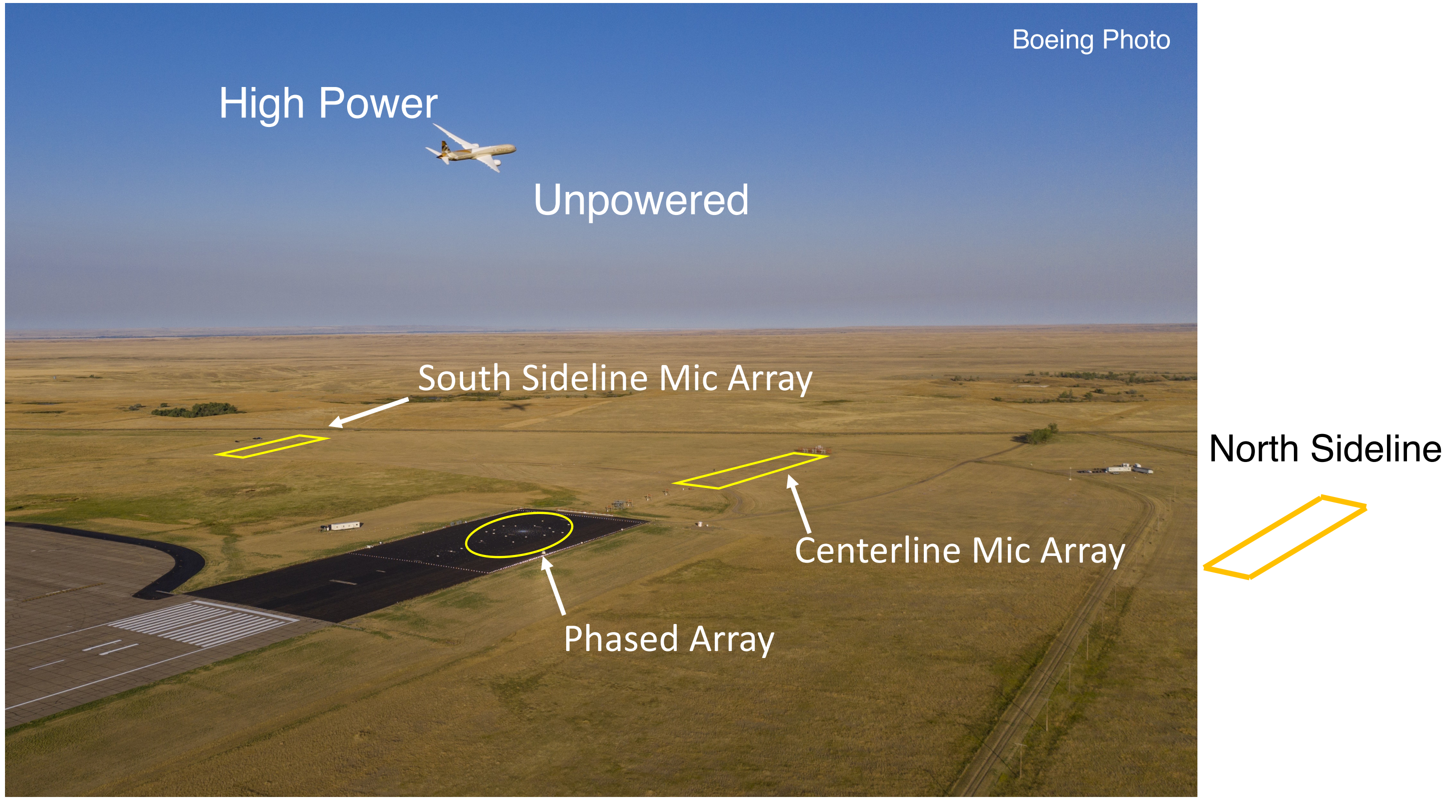
Modify engine-under-wing reflection data from LSAF data for geometry

