Realizing NASA's Vision for Low Noise Subsonic Transport Aircraft

Russell H. Thomas
NASA Langley Research Center

Yueping Guo
NEAT Consulting

Jason C. June
NASA Langley Research Center

Ian A. Clark
NASA Langley Research Center

A Keynote Presentation
Future Aircraft Design and Noise Impact
22nd Workshop of the Aeroacoustics Specialists Committee of the CEAS

Netherlands Aerospace Center, Amsterdam
September 6-7, 2018

Acknowledgments

- Aircraft Noise Reduction (ANR) Subproject of the Advanced Air Transport Technology (AATT) Project for funding this research
- John Rawls and Stuart Pope for contributions to the Aircraft System Noise and PAA Team
- ANOPP2 Team, NASA Langley Aeroacoustics Branch, Dr. Leonard Lopes, Lead
- NASA Glenn Propulsion Systems Analysis Branch and the NASA Langley Aeronautics Systems Analysis Branch

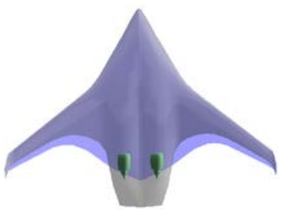
Outline

- Background and Motivation
- Critical Role of Favorable Propulsion Airframe Aeroacoustic Effects
- Hybrid Wing Body (HWB) Noise Reduction Potential
- Mid-Fuselage Nacelle (MFN) Noise Reduction Potential
- X-Plane Demonstrators for Acoustic Objectives
- Remarks on Future Low Noise Aircraft Prediction
- Summary

Background

1999			2002	2003		2005		2007		2009	2010		2012	2013	2014	2015	2016	2017

Begin focus on noise prediction of unconventional aircraft and on low noise HWB research

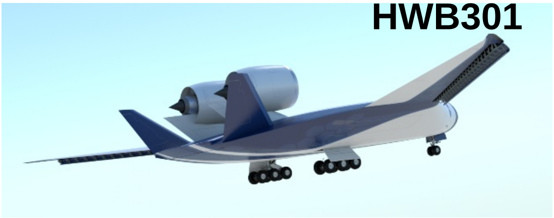


NASA Concept ~2003

Significant system noise prediction milestones

40.3 40.2 40.4 41.7
Cum EPNL dB

HWB301



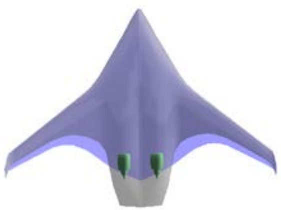
In 1999, NASA's Aircraft Noise Prediction Program (ANOPP) was inadequate for some key challenges of unconventional aircraft:

- Low pressure ratio and geared fan
- High pressure ratio core
- High lift systems (Krueger flap)
- Propulsion Airframe Aeroacoustic (PAA) Interactions: the aeroacoustic effects associated with integration including:
  - Integration effects on inlet and exhaust systems
  - Flow interaction and acoustic scattering effects
  - Configurations from conventional to revolutionary

Background

1999 | 2002 | 2003 | 2005 | 2007 | 2009 | 2010 | 2012 | 2013 | 2014 | 2015 | 2016 | 2017

Begin focus on noise prediction of unconventional aircraft and on low noise HWB research

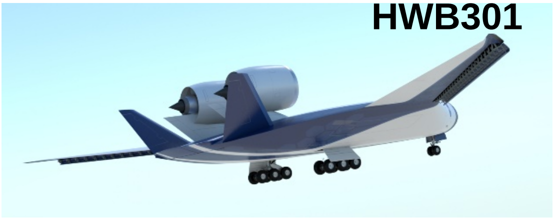


NASA Concept ~2003

Significant system noise prediction milestones

40.3 40.2 40.4 41.7
Cum EPNL dB

HWB301



In 1999, NASA's Aircraft Noise Prediction Program (ANOPP) was inadequate for some key challenges of unconventional aircraft:

- Low pressure ratio and geared fan
- High pressure ratio core
- High lift systems (Krueger flap)
- Propulsion Airframe Aeroacoustic (PAA) Interactions: the aeroacoustic effects associated with integration including:
  - Integration effects on inlet and exhaust systems
  - Flow interaction and acoustic scattering effects
  - Configurations from conventional to revolutionary

Development in Major Areas:

ANOPP2
Lopes, L.V. and Burley, C.L., "ANOPP2 Users Manual," NASA/TM-2016-219342

ANOPP
Sources and PAA Interaction Prediction, System Noise Process

Component and Integrated Technology and Experiments

MDAO of Aircraft Concepts

NASA Aeronautics Goals

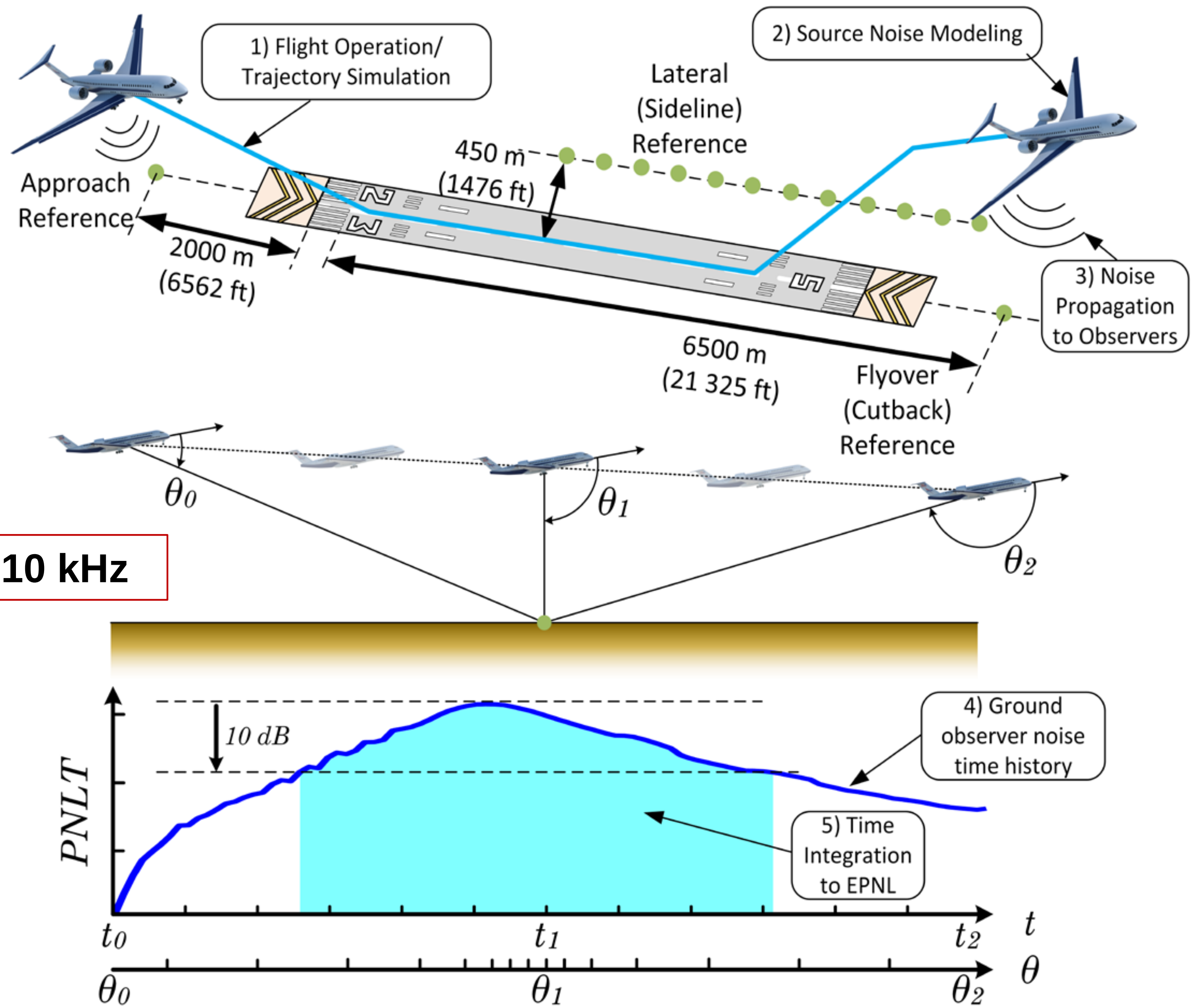
NASA Subsonic Transport Metrics

v2016.1

TECHNOLOGY BENEFITS	TECHNOLOGY GENERATIONS (Technology Readiness Level = 5-6)		
	Near Term 2015-2025	**Mid Term** 2025-2035	**Far Term** beyond 2035
Noise (cum below Stage 4)	**22 - 32 dB**	**32 - 42 dB**	**42 - 52 dB**
LTO NOx Emissions (below CAEP 6)	**70 - 75%**	**80%**	**> 80%**
Cruise NOx Emissions (rel. to 2005 best in class)	**65 - 70%**	**80%**	**> 80%**
Aircraft Fuel/Energy Consumption (rel. to 2005 best in class)	**40 - 50%**	**50 - 60%**	**60 - 80%**

