



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

Dr. Russell H. Thomas, Aeroacoustics Branch

Dr. Yueping Guo, NEAT Consulting

Dr. Ian A. Clark, Aeroacoustics Branch

Dr. Jason C. June, Aeroacoustics Branch

John W. Rawls, NIA

Stuart Pope, AMA

October 22, 2019

Acoustics Technical Working Group

NASA Glenn Research Center

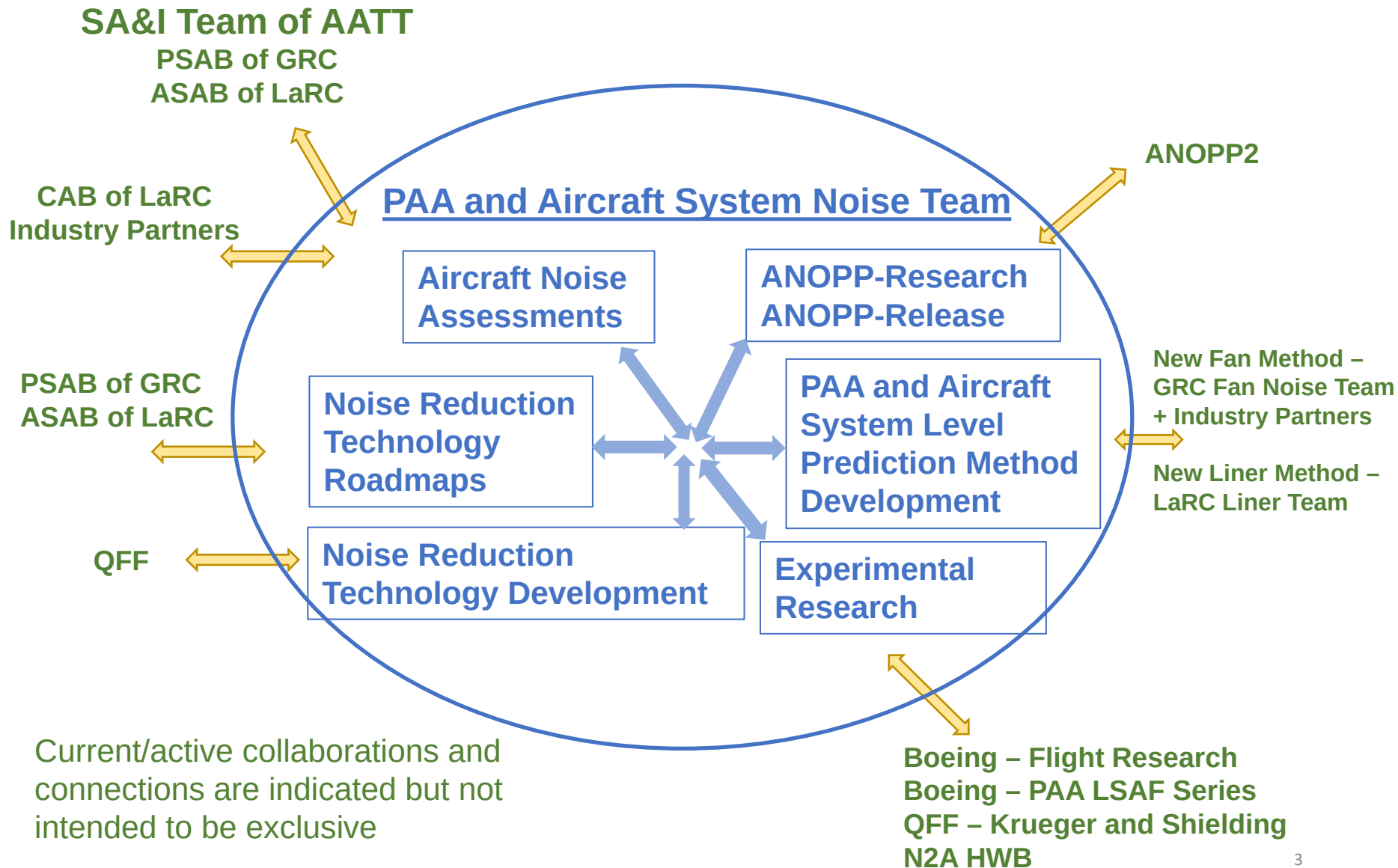
# Outline

---



- 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



# ANOPP-Research v. ANOPP-Release

---



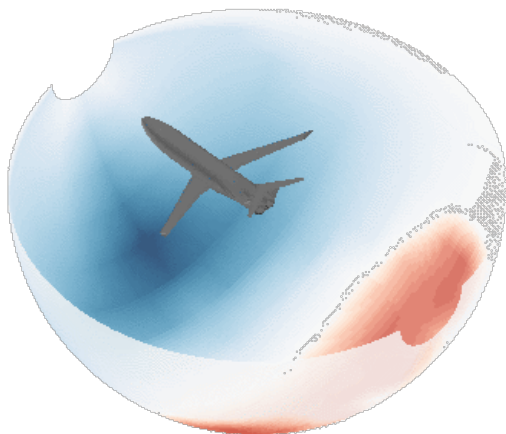
- L31v7 (Next Planned Release)
  - Windows execution time improvement
  
- L32v1 (Future Planned Release)
  - Initial release of new generation of Guo airframe noise prediction methods (for gear, slat leading edge, trailing edge high lift)
  
- ANOPP-Research (In-House)
  - Additional modeling (in ANOPP 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

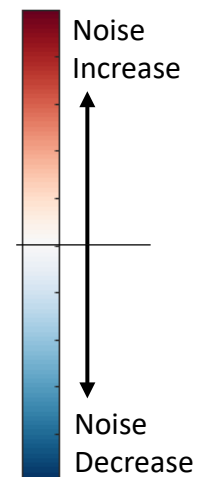
Shielding/Reflection



Krueger Dual Use  
Fairing – Low  $f$



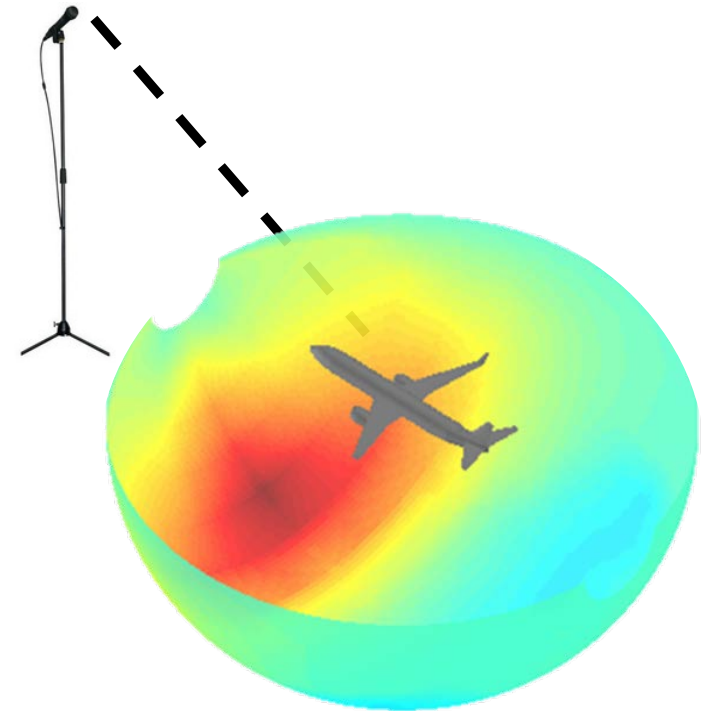
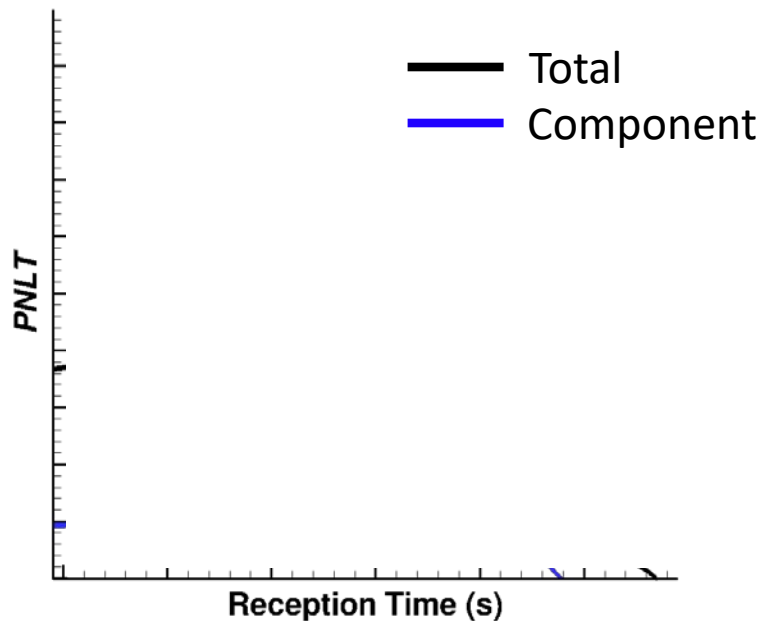
Krueger Dual Use  
Fairing – High  $f$