Clark, Thomas, and Guo, AIAA 2019-2427

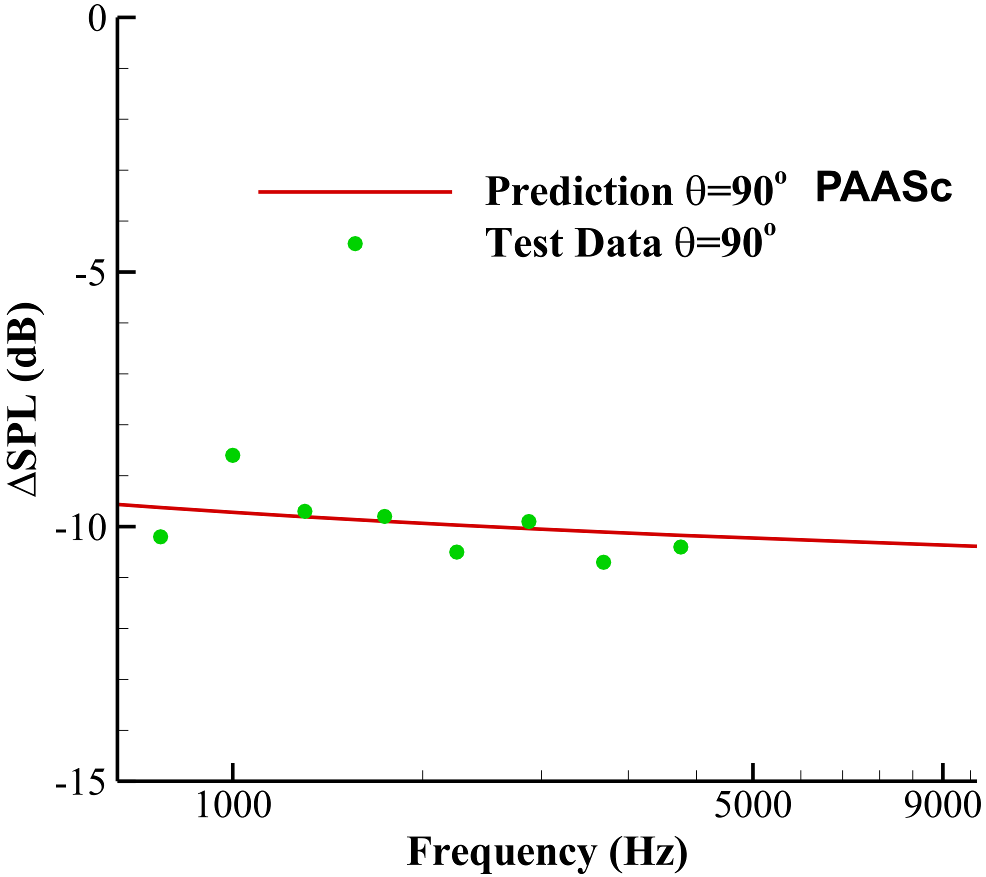


PAASc Prediction Validation with 787 Flight Data

- Banking angle 34 degrees
- Altitude 800 feet
- Mach 0.3

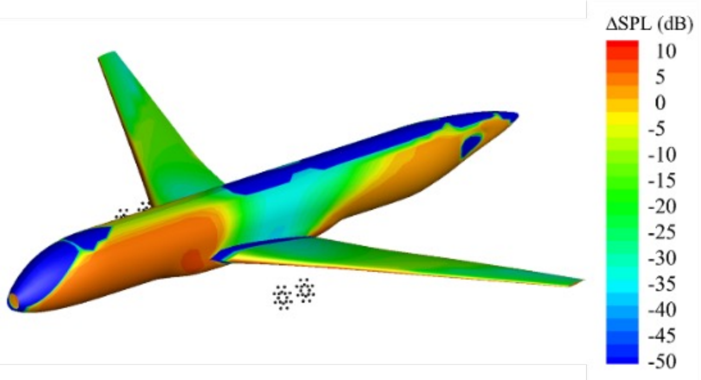


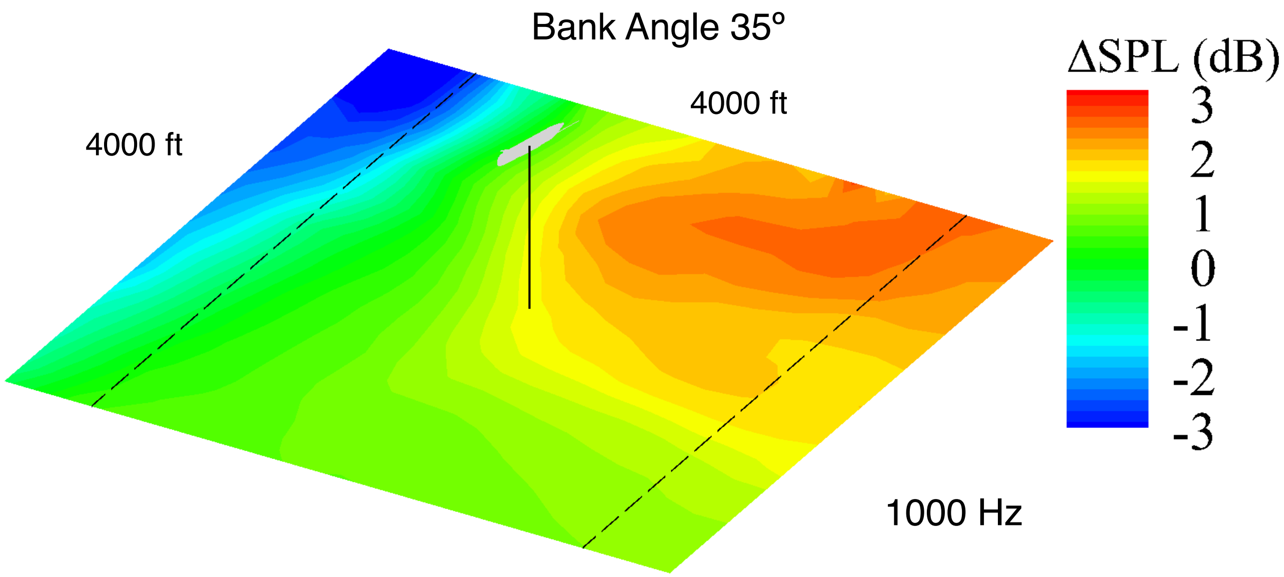
ΔSPL = North Sideline – South Sideline



Benchmark Validation Result

Many PAASc Applications and Developments in Progress





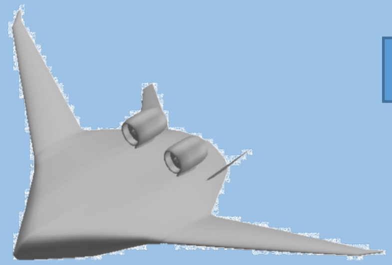
Predicted scattered field for combined forward and aft fan broadband noise, both engines at high power.