Evolutionary Revolutionary Transformational

Certification Conditions for Aircraft System Noise



50 Hz to 10 kHz

Continuing Development of the NASA *Research* Level Aircraft System Noise Prediction Process

ANOPP2

Aircraft Flight Definition

ANOPP:
- **Jet**
- **Core**
- **Fan**
- **Duct Treatment**
- **Landing gear**
- **Flap-side-edge**
- **Leading edge (Krueger or Slat)**
- **Trailing edge**

PAA Effects: engine noise installation effects (shielding, diffraction, reflection)

Noise Reduction Technology: predicted suppressions based on methods or best available information

Propagation & Noise Metrics

EPNL predicted at locations defined by Code of Federal Regulations (CFR) Title 14 Part 36

Aircraft, Engine and Flight Path from NASA System Analysis Team

Best Available Methods, Modified Methods or Use of Extensive Databases for Fan Source, Engine and Airframe Noise Reduction Technologies

New Generation of System Level Physics Based Airframe Noise Models for:
Landing Gear, Flap, Slat, and Krueger

Propulsion Airframe Aeroacoustic (PAA) Effects from:
- Extensive Databases for Acoustic and Flow Interactions
- Prediction Methods in Development
- Boundary Layer Ingestion Noise Impact Model

Continuing Development of the NASA *Research* Level Aircraft System Noise Prediction Process

ANOPP2

Aircraft Flight Definition

Aircraft, Engine and Flight Path from NASA System Analysis Team

ANOPP:
- **Jet**
- **Core**
- **Fan**
- **Duct Treatment**
- **Landing gear**
- **Flap-side-edge**
- **Leading edge (Krueger or Slat)**
- **Trailing edge**

PAA Effects: engine noise installation effects (shielding, diffraction, reflection)

Noise Reduction Technology: predicted suppressions based on methods or best available information

Best Available Methods, Modified Methods or Use of Extensive Databases for Fan Source, Engine and Airframe Noise Reduction Technologies

New Generation of System Level Physics Based Airframe Noise Models for:
- Landing Gear, Flap, Slat, and Krueger

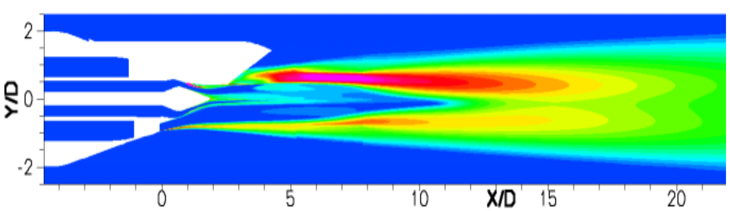
Propulsion Airframe Aeroacoustic (PAA) Effects from:
- Extensive Databases for Acoustic and Flow Interactions
- Prediction Methods in Development
- Boundary Layer Ingestion Noise Impact Model

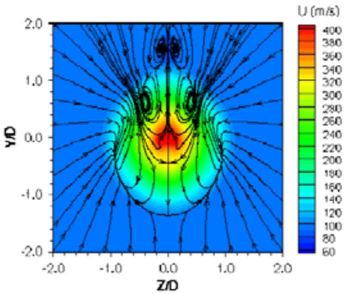
Propagation & Noise Metrics

EPNL predicted at locations defined by Code of Federal Regulations (CFR) Title 14 Part 36

Only noise prediction method used unmodified from the *Released* version of ANOPP

PAA Chevron with Partner Boeing on QTD2: Concept to Flight in Two Years 2003-2005





Exploration of Possible PAA Concepts with QTD2 Partners (5/03 – 4/04)

Extensive PAA CFD/Prediction Work (10/03 – 8/05)

(AIAA 05-3083, 06-2436)