# Acoustic Elements and Total Noise



Multiple noise components contribute to total noise level

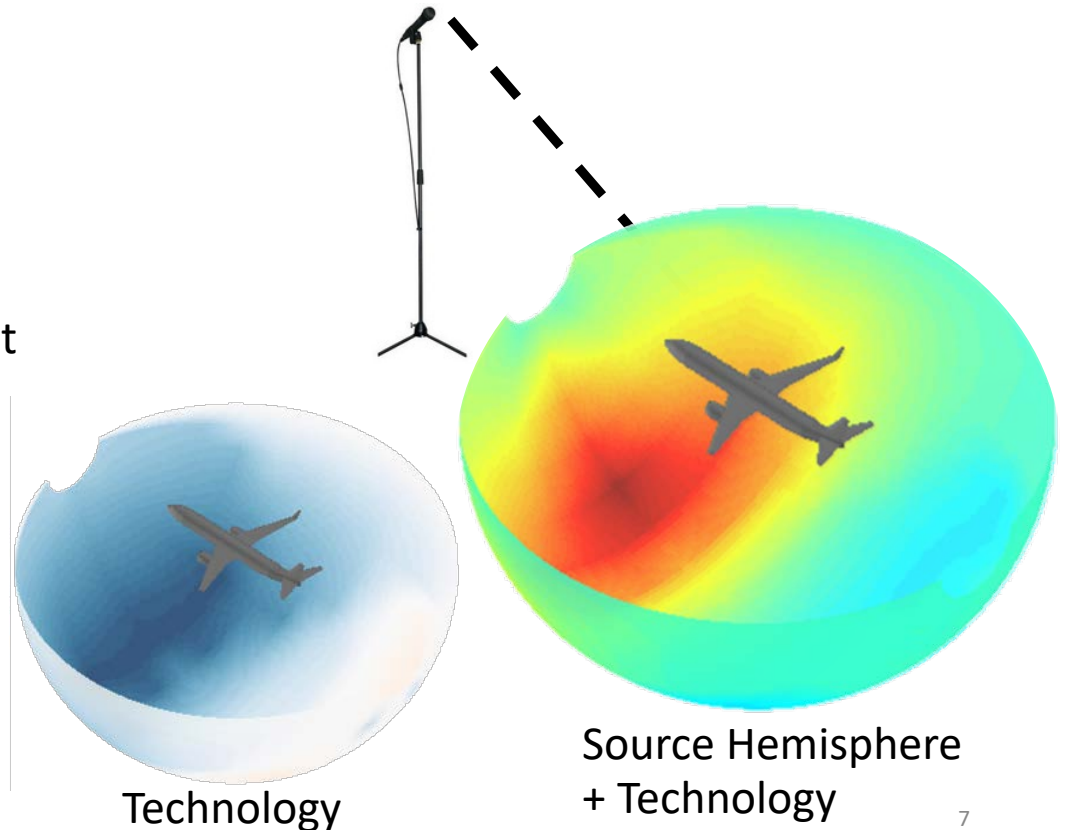
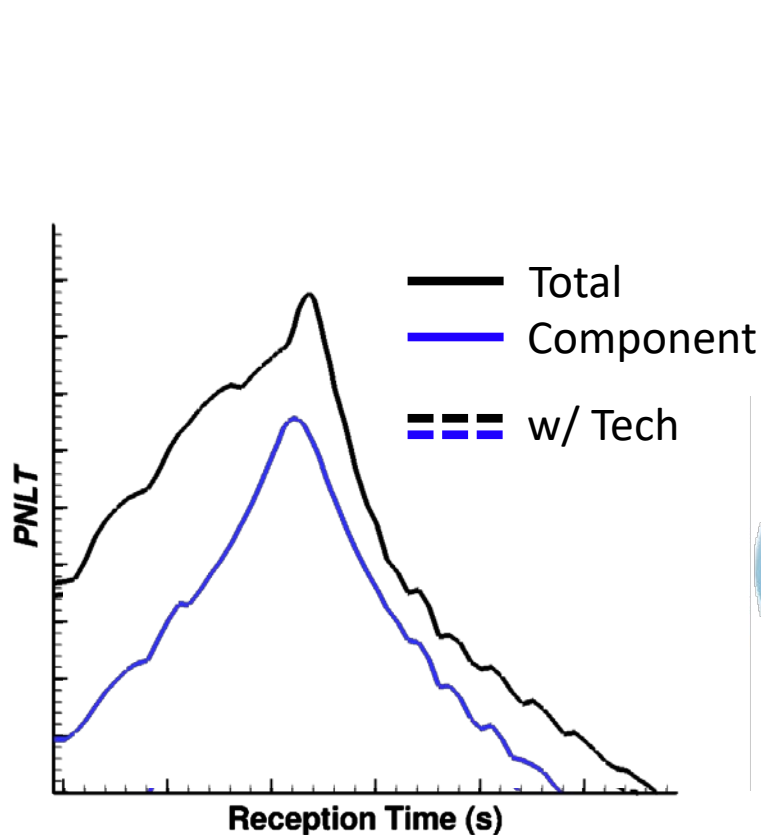


Source Hemisphere

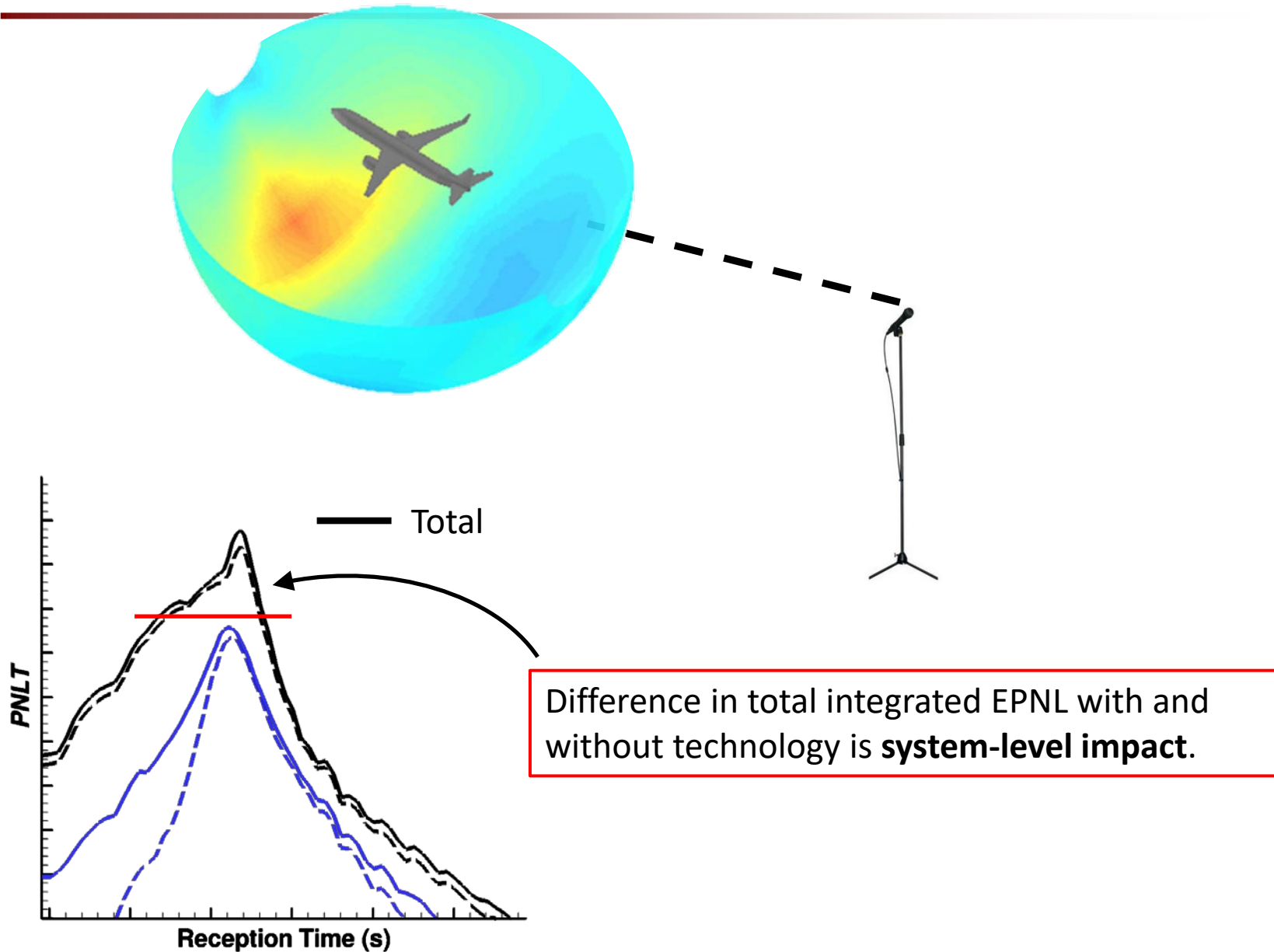
# Including Technologies and PAA Effects



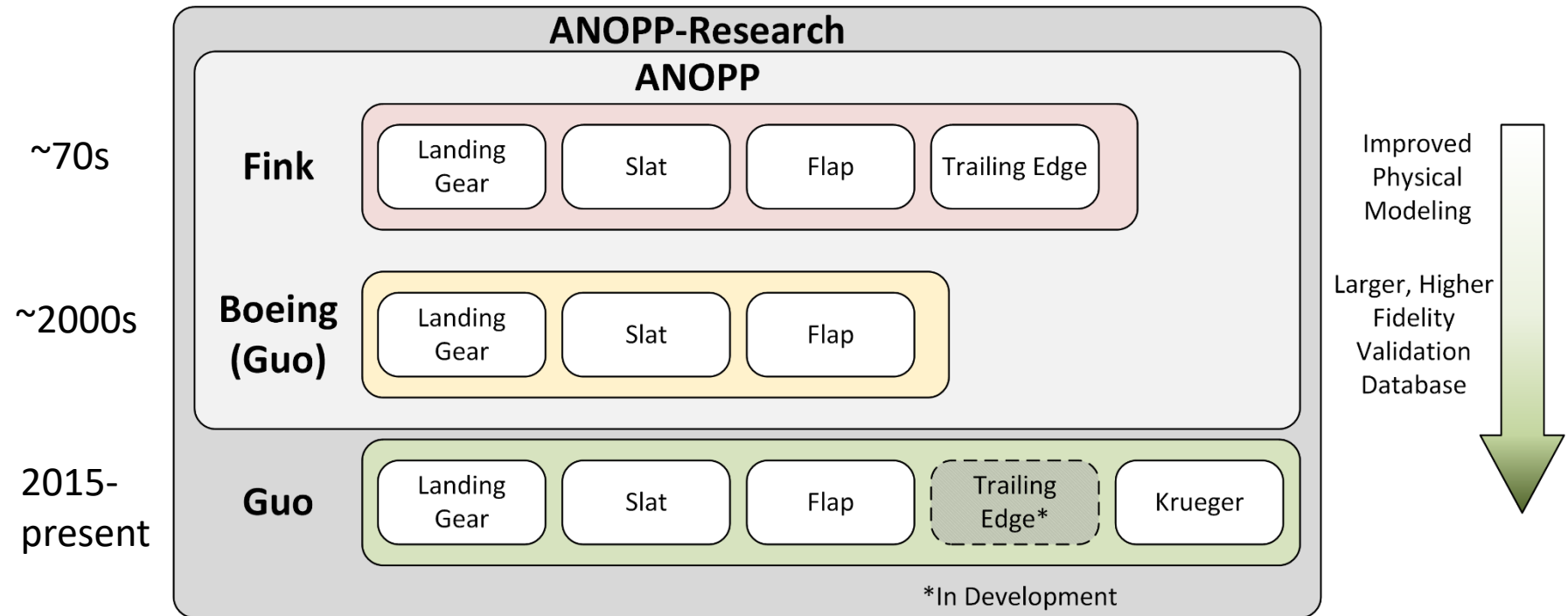
Can be done with PAA effects,  
or with multiple technologies  
for multiple sources