- Continued comparison to experimental and flight test data
- Improvements and documentation
- Development of possible low-noise operational procedures
- Development of innovative PAA noise reduction technologies
- PAA maps for advanced aircraft concept noise assessments:
  - TTBW and others
- PAA maps for noise reduction roadmaps as integrated with advanced aircraft concepts

Development of an Aircraft Concept and Noise Assessment

Systems Analysis and Integration within NASA AATT Project

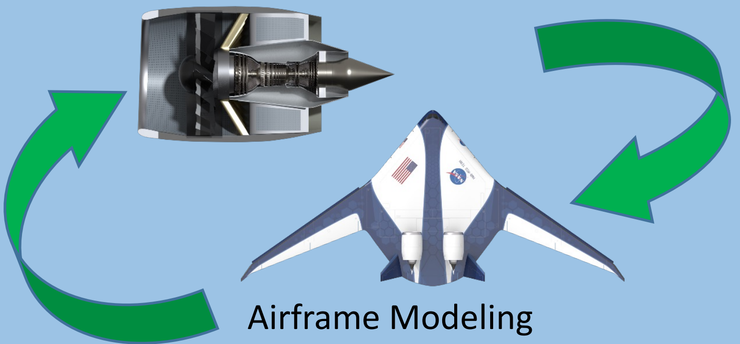
Configuration Layout from:
- NASA
- Industry
- Academia



Refine

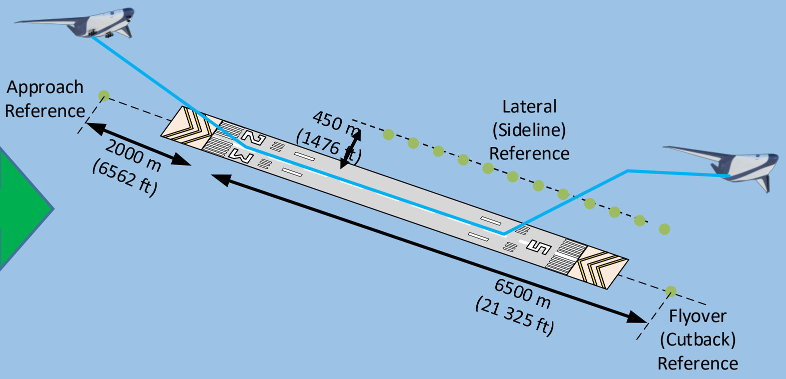
Technology Assumptions

Propulsion System Modeling



Airframe Modeling

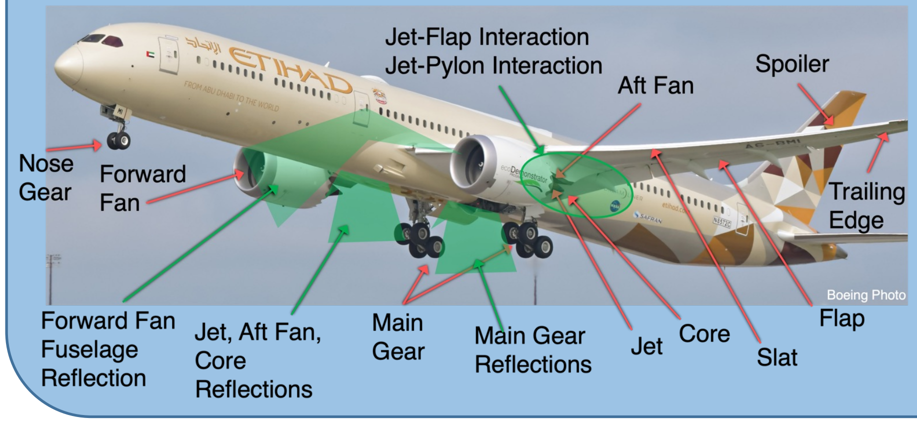
Mission Analysis (e.g., noise certification)