PAA Experiment at Boeing LSAF 9/04

PAA Effects and Noise Reduction Technologies Studied

AIAA 06-2467, 06-2434, 06-2435

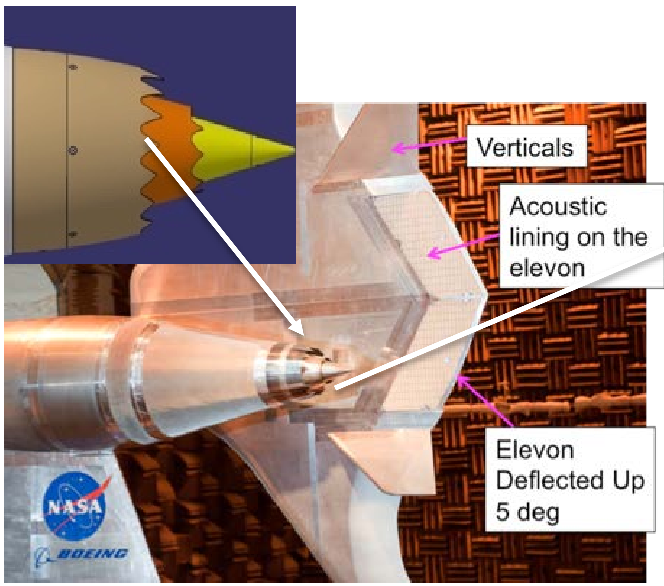
PAA on QTD2 – 8/05

- PAA T-Fan Chevron Nozzle
- PAA Effects Instrumentation

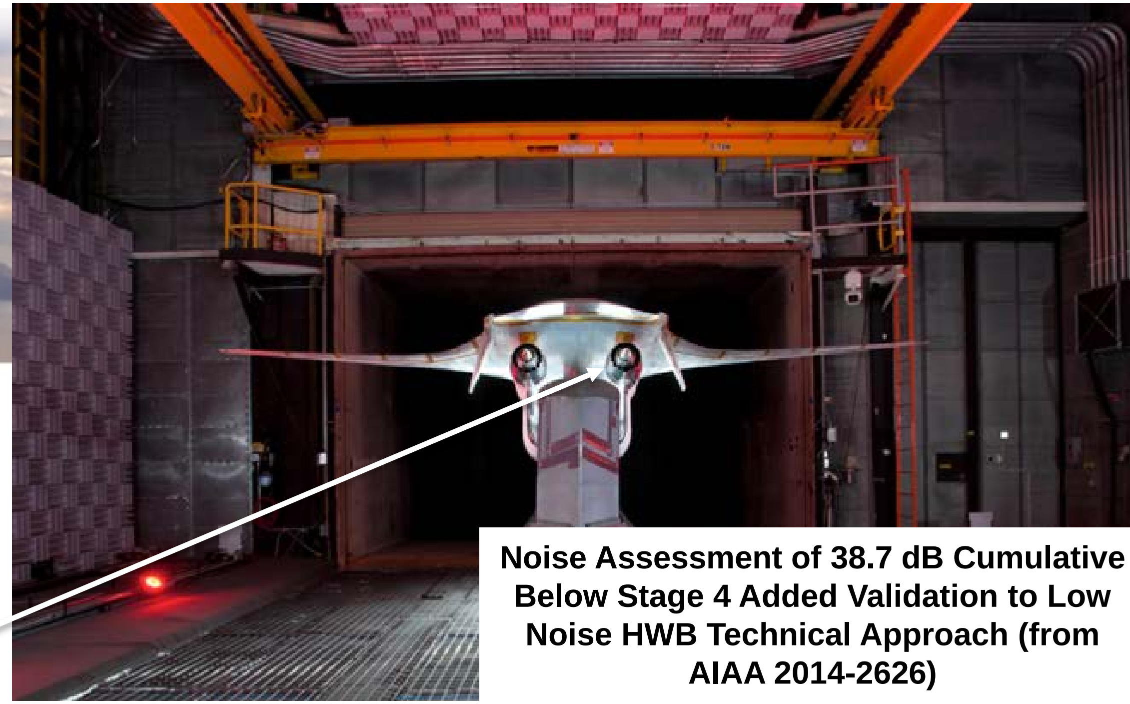
AIAA 06-2438, 06-2439

2004-2013: PAA on Hybrid Wing Body (HWB) Concept

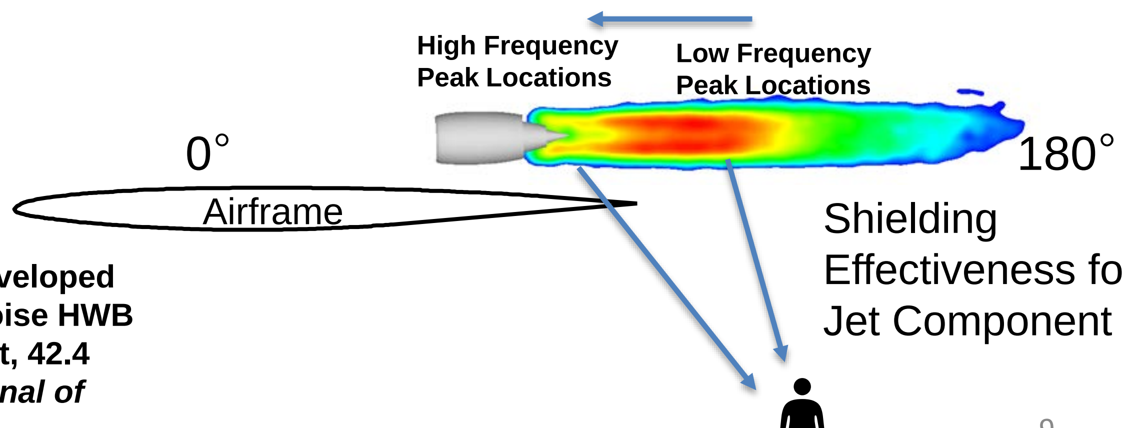
Boeing Designed N2A Concept



Series of NASA/Boeing PAA experiments developed PAA database, technologies, and first Low Noise HWB Technical Roadmap and Noise Assessment, 42.4 EPNLdB below Stage 4 (*International Journal of Aeroacoustics*, Vol 11 (3+4), 2012)



Noise Assessment of 38.7 dB Cumulative Below Stage 4 Added Validation to Low Noise HWB Technical Approach (from AIAA 2014-2626)



Mid Term Technology: Large Twin Aisle 301 Pax Class Results

Nickol, C.L. and Haller, W.J., "Assessment of the Performance Potential of Advanced Subsonic Transport Concepts for NASA's Environmentally Responsible Aviation Project," AIAA-2016-1030.
Thomas, R.H., Burley, C.L., and Nickol, C.L., "Assessment of the Noise Reduction Potential of Advanced Subsonic Transport Concepts for the NASA Environmentally Responsible Aviation Project," AIAA-2016-0863.

Tube and Wing
T+W301-GTF
22.1 EPNLdB cumulative below Stage 4

Mid-Fuselage Nacelle
MFN301-GTF
33.9 EPNLdB cumulative below Stage 4

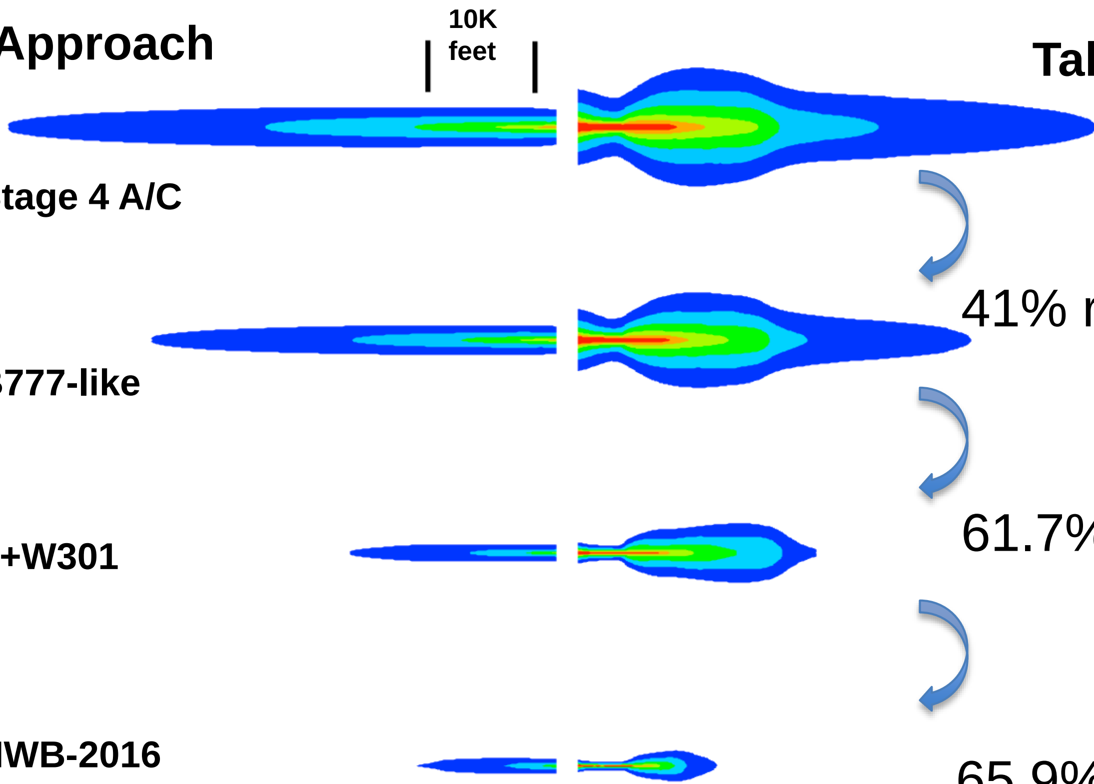
Hybrid Wing Body
HWB301-GTF
40.3 EPNLdB cumulative below Stage 4

- Aircraft with the most favorable PAA effects are the ones able to achieve the Mid Term goal
- Configuration change is required to achieve low noise levels