# Including Technologies and PAA Effects



# ANOPP Airframe Noise Prediction Methods



## Overview of the 3<sup>rd</sup> 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



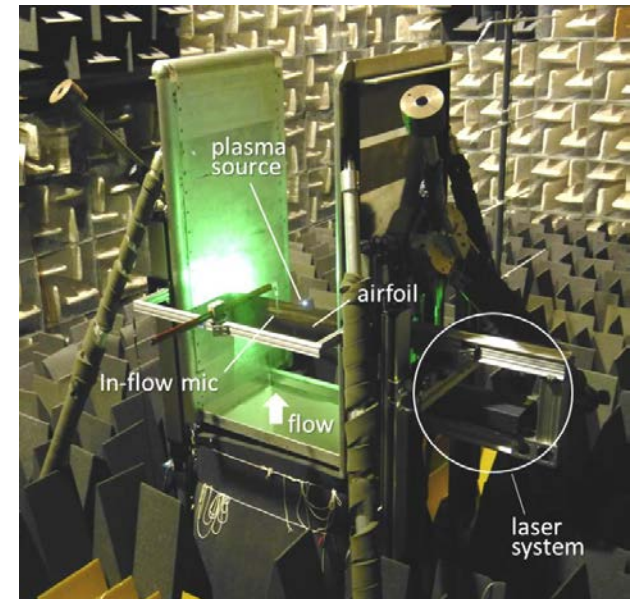
N2A HWB 14x22

Series of Canonical Geometries:  
plate, sphere and cylinder

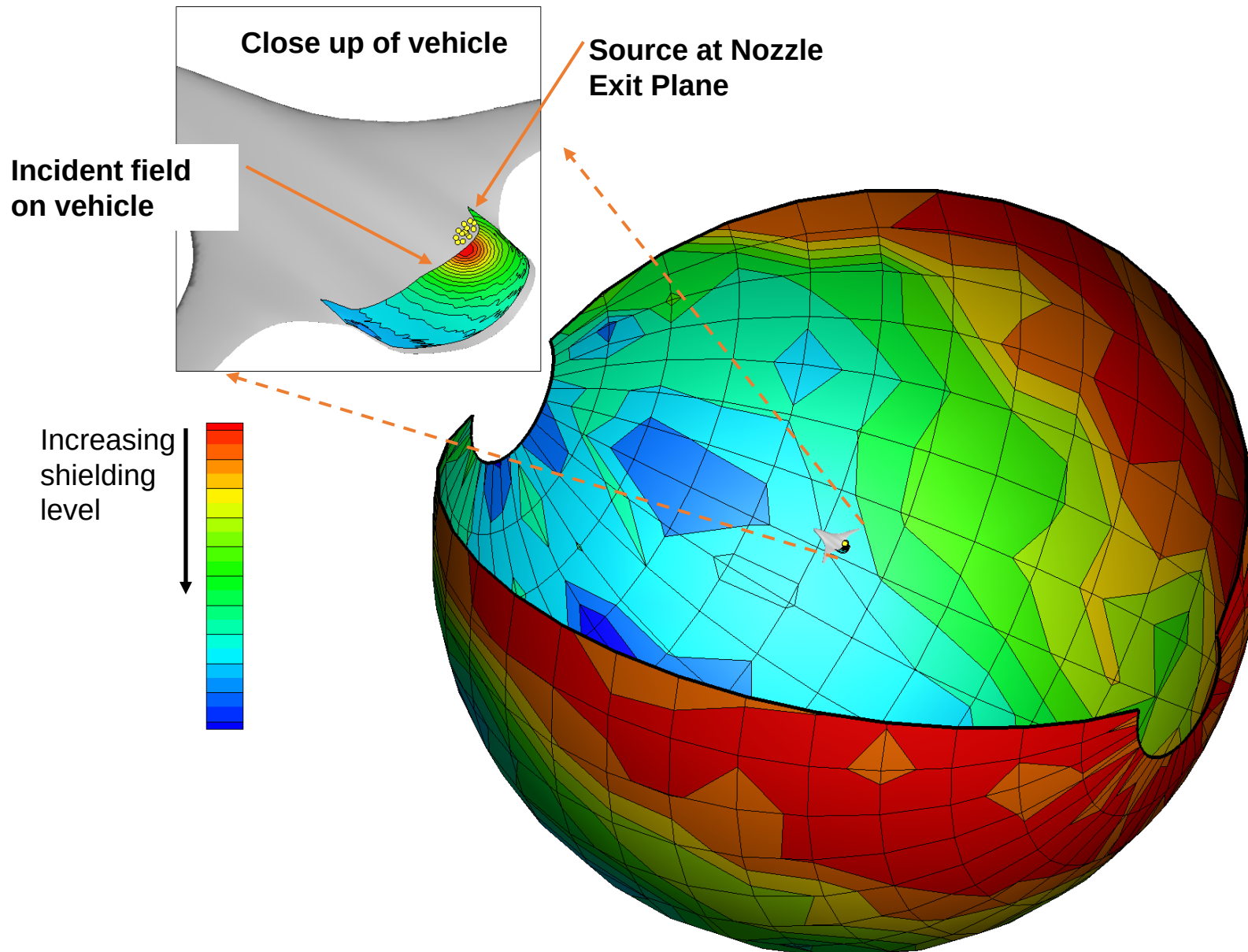
QFF NACA 0012  
Spark Shielding (part  
of NATO AVT-233)



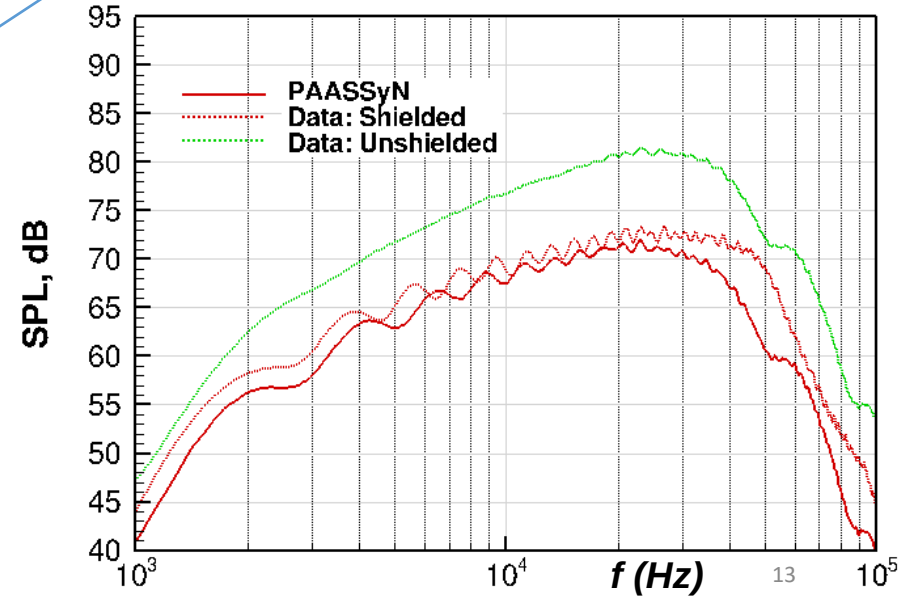
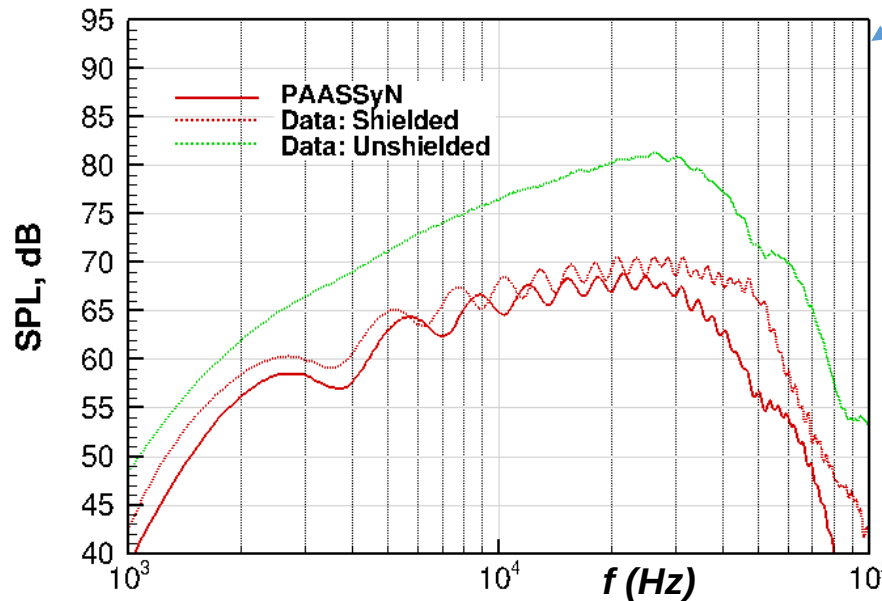
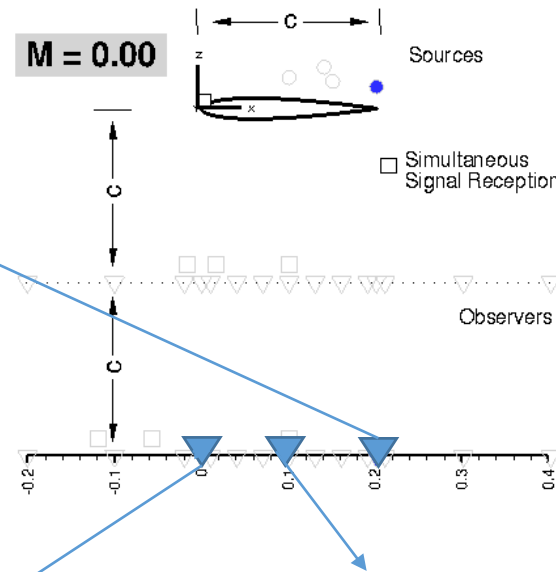
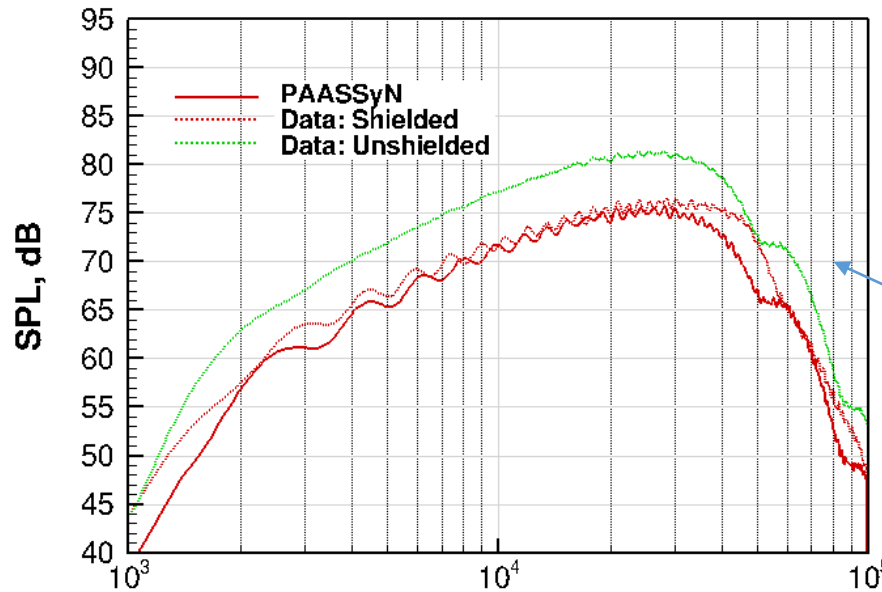
Boeing/NASA  
Series of PAA  
LSAF Experiments