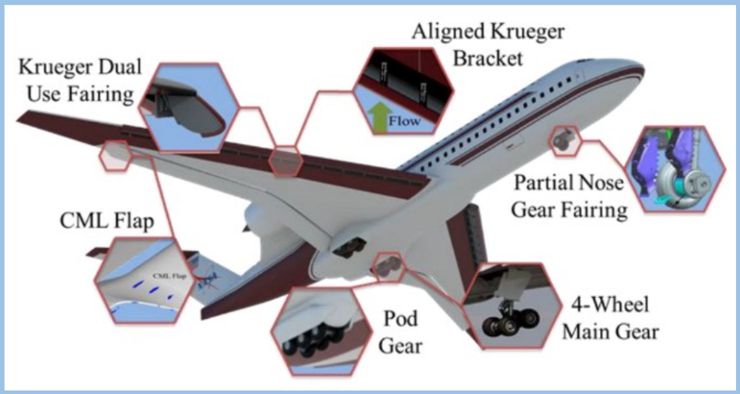
Detailed Flight Characteristics

Inform

Aircraft System Noise Prediction (with ANOPP-Research)

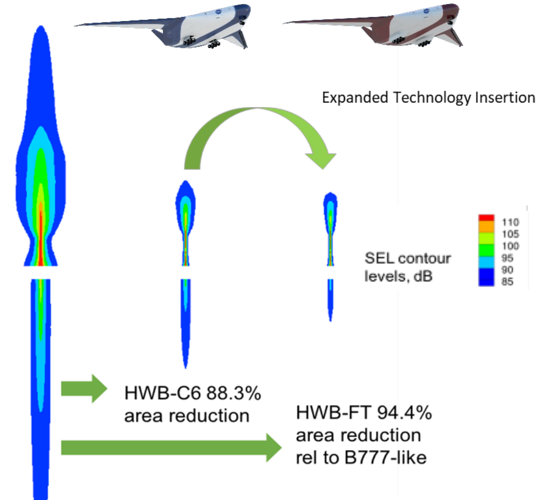


Technology Package



Results

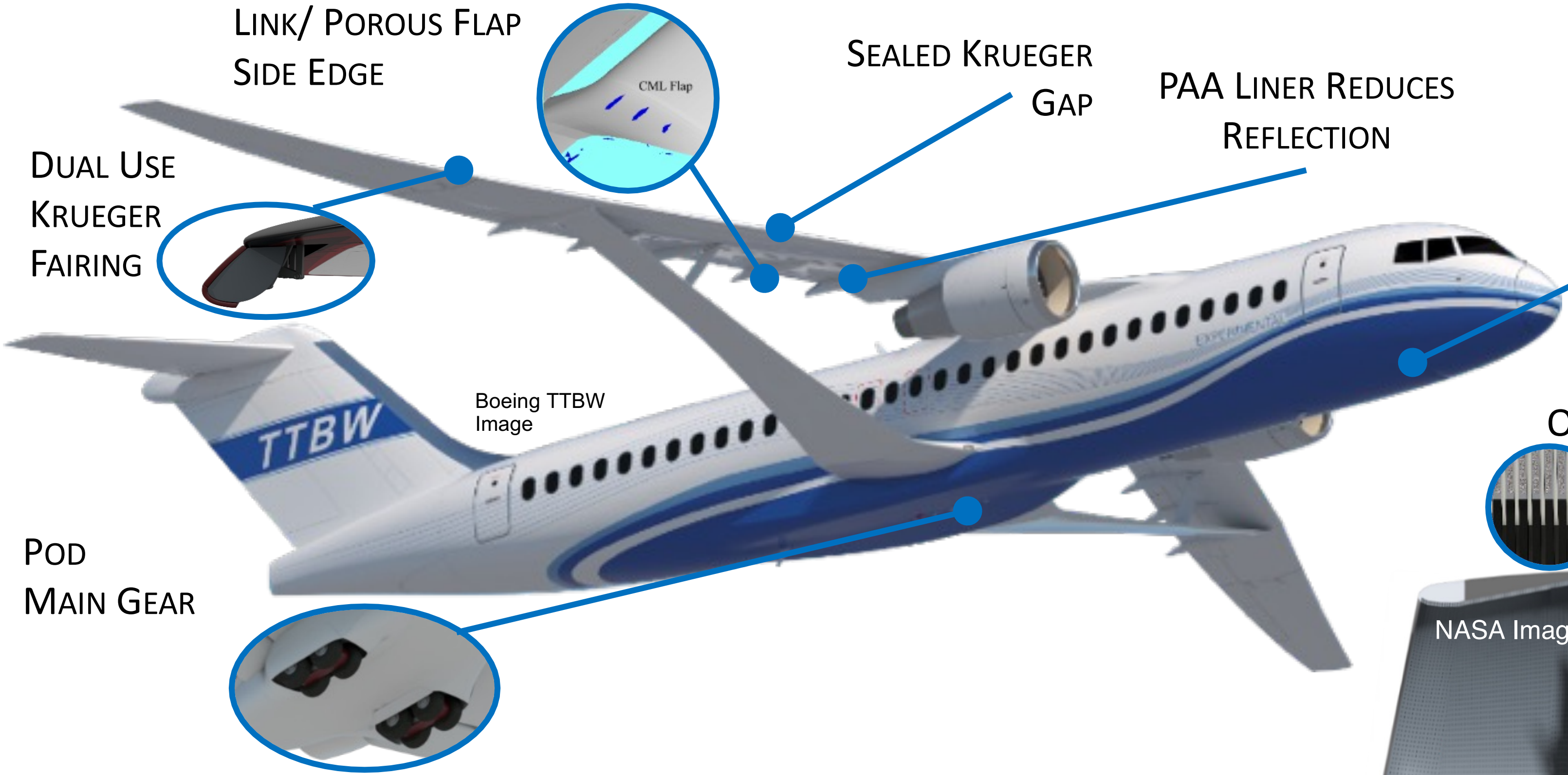
Acoustic Assessment

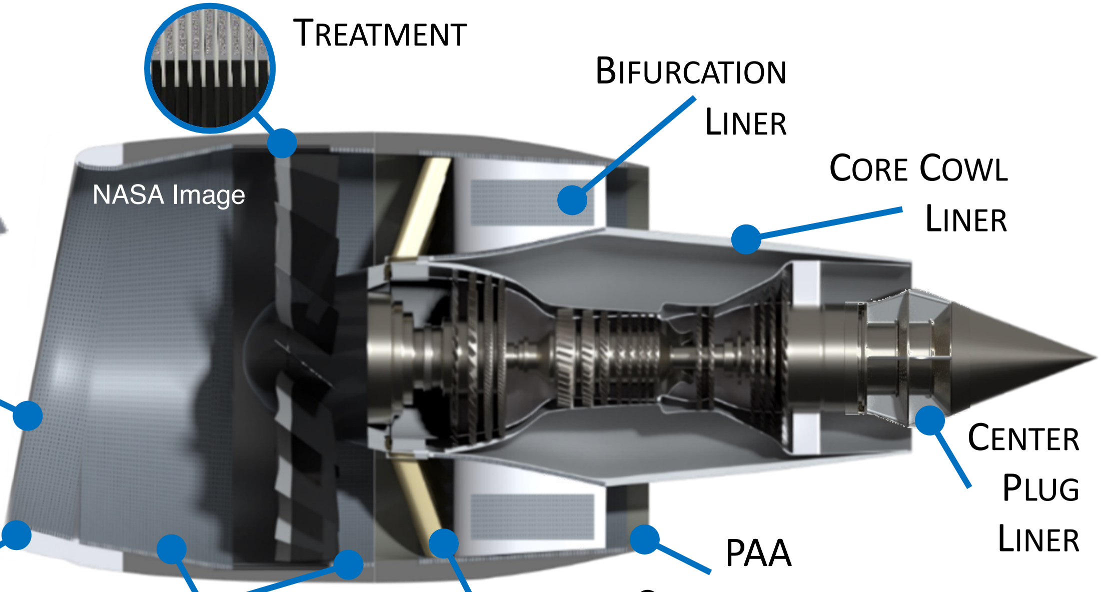


From AIAA-2017-3193

Transonic Truss Braced Wing (TTBW) Roadmap Technologies and Plans

June, Thomas, and Guo, AIAA 2022-3049

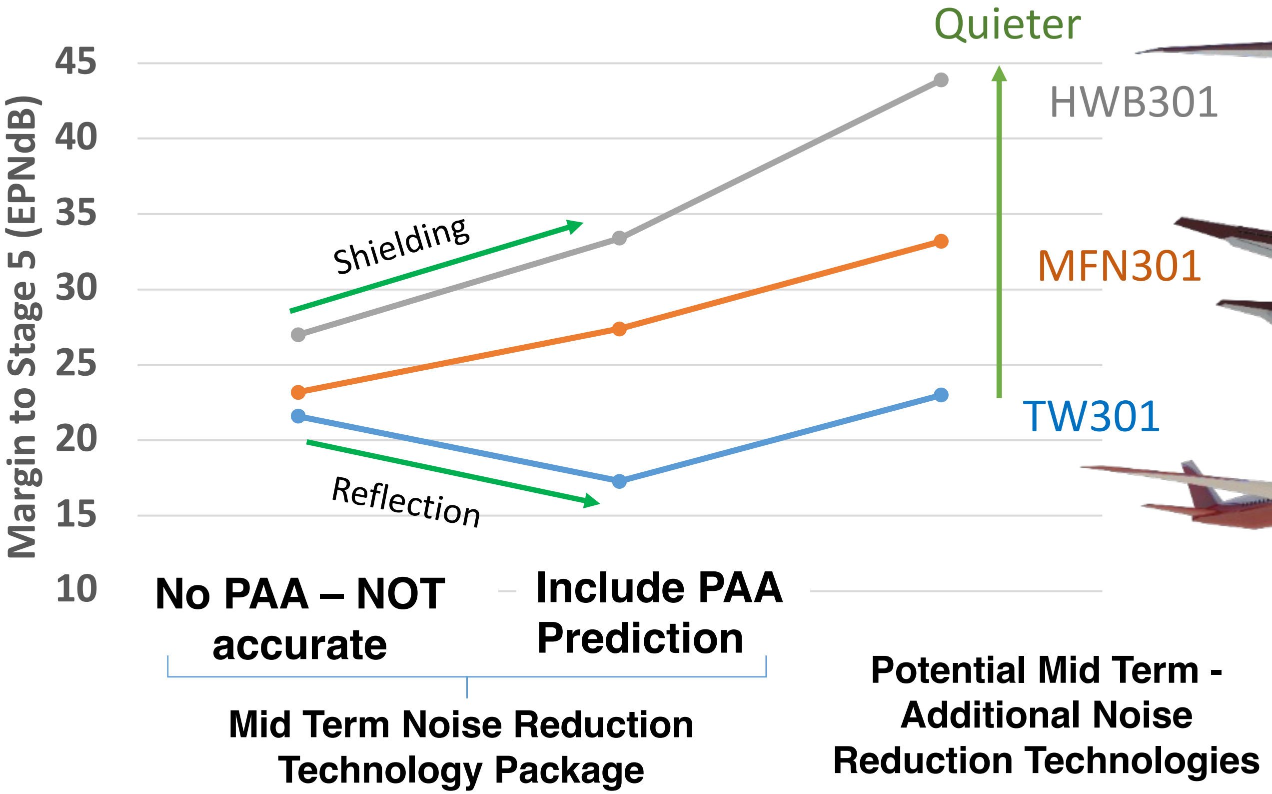




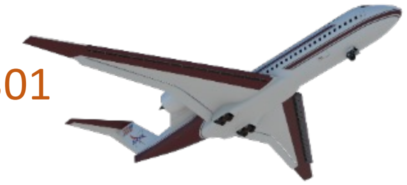
Configuration	Roadmap Noise Reduction [EPNdB]	Resulting Cumulative Margin to Stage 5 [EPNdB]
TTBW	7.8	25.8