Aircraft Configuration Impact on Ground Contour Area

From AIAA-2017-3194

Approach **Takeoff**



Stage 4 A/C

41% reduction

B777-like

61.7% reduction

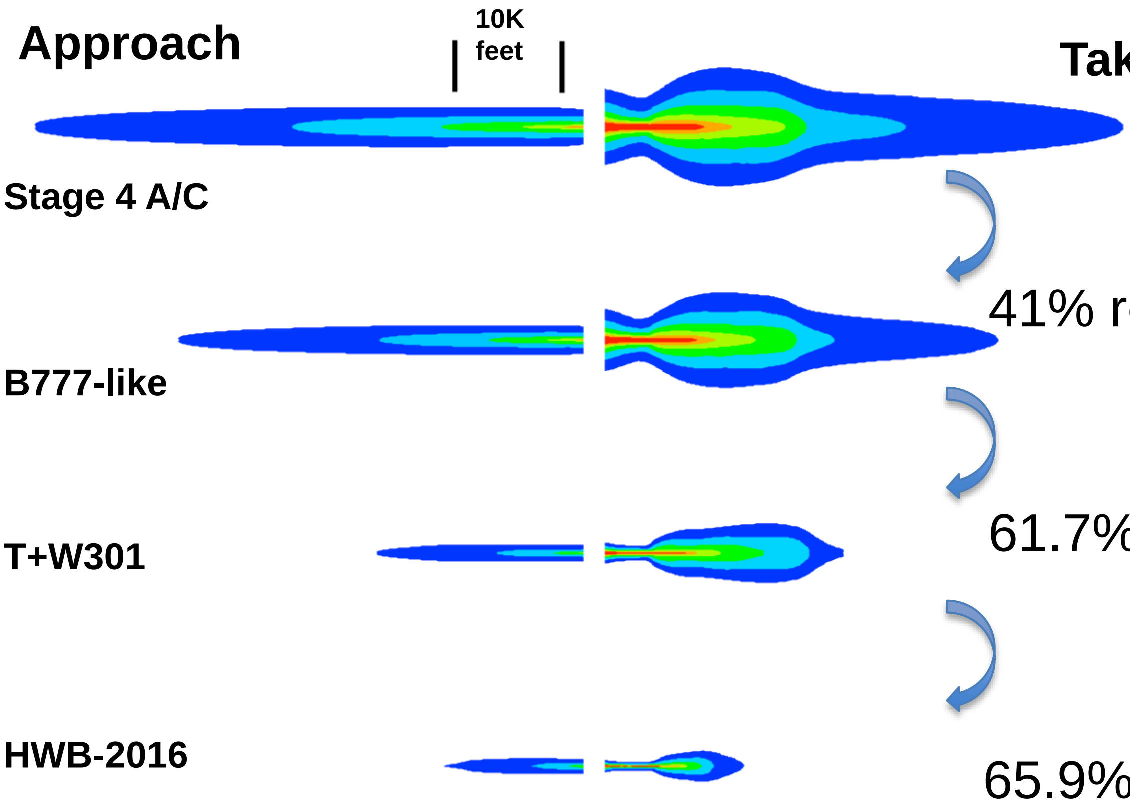
T+W301

65.9% reduction

HWB-2016

Aircraft Configuration Impact on Ground Contour Area

From AIAA-2017-3194



41% reduction

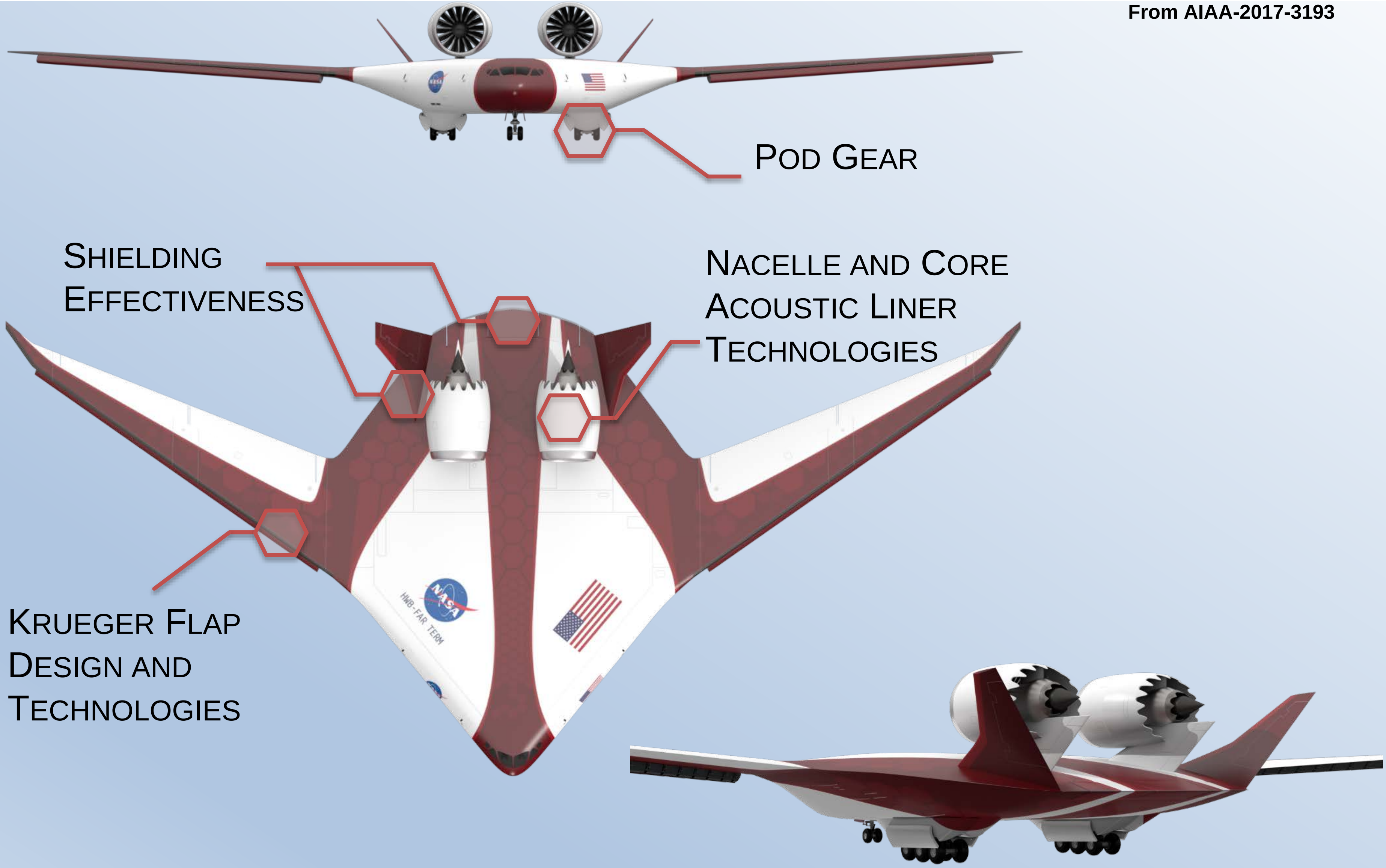
61.7% reduction

65.9% reduction

- T+W301 and HWB-2016 are of equal technology levels except for aircraft configuration
- About 12 of the 17.7 EPNL dB total difference is due to PAA effects

HWB Far Term Technology Roadmap

From AIAA-2017-3193



HWB Far Term Roadmap One Off Results

From AIAA-2017-3193

One technology at a time from the final configuration is the most effective way of measuring impact at the system level on equivalent basis

Description	Cumulative below Stage 4 with one technology "off"	One-off cumulative noise reduction due to technology
Lip Liner	50.9	0.0
Center Plug Liner	49.7	1.3
Over-the-Rotor Treatment	50.6	0.4
Center Elevon PAA Liner	50.4	0.5
Increase Upper Bifurcation Liner	50.9	0.0
PAA Chevrons	50.0	0.9
Fan Noise Shielding Effectiveness via Duct Liner	50.5	0.4
Fan Noise Shielding Effectiveness via PAA Design	50.6	0.3
Trailing Edge Treatment	50.5	0.4
Krueger Flap Bracket Alignment	48.4	2.6
Krueger Flap Cove Filler	49.8	1.1
Pod Gear	47.7	3.3
Aircraft cumulative margin to Stage 4, with all technologies	**50.9**	

Nacelle and Core Liner Technologies **1.7 dB**

Shielding Effectiveness Technologies and Design **2.5 dB**

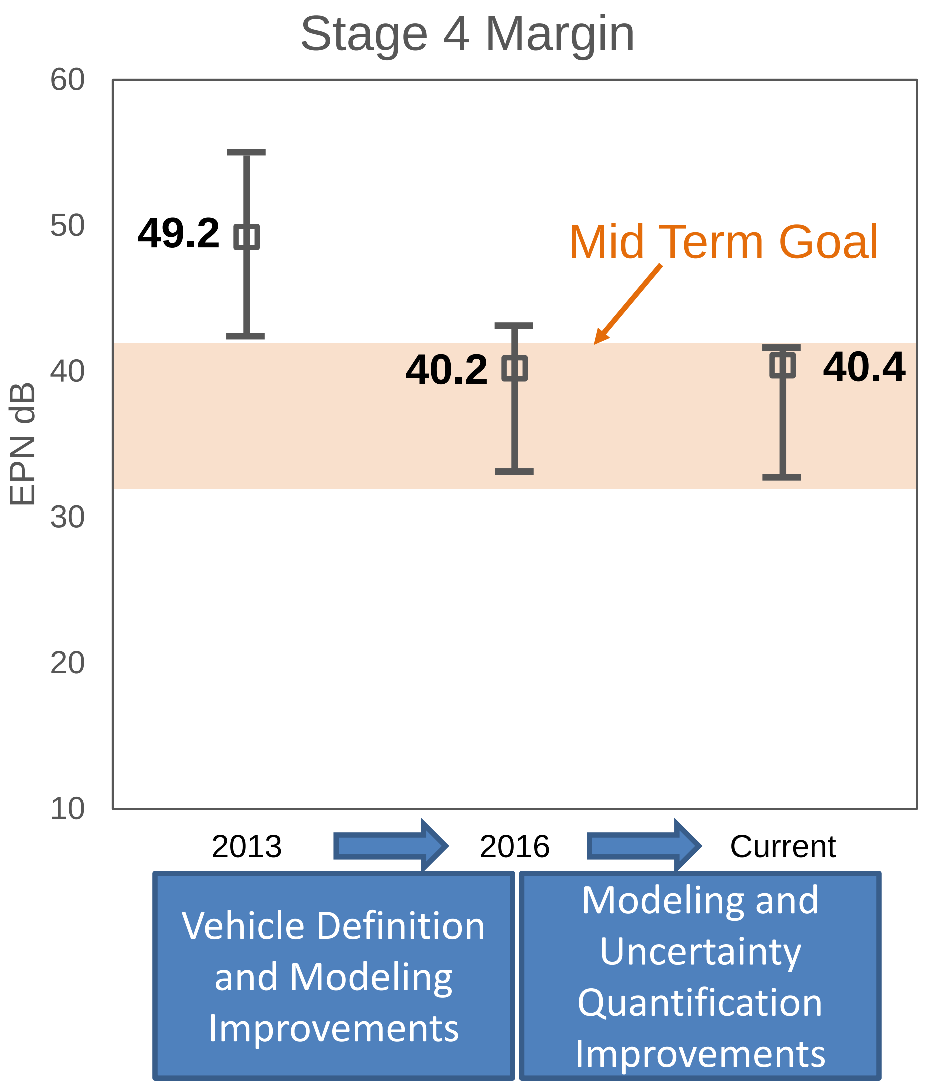
Krueger and Main Gear Technologies and Design **7.0 dB**

Uncertainty Quantification for the System Noise Prediction of the HWB

June, J.C., Thomas, R.H., and Guo, Y., “Aircraft System Noise Prediction Uncertainty Quantification for a Hybrid Wind Body Subsonic Transport Concept,” AIAA 2018-3125.