# PAASSyN-K Prediction of N2A HWB Shielding



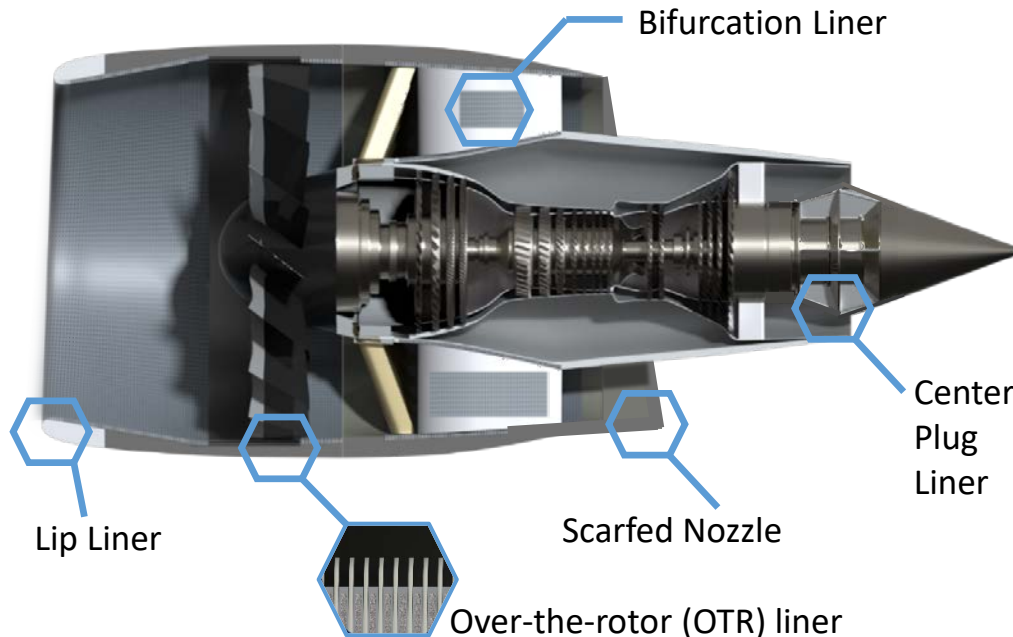
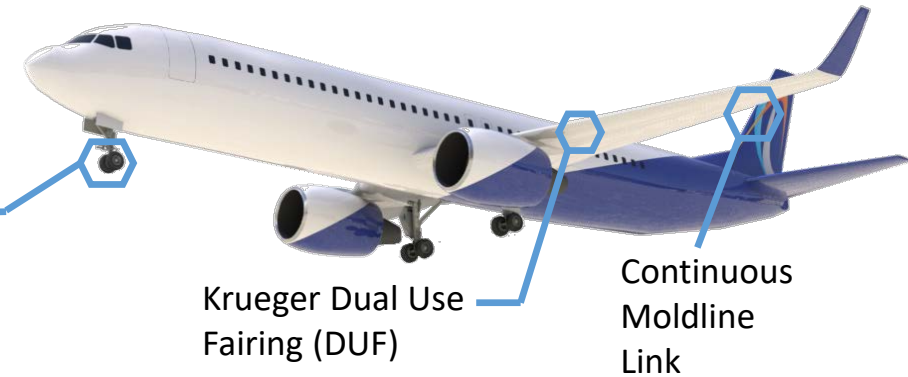
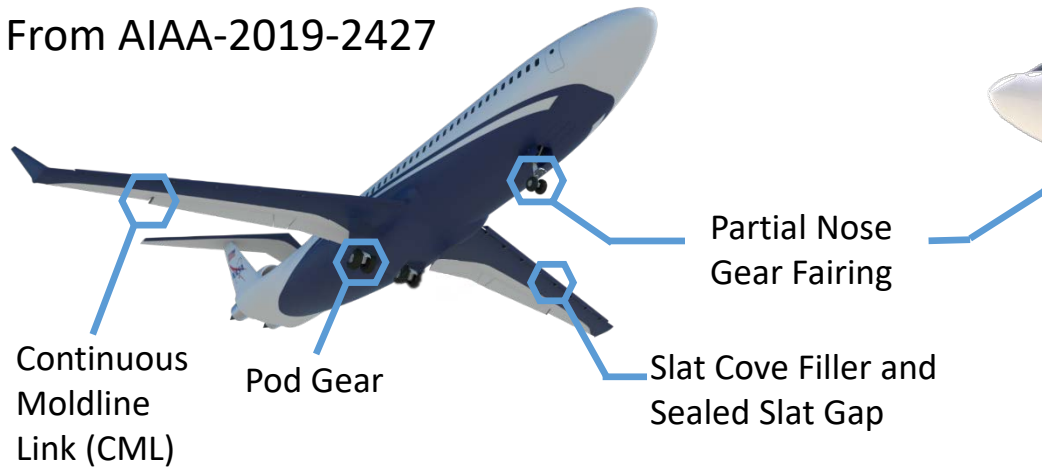
# PAASSyN-K Prediction of QFF NACA 0012 Spark Shielding



# ND8 / TW160 Technology Roadmap



From AIAA-2019-2427



## Most Effective ND8 Technologies:

| Technology   | Source          | $\Delta \text{EPNdB}$ |
|--------------|-----------------|-----------------------|
| Scarf Nozzle | Fan Propagation | -3.3                  |
| OTR          | Fan             | -1.5                  |
| Bifi Liner   | Fan             | -0.8                  |