N3 Conventional	7.2	20.5

Low-Noise Value of Configuration Change

Multiyear study on a set of equivalently modeled advanced concepts to determine the noise reduction value of configuration change.



Thomas et al., AIAA 2017-3193



Guo et al., *J of Aircraft* Vol. 56, No. 5, 2019

June et al., AIAA 2019-2428

- Total PAA effect is the largest share of the 16.1 EPNdB difference.
- Add innovative technologies including improving PAA effectiveness. Increases difference to 20.9 EPNdB cumulative.

High Level Summary of System Studies – Results and Progress

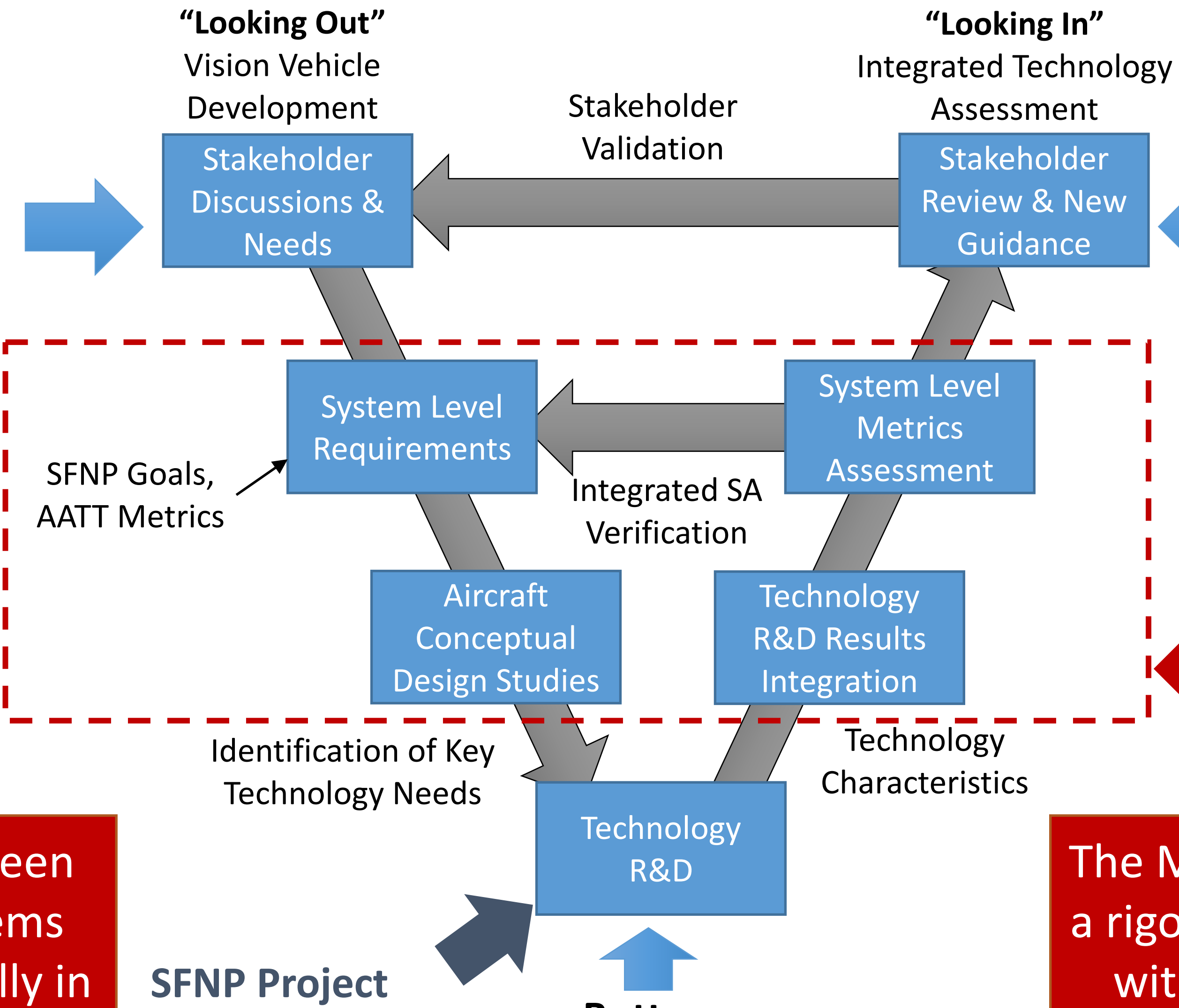
- From studies such as: TW301, MFN301, HWB301, TW160, OWN160, ND8, TTBW154 and others
- Assessment and technology roadmap findings:
  - Many advanced concepts and technologies considered
  - Future noise reduction potential:
    - About 7 dB from noise reduction technology roadmaps
    - About 7 dB from more advanced aircraft technology levels
    - Up to 11 dB from favorable configuration change – PAA effects
    - Significant risk and cost to development
  - Transformative technology could expand the design space and could enable configuration change
  - Can stimulate new technology with more near-term application supporting sustainable growth