- Considerable progress over time in 95% coverage interval (CI)
- One-sided distributions increasingly important over time

Case	Standard Uncertainty	95% CI Span	Reduction
2013	3.1	12.2	–
2016	2.4	9.6	2.6
Current	2.2	8.5	1.1



Boeing Advanced Tube-and-Wing from 2013

Bonet et al., NASA CR 2013-216519

ERA-0027 Configuration assessed at 28.0 EPNL dB below St 4 with a Direct Drive BPR 13.5 Turbofan at Fan Pressure Ratio 1.6

Boeing Advanced Tube-and-Wing from 2013

Bonet et al., NASA CR 2013-216519

ERA-0027 Configuration assessed at 28.0 EPNL dB below St 4 with a Direct Drive BPR 13.5 Turbofan at Fan Pressure Ratio 1.6

AIAA 2014-0257 an additional detailed noise prediction was performed with an early far term suite of technologies,
36 EPNL dB below St 4

With advanced GTF, FPR 1.375, estimated the system noise could reach 40-42 EPNL dB below St 4

NASA MFN Aircraft in 2016

- AIAA Paper 2016-1030, Nickol and Haller
- Mid Term Technology Level

Block Fuel Reduction of 46.8% relative to 777-200LR-like on a 7500 nm mission

Airframe	T+W
Fuselage	Double Deck
Engine	GTF
Engine Mounting	Fuselage
Leading Edge Device	Krueger
Trailing Edge Device	Simple Flap
Main Gear Type	6 Wheels
Takeoff Gross Weight	544,748 lb
Lift/Drag Ratio (Sideline/Cutback/Approach)	13.92/13.5/8.9
Bypass Ratio (Sideline/Cutback/Approach)	23.34/25.38/31.91
Fan Pressure Ratio (Sideline/Cutback/Approach)	1.25/1.2/1.06

MFN System Noise in 2016

Reported in AIAA 2016-0863, Thomas, Burley and Nickol
(with calculations updated)

	Approach	*Cutback*	*Sideline*	*Cumulative*
MFN (C0)	91.0	84.8	85.0	260.8
Stage 4 Limit	104.6	98.4	101.2	294.2
Margin to Stage 4	13.6	13.6	16.2	33.4
NASA Mid Term Goal	-	-	-	32 - 42

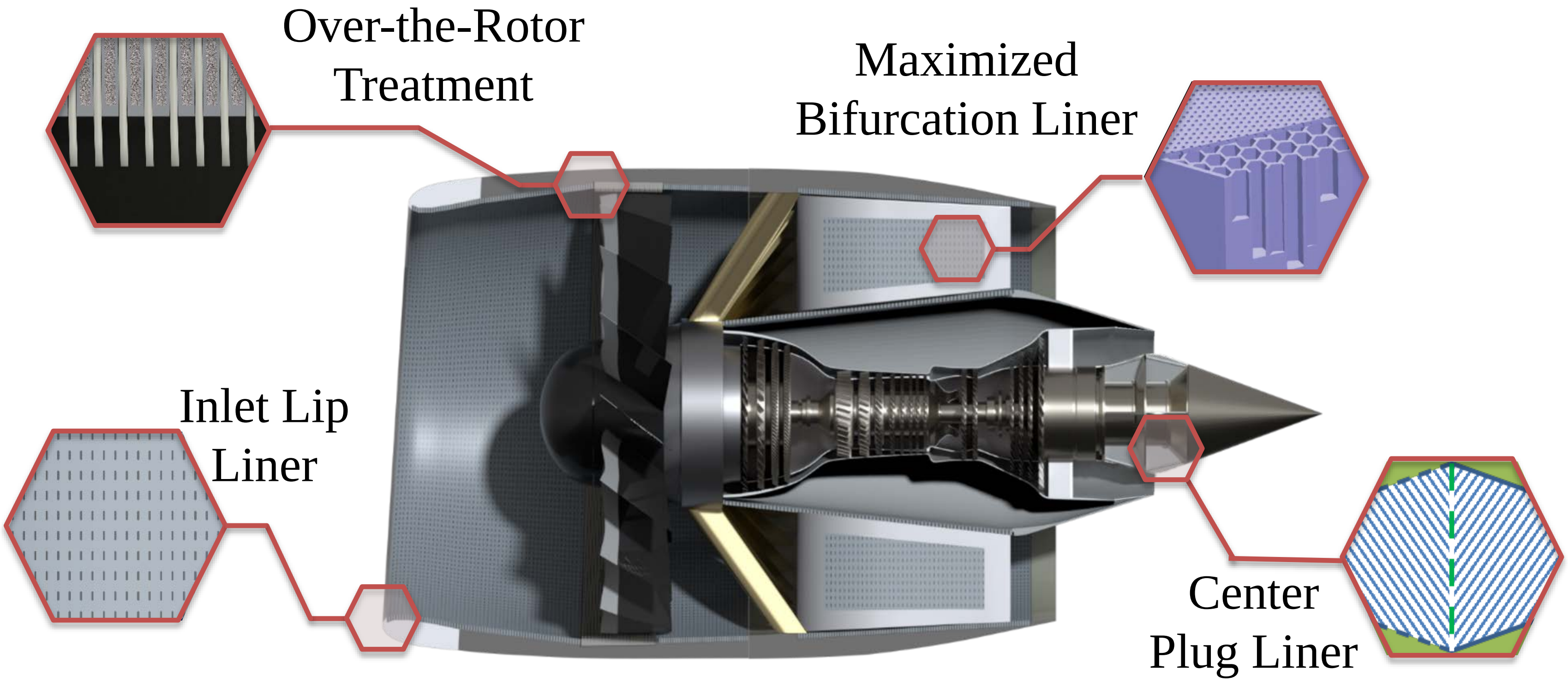
MFN aircraft with mid term technology

- PAA: propulsion airframe aeroacoustics
- MDOF: multidegree-of-freedom duct acoustic liner
- MG: main gear partial fairing
- Fan: soft stator vane treatment
- Flap: side edge treatment