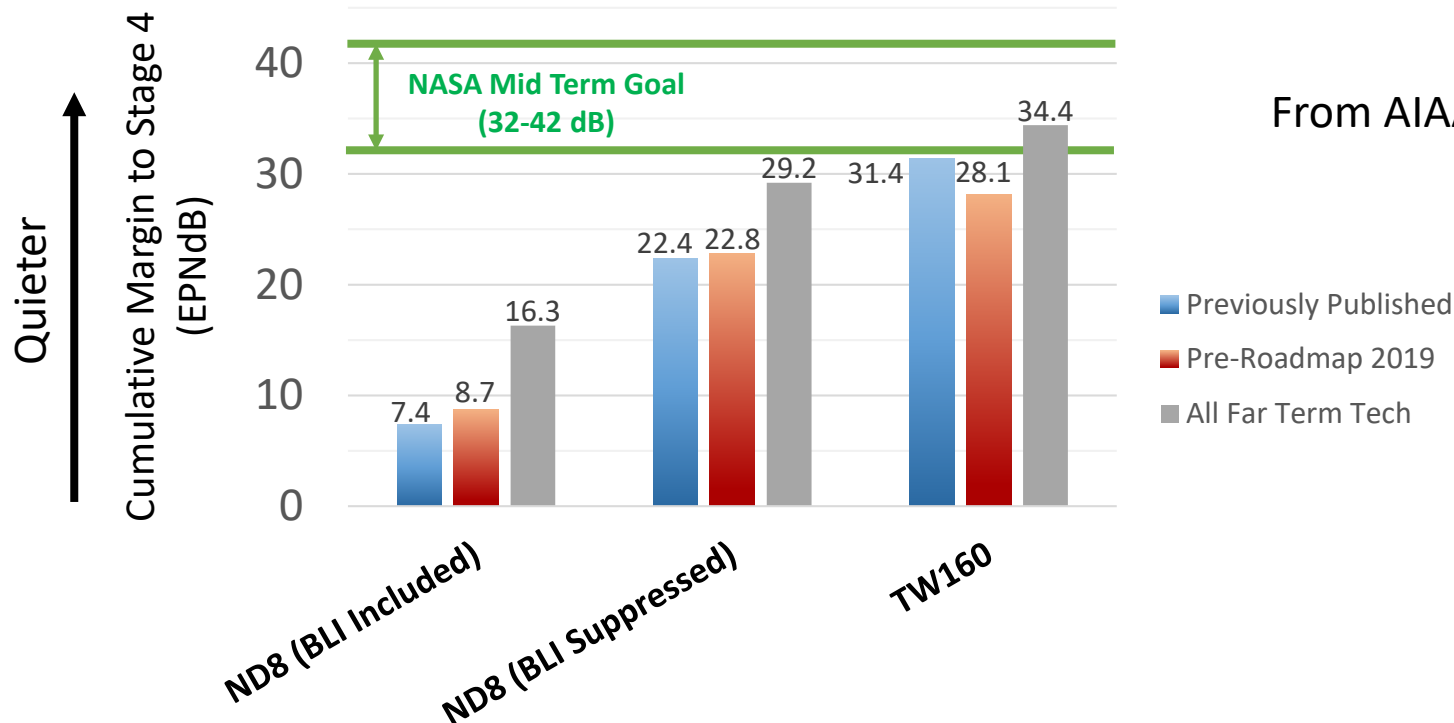
## Most Effective TW160 Technologies:

| Technology  | Source          | $\Delta \text{EPNdB}$ |
|-------------|-----------------|-----------------------|
| OTR         | Fan             | -1.5                  |
| Scarf Inlet | Fan Directivity | -1.3                  |
| Krueger DUF | Leading Edge    | -1.0                  |

# 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.



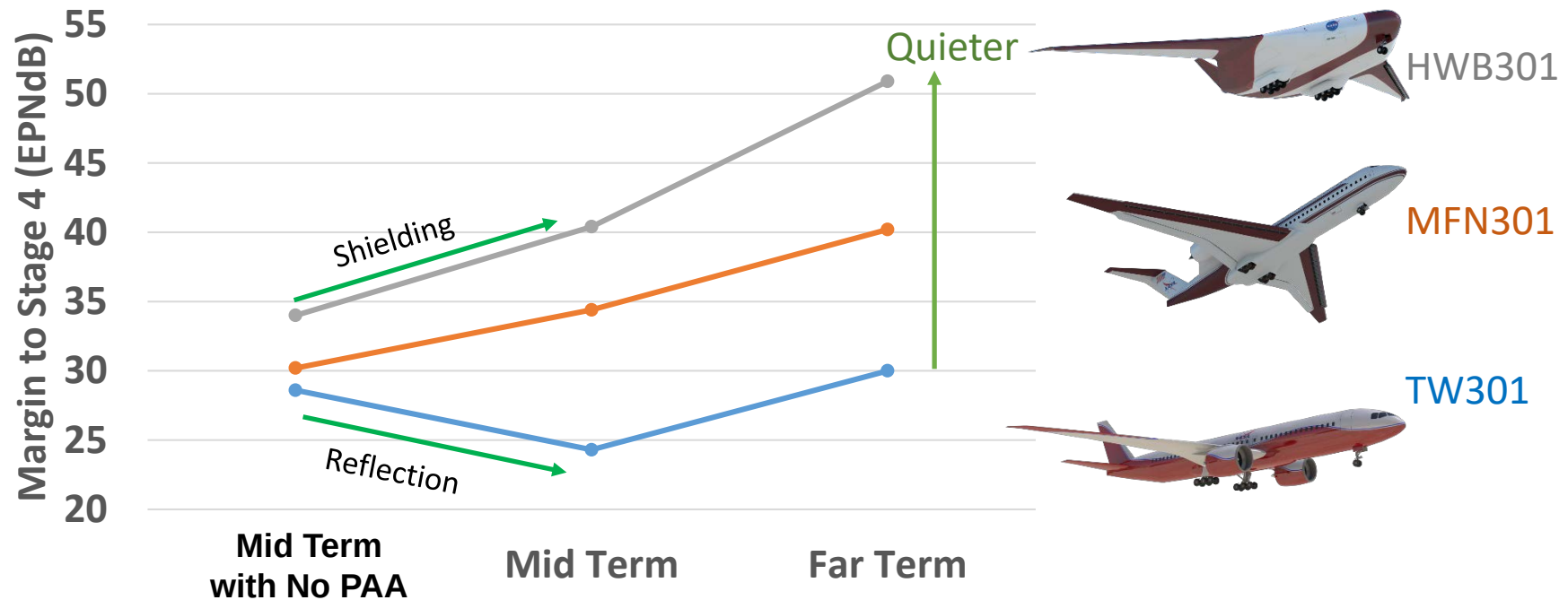
From AIAA-2019-2427

|                                 | Approach | Sideline | Cutback | Total |
|---------------------------------|----------|----------|---------|-------|
| Pre-Roadmap BLI Penalty (EPNdB) | 3.0      | 5.6      | 5.5     | 14.1  |
| Far Term BLI Penalty (EPNdB)    | 3.0      | 5.0      | 4.9     | 12.9  |

# Configuration Change and Technology Roadmap Impact



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.

# AATT Reference Aircraft – NASA 737 MAX 8

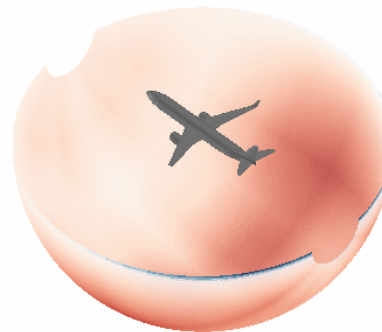


- Boeing 737 MAX 8 set to become new reference aircraft in AATT for fuel burn, emissions, and noise.
- Modeling of LEAP-1B engine undertaken at Glenn (Propulsion Systems Analysis Branch).
- Modeling of airframe and flight path done at Langley (Aeronautics Systems Analysis Branch).
- ANOPP-Research currently being used to predict noise characteristics, including PAA effects.



[www.boeing.com](http://www.boeing.com)

Fan Reflection:



1kHz

Jet Reflection:



# 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



# Propulsion Airframe Aeroacoustic (PAA) and Aircraft System Noise Flight Test on Boeing 787 ecoDemonstrator – Overview



## 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



# Propulsion Airframe Aeroacoustic (PAA) and Aircraft System Noise Flight Test on Boeing 787 ecoDemonstrator

---



## 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.

# Propulsion Airframe Aeroacoustic (PAA) and Aircraft System Noise Flight Test on Boeing 787 ecoDemonstrator



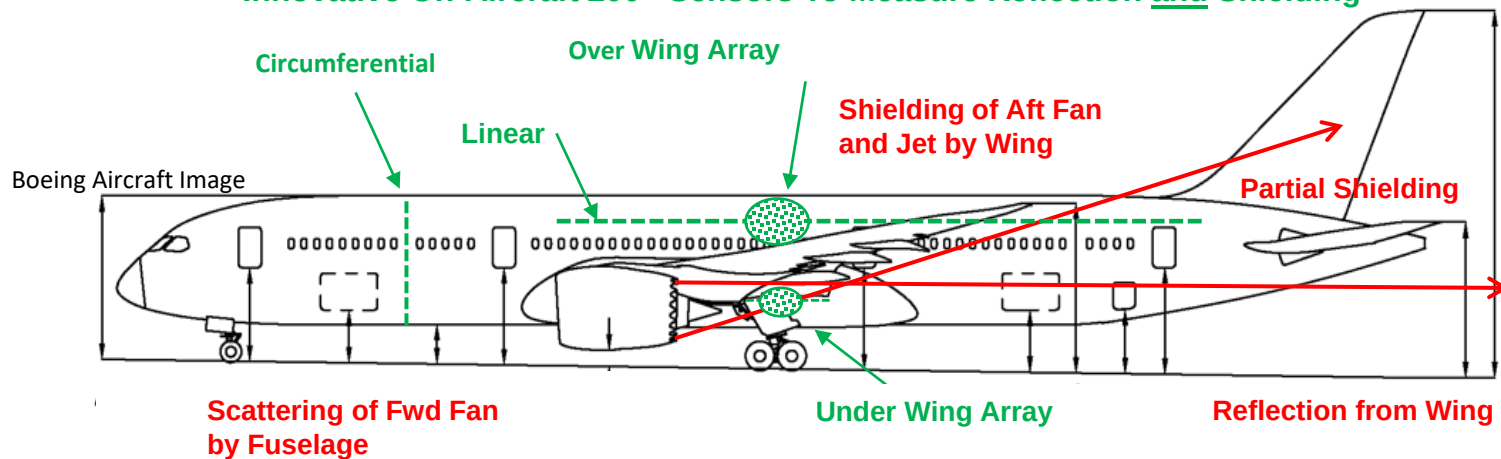
Microphones above the wing are well shielded from aft fan and jet noise:

- Quantify transition from fully lit to fully shielded zones
- Together with under wing array, quantify the attenuation due to shielding