- Significant improvements are being made in NASA's system noise capability, continuing to increase realism of noise prediction for advanced concepts

Sustainable Flight National Partnership (SFNP) System Analysis V-Model

From SA&I Co-Lead Eric Hendricks, November 2021

Left Side: specification of the system properties (requirements, architecture, interfaces, etc.)



Right Side: verification of the system against the specifications

New MBSA&E Framework

Bottom: discipline-specific engineering and design work

Both legs of this V have been done historically by systems analysis teams but generally in an ad-hoc manner

The MBSA Framework will provide a rigorous and traceable approach with improved interfaces with internal/external tech R&D efforts

Summary

- AATT is providing robust, collaborative, and ambitious research that is advancing the capabilities and understanding of PAA integration effects and aircraft system noise
- New prediction methods in development to improve ANOPP's accuracy and capabilities
- Working from the PAA & ASN perspective, developing innovative technology concepts for NASA's aircraft concept applications
- NASA / Boeing PAA & ASN flight test on the 787 ecoDemonstrator in 2020 was a major effort
  - First true system level validation of ANOPP
  - Measured PAA scattering effects in flight
  - Demonstrated progress in airframe and PAA scattering predictions
  - Analysis continuing and expect many developments in the future

Recent Publications (1)

- Thomas, R.H., Guo, Y., Clark, I.A., and June, J.C., “Propulsion Airframe Aeroacoustics and Aircraft System Noise Flight Research Test: NASA Overview,” AIAA 2022-2993.
- Czech, M.J., Thomas, R.H., Guo, Y., June, J.C., Clark, I.A., and Shoemaker, C.M., “Propulsion Airframe Aeroacoustics and Aircraft System Noise Flight Test on the ecoDemonstrator 2020 – Boeing 787 Testbed Aircraft,” AIAA 2022-2994.
- Guo, Y. and Thomas, R.H., “Assessment of Next Generation Airframe System Noise Prediction Methods with PAA & ASN Flight Test Data,” AIAA 2022-2995.
- Clark, I.A., Thomas, R.H., and Guo, Y., “Fan Acoustic Flight Effects on the PAA & ASN Flight Test,” AIAA 2022-2996.
- Thomas, R.H. and Guo, Y., “Systematic Validation of the PAAShA Shielding Prediction Method,” *International Journal of Aeroacoustics*, Vol. 21(5-7), pp. 558-584.
- Guo, Y. and Thomas, R.H., “Geometric Acoustics for Aircraft Noise Scattering,” AIAA 2022-3077.
- June, J.C., Thomas, R.H., and Guo, Y., “System Noise Technology Roadmaps for a Transonic Truss-Braced Wing and Peer Conventional Configuration,” AIAA 2022-3049.
- Shelts, K.M., Clark, I.A., Thomas, R.H., and Guo, Y., “Aircraft System Noise Assessment of the NASA Single-Aisle Over-the-Wing Nacelle Configuration,” AIAA 2022-3048.