Establishes the starting point for the far term roadmap

MFN Engine Far Term Noise Technologies

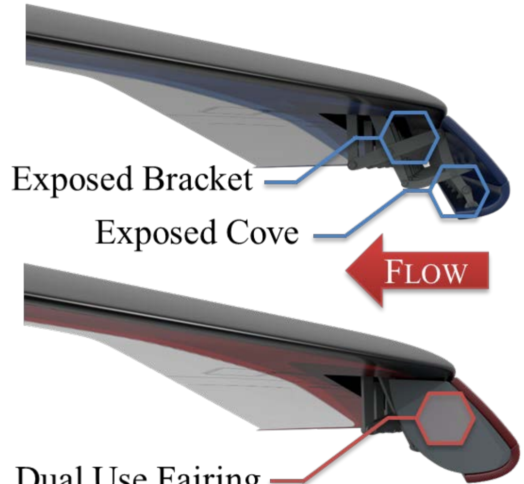
From AIAA-2018-3126

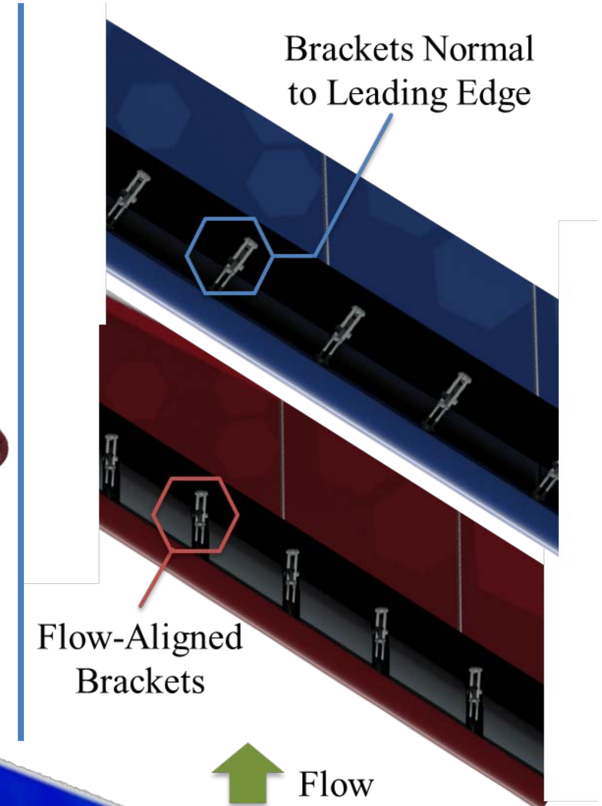


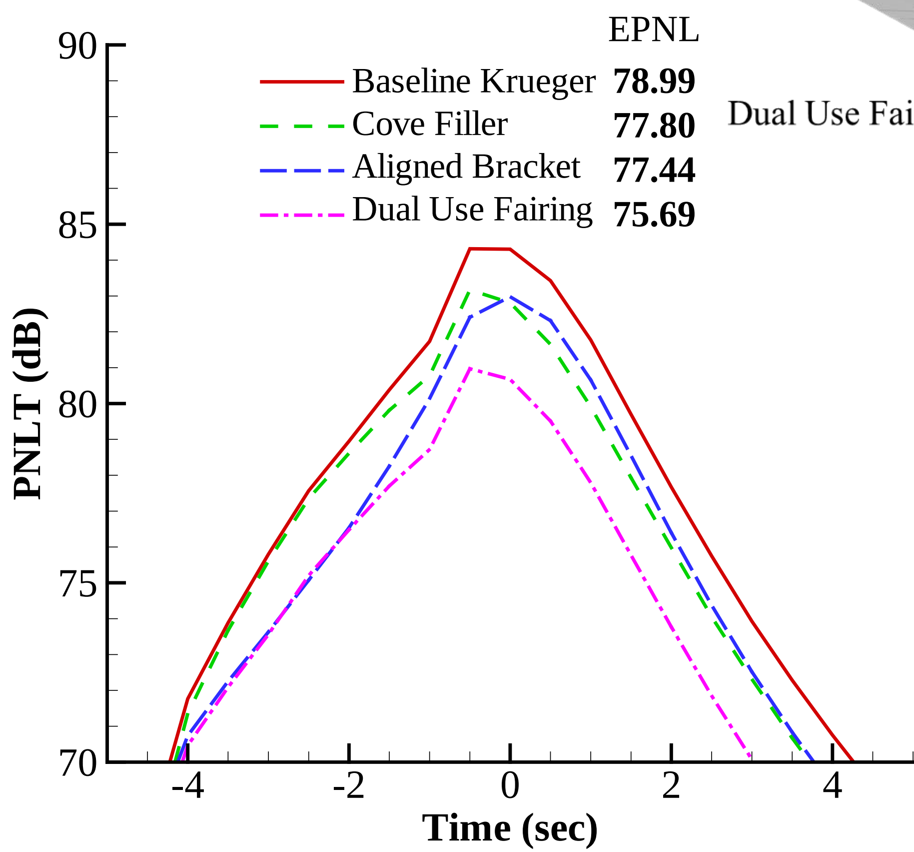
- No chevrons and scarf on MFN engine
- Example references
  - Inlet lip liner: AIAA 2006-2720, Herkes, Olsen and Uellenberg
  - Over-the-rotor treatment: AIAA 2006-2681, Sutliff, Jones and Hartley
  - Center plug liner: AIAA 2009-3141, Yu and Chien
  - Maximized Bifurcation liner: AIAA 2017-3193, Thomas et al.

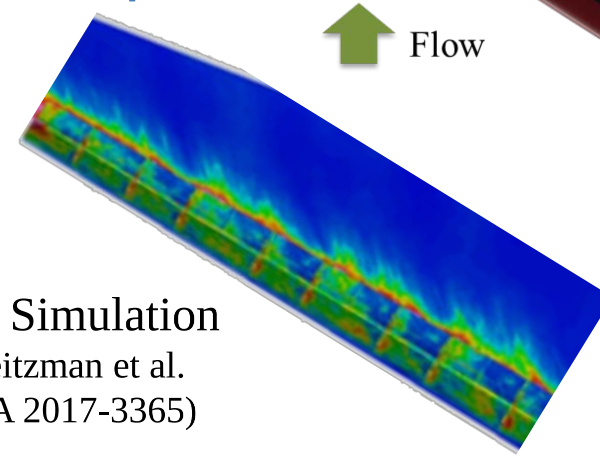
Krueger Dual Use Fairing

From AIAA-2018-3126









Flow Simulation
(Kreitzman et al.
AIAA 2017-3365)

MFN Pod Gear in 2016

Pod gear concept has the potential of a breakthrough in reducing main landing gear component noise

6.5 EPNLdB noise reduction

MG Strut Length Uncompressed

19.2 ft

8 ft

5.1 EPNLdB noise reduction and a 1910 pound reduction in TOGW

12.1 ft

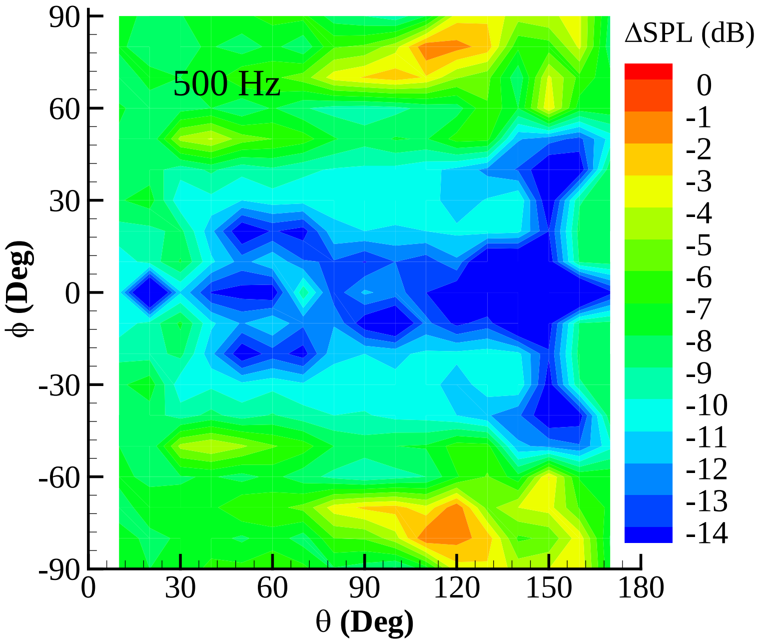
Thomas, R.H., Nickol, C.L., Burley, C.L., and Guo, Y. “Potential for Landing Gear Noise Reduction on Advanced Aircraft Configurations,” AIAA-2016-3039.

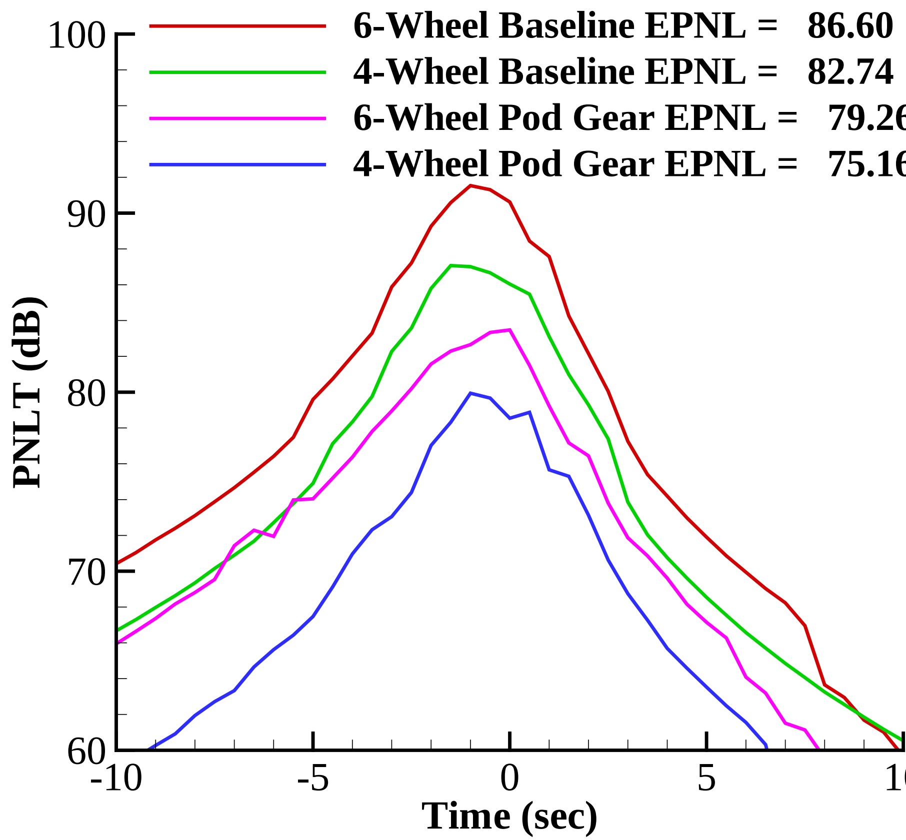
MFN Pod Gear in 2018

From AIAA-2018-3126

Noise calculation:

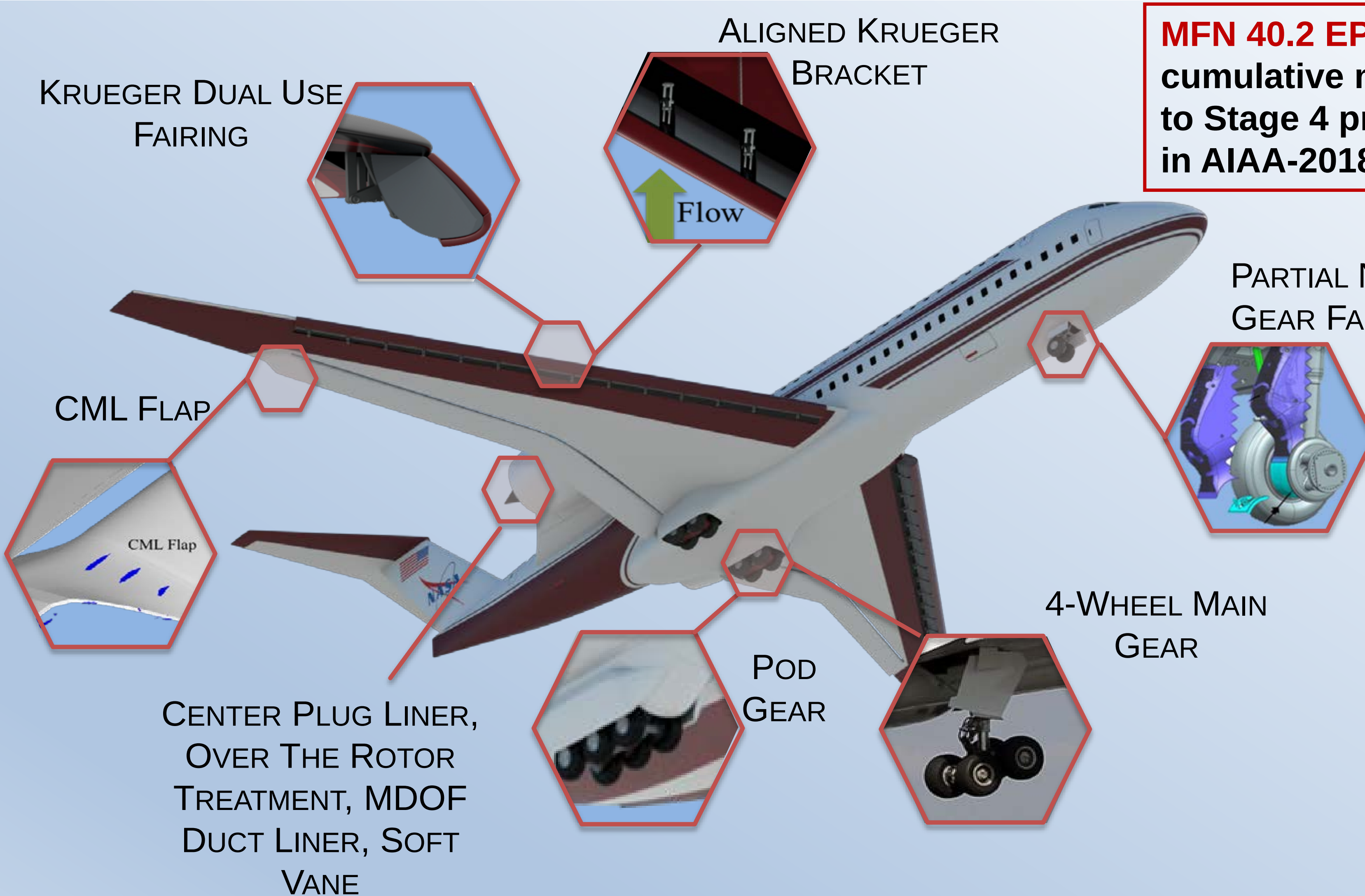
- Reflection from airframe with pod geometry
- Reduced flow velocity inside the pod





MFN Far Term Technology Roadmap

MFN 40.2 EPNL dB cumulative margin to Stage 4 predicted in AIAA-2018-3126



MFN Far Term Predicted at 40.2 EPNL dB below Stage 4

From AIAA-2018-3126

Reduction	*Technology*	*EPNL Impact* (dB)
Significant	• PAA Effects	4.7
	• MDOF Liner (mid term)	2.4
	• 4-Wheel Pod Gear	2.2
Substantial	• Soft Vane Liner (mid term)	1.0
	• Center Plug Liner	0.8
	• Over-the-Rotor Liner	1.6
	• Dual Use Krueger Fairing	0.6
	• Continuous Mold Line Flap	0.6
Small	• Inlet Lip Liner • Increased Outer Bifurcation Liner • Sealed Krueger Gap • Partial Nose Gear Fairing	~0.0
Not Used	• 6-Wheel Pod Gear • Krueger Bracket Alignment	-

Precedence for MFN Configuration

Design Heritage Examples:
- Engine Above Wing
- Short Gear
- Double Deck
- Pod Gear Similar

Accessed www.lockheedmartin.com August 19, 2018

Precedence for MFN Configuration

Design Heritage Examples:

- Engine Above Wing
- Short Gear
- Double Deck
- Pod Gear Similar

Accessed www.lockheedmartin.com August 19, 2018

MFN Advantages:

- Improved Weight/Balance from Mid-Fuselage
- Engine Mounting Structure through the Deck
- Favorable PAA Effects
- Faster Passenger Loading
- Integration of Pod with Wing/Body Joint

Precedence for MFN Configuration

Design Heritage Examples:
- Engine Above Wing
- Short Gear
- Double Deck
- Pod Gear Similar

Accessed www.lockheedmartin.com August 19, 2018

MFN Advantages:
- Improved Weight/Balance from Mid-Fuselage
- Engine Mounting Structure through the Deck
- Favorable PAA Effects
- Faster Passenger Loading
- Integration of Pod with Wing/Body Joint

40.2 EPNL dB below Stage 4 represents a community noise breakthrough with what is still a “Tube-and-Wing” aircraft

NASA X-59 QueSST

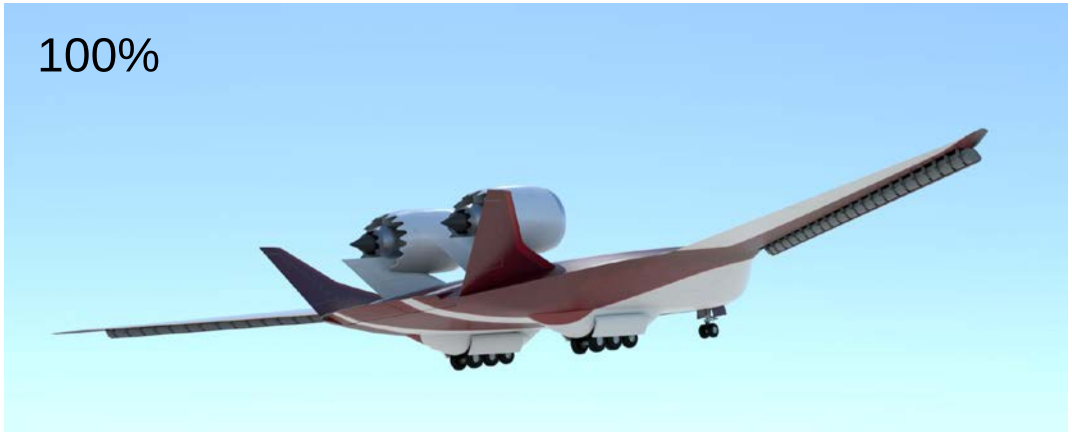
April 3, 2018 Lockheed Martin Aeronautics Company awarded the Low-Boom Flight Demonstration contract for $247.5 million to design, build and test an experimental aircraft that reduces the sonic boom to a gentle thump.

Beginning in mid-2022, NASA will fly the X-59 over select cities to collect data on community responses.

Scenarios for a Subsonic X-Plane Demonstrator for Acoustic Research

X-48B 8.5% Dynamically Scaled
Built and Flight Tested for Low Speed
Flight Dynamics Characteristics

Scenarios for a Subsonic X-Plane Demonstrator for Acoustic Research



X-48B 8.5% Dynamically Scaled Built and Flight Tested for Low Speed Flight Dynamics Characteristics

One-of-a-kind HWB X-Plane

- At what scale ?
- What type of scaling ?
    - Perfect scaling
    - Realistic scaling
- Engine Selection ?
- Technologies ?