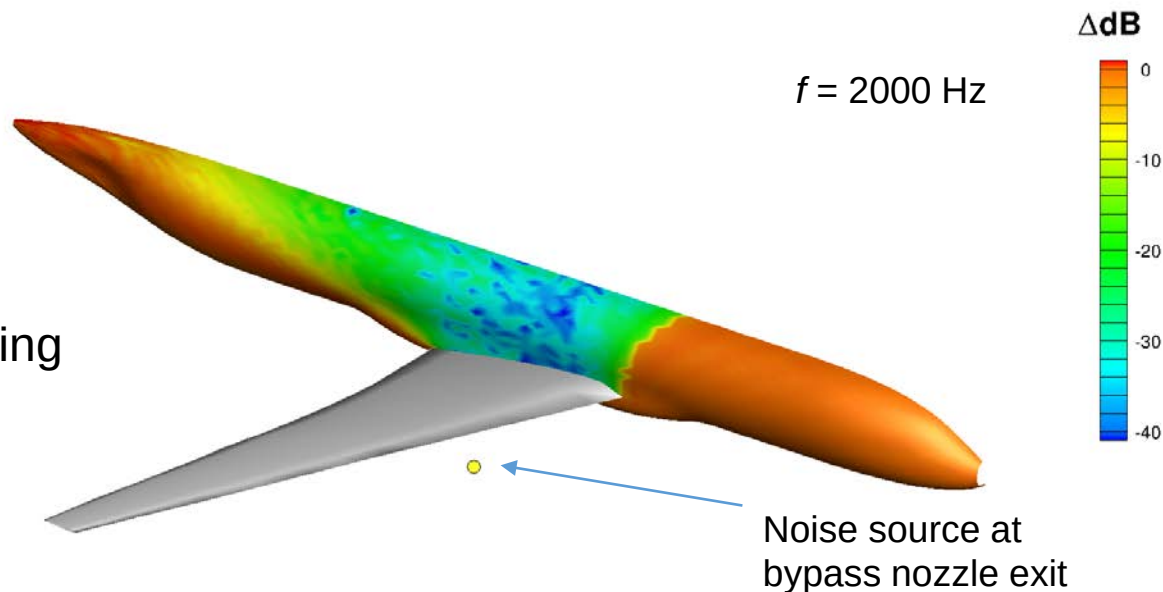
# Propulsion Airframe Aeroacoustic (PAA) and Aircraft System Noise Flight Test on Boeing 787 ecoDemonstrator



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



PAASSyN-K  
prediction of  
shielding by wing



# Propulsion Airframe Aeroacoustic (PAA) and Aircraft System Noise Flight Test on Boeing 787 ecoDemonstrator

---



## 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)



- Guo, Y.P. and Thomas, R.H., "On Aircraft Trailing Edge Noise," AIAA paper 2019-2610 (submitted to the *AIAA Journal*)
- 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 Mid-Fuselage Nacelle Subsonic Transport," AIAA 2018-3126 (accepted for publication in the *AIAA Journal of Aircraft*)
- 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., "Aircraft System Noise Prediction Uncertainty Quantification for a Hybrid Wing Body Subsonic Transport Concept," AIAA Paper 2018-3125 (submitted to the *AIAA Journal*)
- 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.

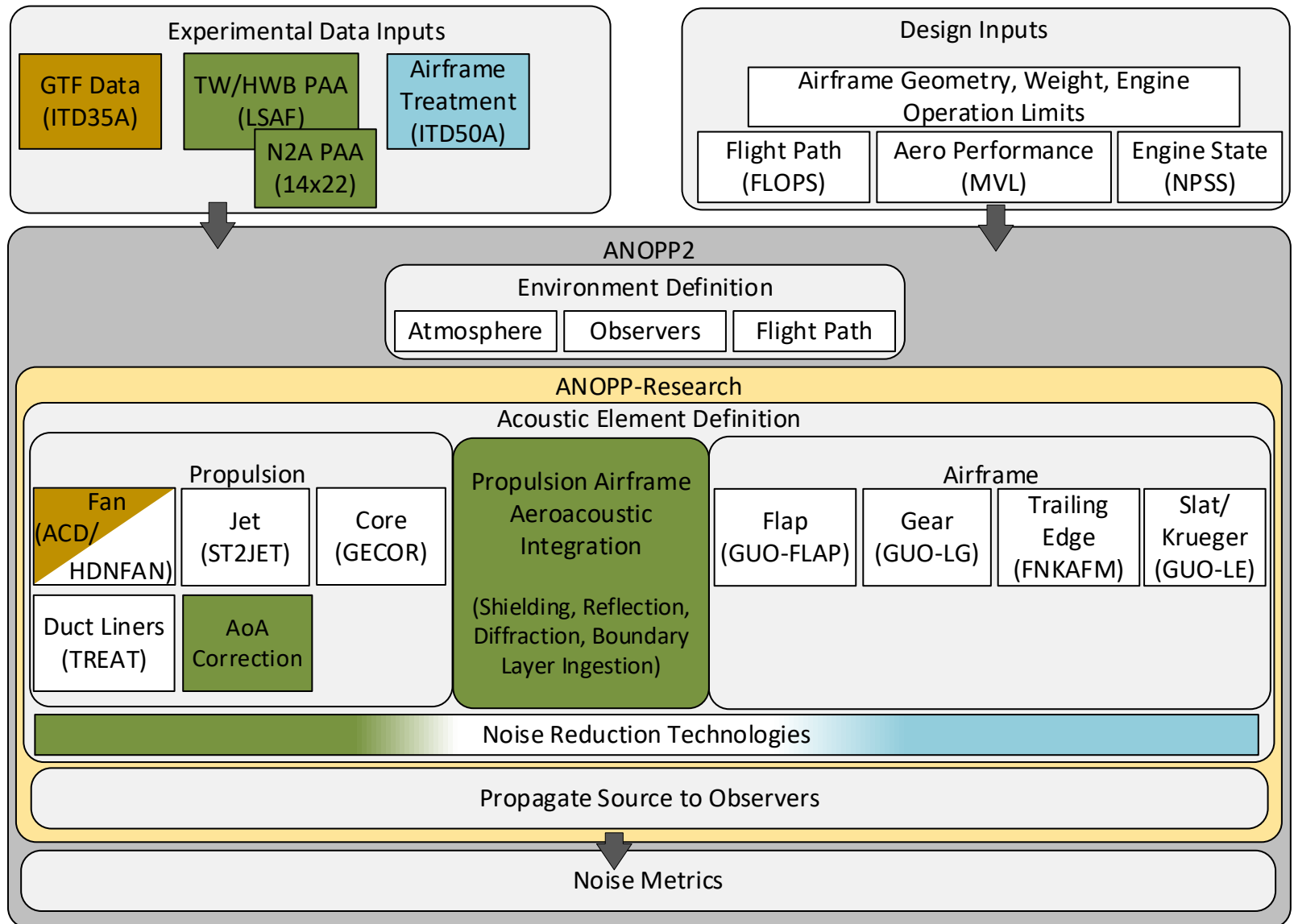
# Recent Publications (2)



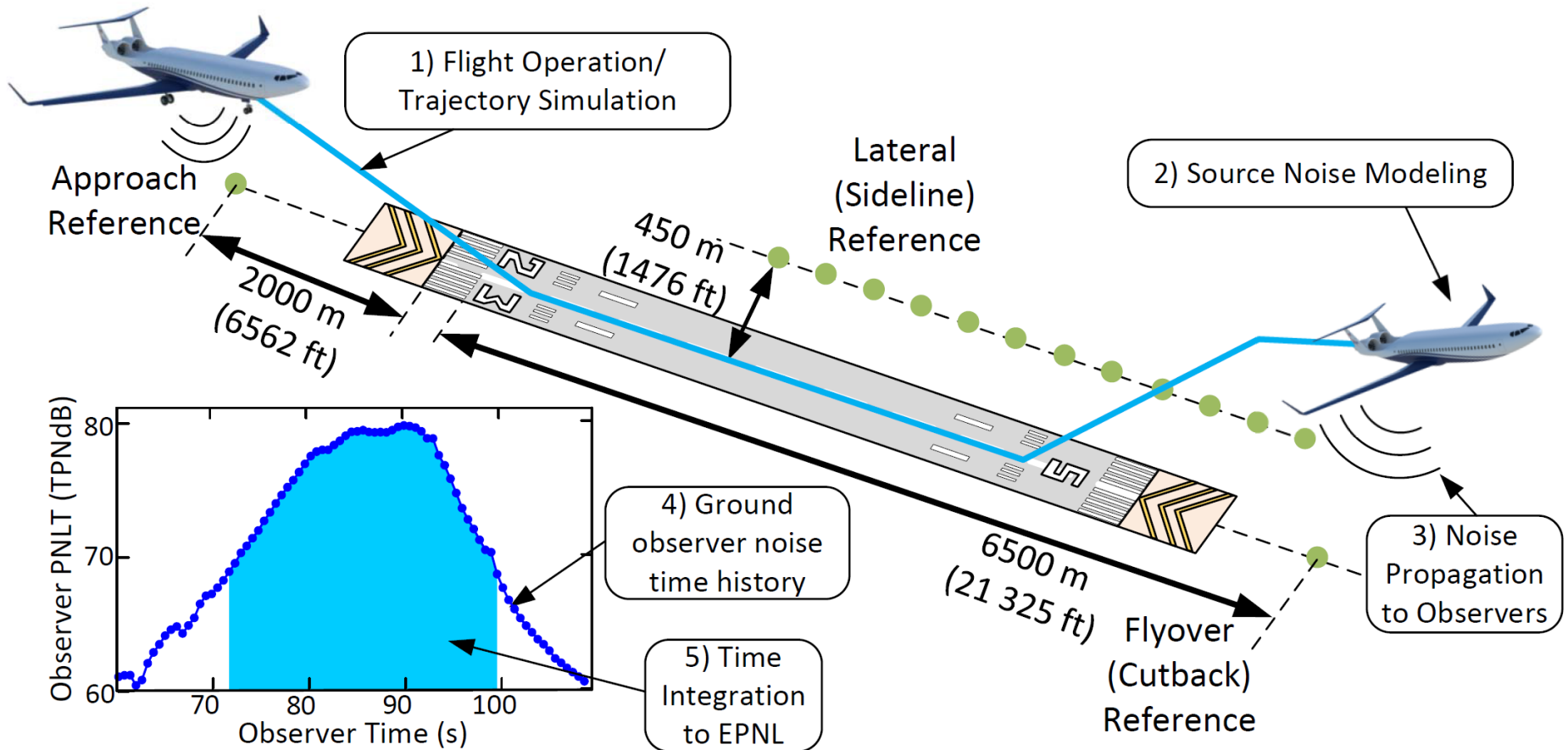
- Guo, Y. and Thomas, R.H., "Experimental Study on Open Rotor Noise Shielding by Hybrid Wing Body Aircraft," *AIAA Journal*, 2016, Vol. 54, pp. 242-253
- Guo, Y. and Thomas, R.H., "System Noise Assessment of Hybrid Wing Body Aircraft with Open Rotor Propulsion," *AIAA Journal of Aircraft*, 2015, Vol. 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