Recent Publications (2)

- Guo, Y.P. and Thomas, R.H., “On Aircraft Trailing Edge Noise,” AIAA paper 2019-2610.
- June, J.C., Thomas, R.H., Guo, Y. and Clark, I.A., “Far Term Noise Reduction Technology Roadmap for a Large Twin-Aisle Tube-and-Wing Subsonic Transport,” AIAA Paper 2019-2428.
- Clark, I.A., Thomas, R.H., and Y. Guo, “Far Term Noise Reduction Roadmap for the NASA D8 and Single-Aisle Tube-and-Wing Aircraft Concepts,” AIAA Paper 2019-2427.
- Bertsch, L., Clark, I.A., Thomas, R.H., Sanders, L., LeGriffon I., “The Aircraft Noise Simulation Working Group (ANSWr) - Tool Benchmark and Reference Aircraft Results,” AIAA Paper 2019-2539.
- Sanders, L., Thomas, R.H., Bertsch, L., LeGriffon, I., Clark, I.A., June, J.C., Lorteau, M., “The Aircraft Noise Simulation Working Group (ANSWr) – V-2 Aircraft Results,” AIAA Paper 2019-2540.
- Guo, Y. P., Thomas, R. H., Clark, I. A. and June, J. C., “Far Term Noise Reduction Roadmap for the Midfuselage Nacelle Subsonic Transport,” Vol. 56, No. 5, *AIAA Journal of Aircraft*, https://doi.org/10.2514/1.C035307
- Thomas, R.H., Guo, Y., Clark, I.A. and June, J.C., “Challenges and Opportunities for Subsonic Transport X-Plane Acoustic Flight Research,” AIAA Paper 2018-3127.
- Clark, I.A., Thomas, R.H., Guo, Y., “Aircraft System Noise Assessment of the NASA D8 Subsonic Transport Concept,” AIAA Paper 2018-3124.
- June, J.C., Thomas, R.H., and Guo, Y., “System Noise Prediction Uncertainty Quantification for a Hybrid Wing-Body Subsonic Transport Concept,” Vol. 58, No. 3, *AIAA Journal*, https://doi.org/10.2514/1.J058226
- Hutcheson, F.V., Bahr, C.J., Thomas, R.H., Stead, D.J., “Experimental Study of Noise Shielding by a NACA 0012 Airfoil,” AIAA Paper 2018-2821.
- Thomas, R. H., Guo, Y., Berton, J. J., and Fernandez, H., “Aircraft Noise Reduction Technology Roadmap Toward Achieving the NASA 2035 Noise Goal,” AIAA Paper 2017-3193.
- Thomas, R. H., Burley, C. L., and Nickol, C. L., “Assessment of the Noise Reduction Potential of Advanced Subsonic Transport Concepts for NASA’s Environmentally Responsible Aviation Project,” AIAA Paper 2016-0863.

Recent Publications (3)

- Guo, Y. and Thomas, R.H., “Experimental Study on Open Rotor Noise Shielding by Hybrid Wing Body Aircraft,” *AIAA Journal*, 2016, Vol. 54, pp. 242-253.
- Guo, Y. and Thomas, R.H., “System Noise Assessment of Hybrid Wing Body Aircraft with Open Rotor Propulsion,” *AIAA Journal of Aircraft*, 2015, Vol. 52 pp. 1767-1779.
- Guo, Y. P., Burley, C.L., and Thomas, R. H., “Landing Gear Noise Prediction and Analysis for Tube-And-Wing and Hybrid-Wing-Body Aircraft,” AIAA Paper 2016-1273, May 2016.
- Thomas, R. H., Nickol, C. L., Burley, C. L., and Guo, Y., “Potential for Landing Gear Noise Reduction on Advanced Aircraft Configurations,” AIAA Paper 2016-3039.
- Guo, Y. P., Burley, C. L., and Thomas, R. H., “Modeling and Prediction of Krueger Device Noise,” AIAA Paper 2016-2957.
- Guo, Y. P., Nickol, C. L., and Thomas, R. H., “Noise and Fuel Burn Reduction Potential of an Innovative Subsonic Transport Configuration,” AIAA Paper 2014-0257.
- Guo, Y. P., Burley, C. L., and Thomas, R. H., “On Noise Assessment for Blended Wing Body Aircraft,” AIAA Paper 2014-365, January 2014.
- Thomas, R.H., Czech, M.J., Doty, M.J., “High Bypass Ratio Jet Noise Reduction and Installation Effects Including Shielding Effectiveness,” AIAA Paper 2013-0541.
- Czech, M.J., Thomas, R.H., “Open Rotor Aeroacoustic Installation Effects for Conventional and Unconventional Airframes,” AIAA Paper 2013-2185.
- Doty, M.J., Brooks, T.F., Burley, C.L., Bahr, C.J., Pope, D.S., “Jet Noise Shielding Provided by a Hybrid Wing Body Aircraft,” AIAA Paper 2014-2625.
- Thomas, R.H., Burley, C.L., and Olson, E.D., "Hybrid Wing Body Aircraft System Noise Assessment With Propulsion Airframe Aeroacoustic Experiments," *International Journal of Aeroacoustics*, Vol 11 (3&4), 2012.
- Czech, M.J., Thomas, R.H., and Elkoby, R., "Propulsion Airframe Aeroacoustic Integration Effects for a Hybrid Wing Body Aircraft Configuration," *International Journal of Aeroacoustics*, Vol 11 (3&4), 2012
- Guo, Y., Brusniak, L., Czech, M., and Thomas, R.H., “Hybrid Wing Body Aircraft Slat Noise,” *AIAA Journal*, 2013, Vol. 51, pp. 2935-2945.

NASA