# ANOPP-Research Level Prediction Method



# Noise Prediction Framework

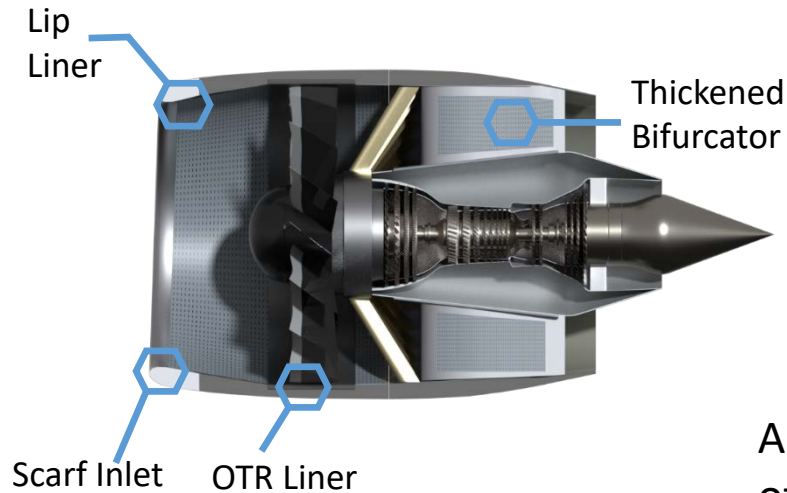
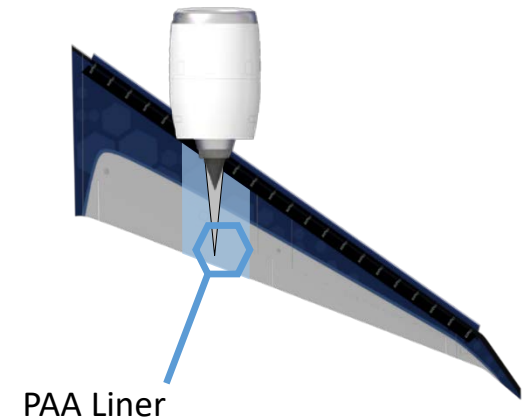
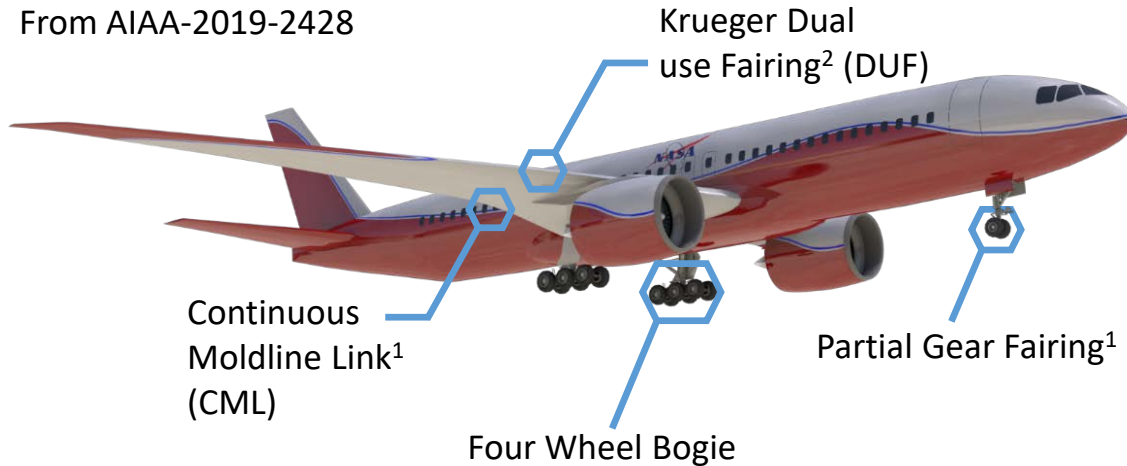


All predictions made using ANOPP-Research within the ANOPP2 framework.

# TW301 Technology Roadmap



From AIAA-2019-2428



## Most Effective TW301 Technologies:

| Technology       | Source | $\Delta EPN_{dB}$ |
|------------------|--------|-------------------|
| OTR              | Fan    | -1.4              |
| Four Wheel Bogie | Gear   | -1.0              |
| Krueger DUF      | LE     | -0.8              |

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

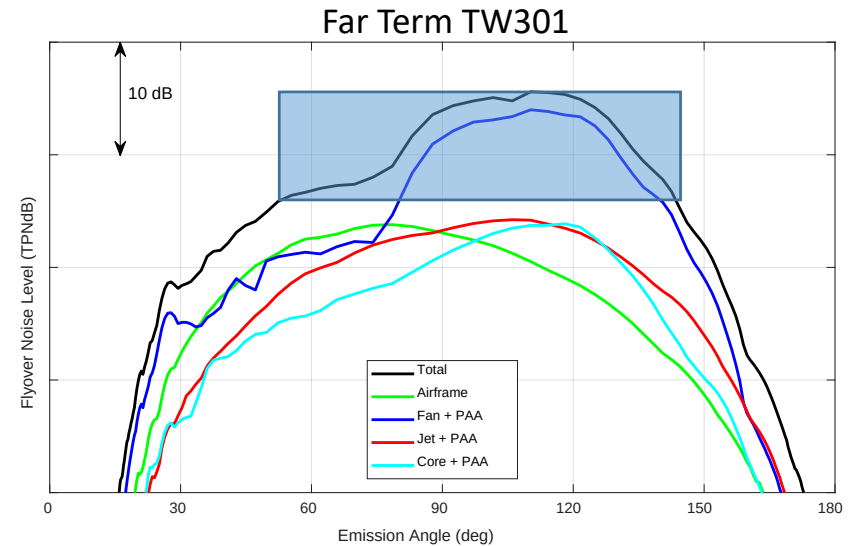
<sup>1</sup>AIAA 2018-2972

<sup>2</sup>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

| Configuration    | Margin With PAA (EPNdB) | Margin Without PAA (EPNdB) | PAA Benefit (EPNdB) | 2016 Value <sup>1</sup> (EPNdB) |
|------------------|-------------------------|----------------------------|---------------------|---------------------------------|
| TW               | 24.3                    | 28.6                       | -4.3                | -4.8                            |
| MFN <sup>2</sup> | 34.4                    | 30.2                       | 4.2                 | —                               |
| HWB <sup>3</sup> | 40.4                    | 34.0                       | 6.4                 | 7.1                             |

<sup>1</sup>AIAA-2016-0863

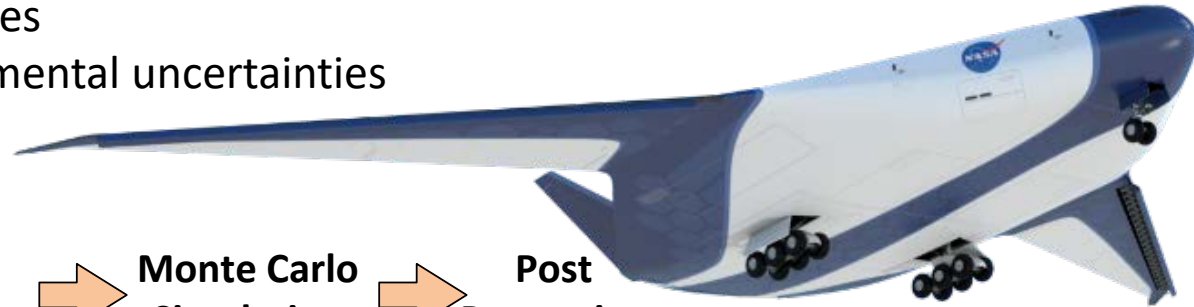
<sup>2</sup>AIAA 2018-3126

<sup>3</sup>AIAA 2018-3125

# HWB301 Uncertainty (1/2)



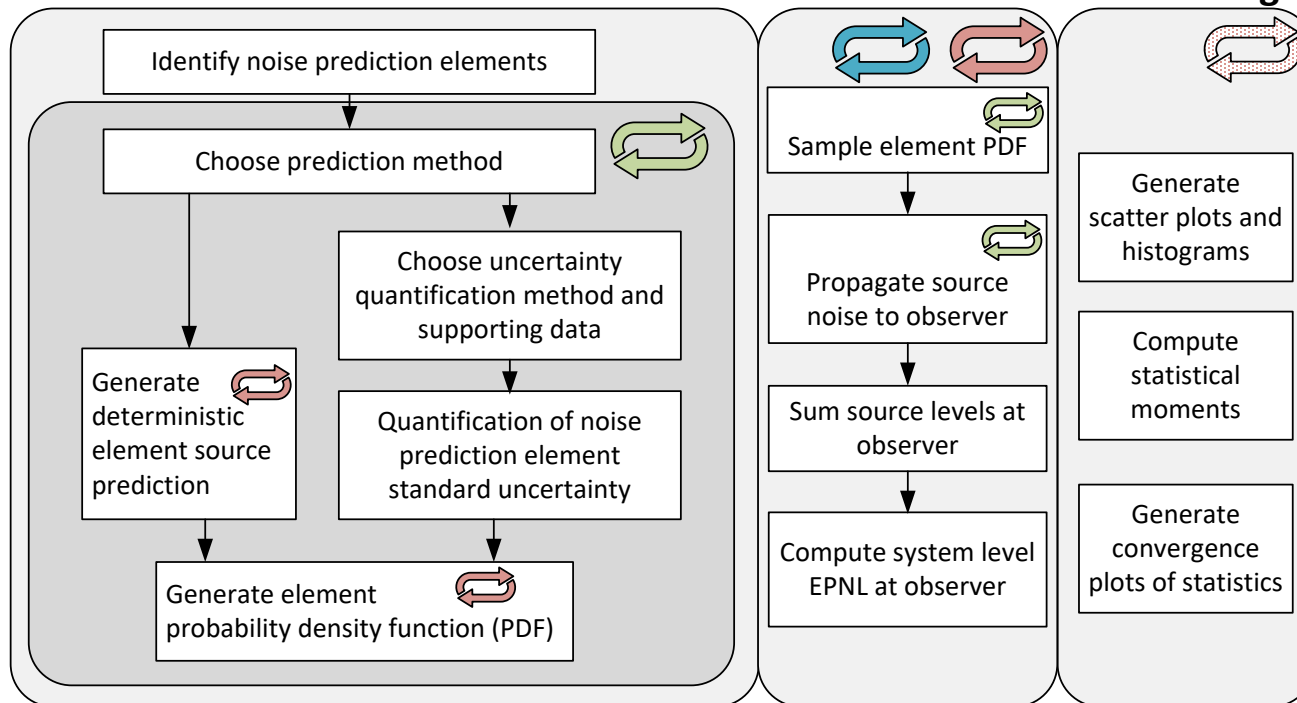
- Quantified uncertainty in certification prediction of HWB301
- Builds on results of past activities
- Improved quantification of elemental uncertainties



## Setup

## Monte Carlo Simulation

## Post Processing

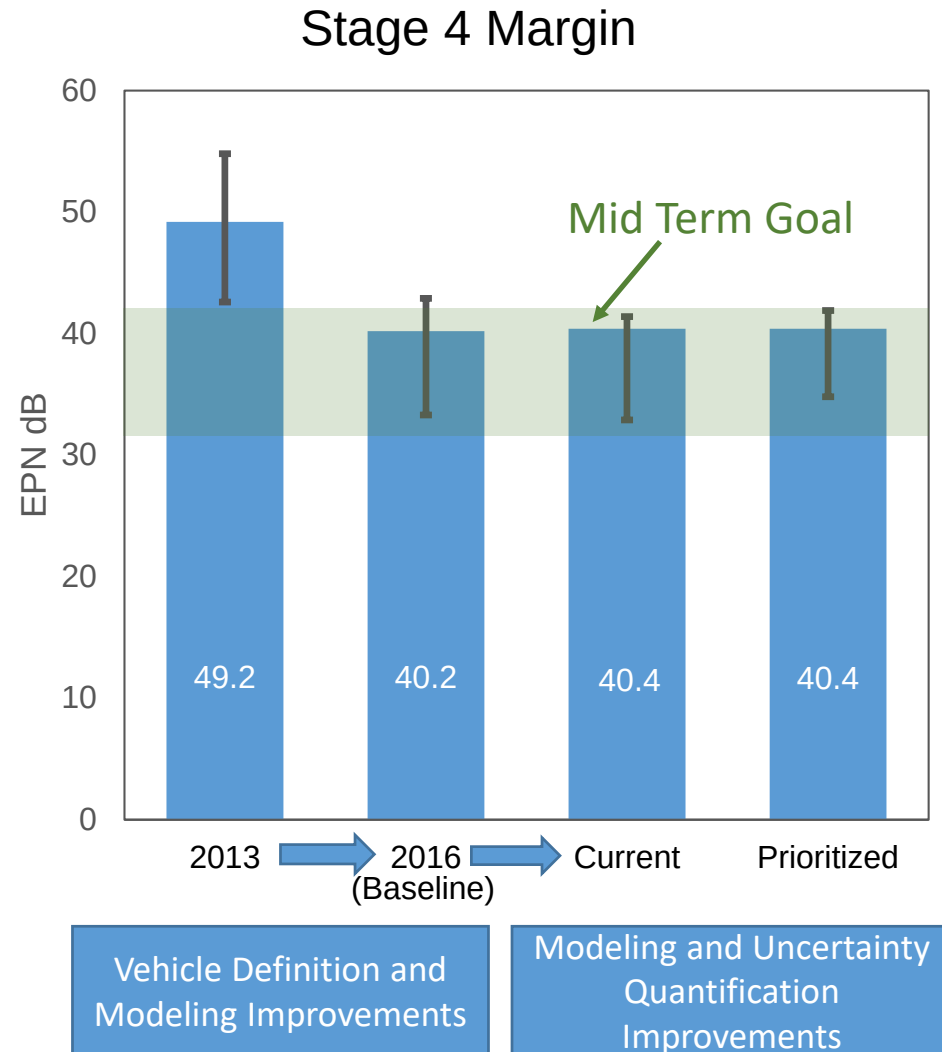


Repeat for each element Repeat for each certification condition Repeat for each certification condition and cumulative Repeat until converged

# HWB301 Uncertainty (2/2)



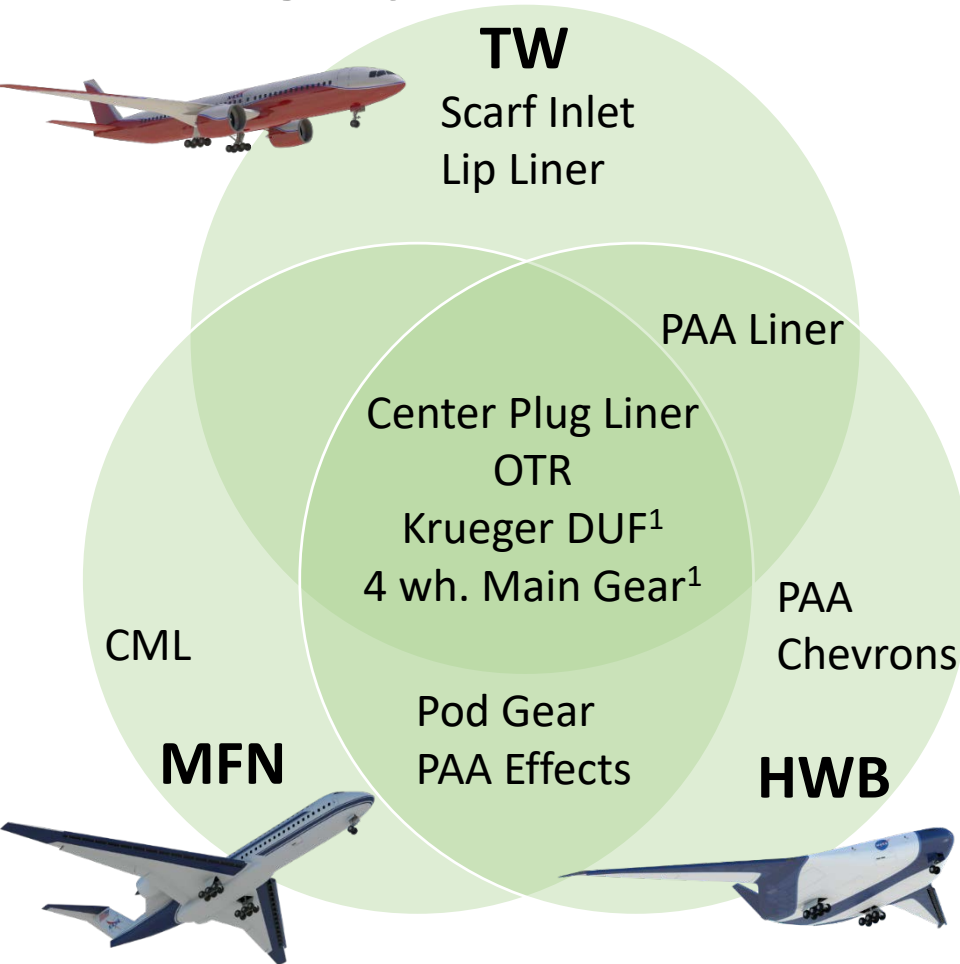
- Considerable progress reducing uncertainty
  - 2.6 EPN dB reduction from 2013-2016
  - 1.1 EPN dB reduction from 2016 to current
  - Improvements in Krueger flap prediction and jet uncertainty quantification
- Likely to reach Mid Term noise reduction goal
- Prioritized case highlights contributions of:
  - Fan with PAA effects and lining
  - Krueger flap



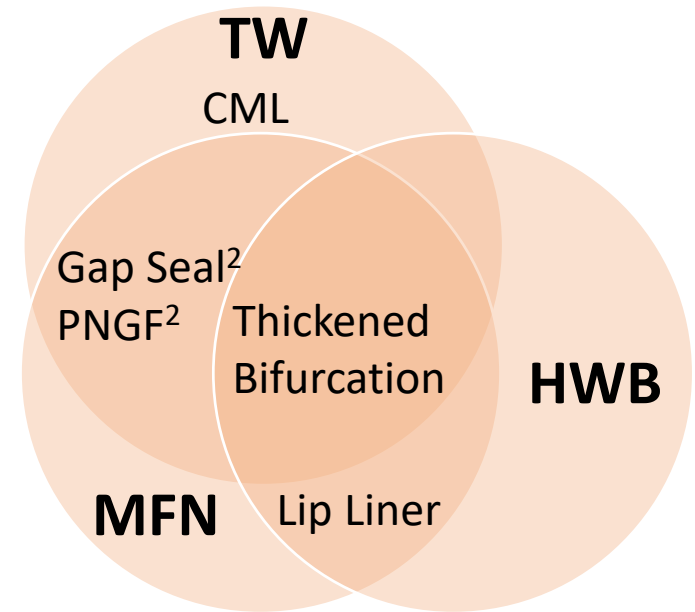
# Twin Aisle Far Term Technology Overlap



## High System Benefit



## Low System Benefit



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

<sup>1</sup> Not included in HWB roadmap

<sup>2</sup> Partial nose gear fairing (PNGF) included in Mid Term HWB technology assumptions