Subsonic X-Plane Demonstrator Framework

A key development step toward maturing an unconventional advanced aircraft configuration with favorable PAA effects and noise reduction technologies

Aircraft configuration, engine selection, technology selection, integration, and scale factor will all drive the cost AND be critical to the value
Therefore, expect:

- X-Plane not an exact copy of the vision vehicle
- focus on selected technologies including the configuration
- use a commercial-off-the-shelf engine

Reference develops a process for formulating the acoustic aspects of an X-Plane Demonstrator scale, design, and flight research

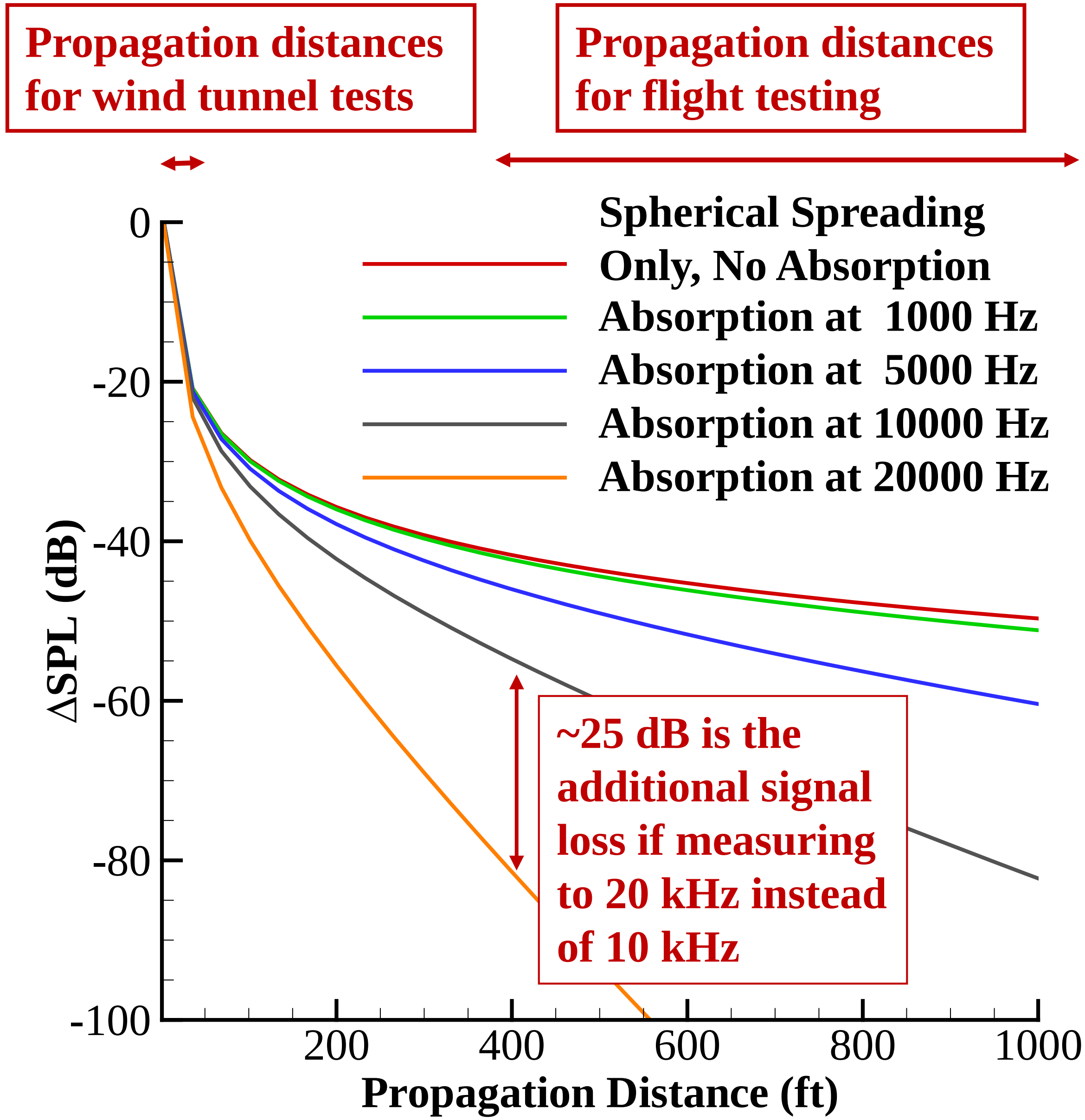
General objectives:

- acoustic flight validation of configuration PAA effects and selected technologies
- improving the prediction of the vision vehicle

Thomas, R.H. and Guo, Y., "Challenges and Opportunities for Subsonic Transport X-Plane Acoustic Flight Research," AIAA 2018-3127

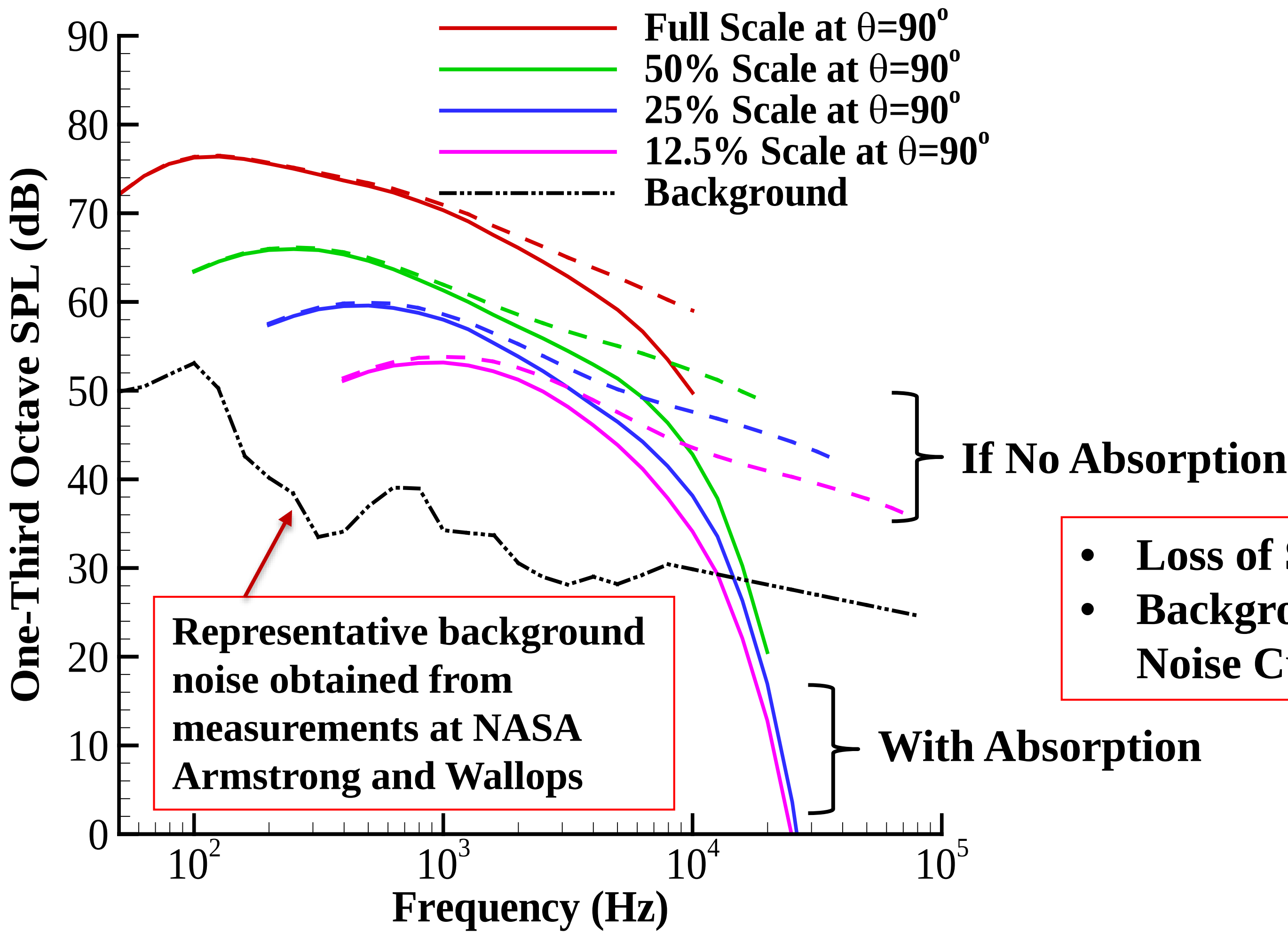
Flight Test Distances and Absorption

From AIAA-2018-3127



Scaled MFN at Approach

From AIAA-2018-3127

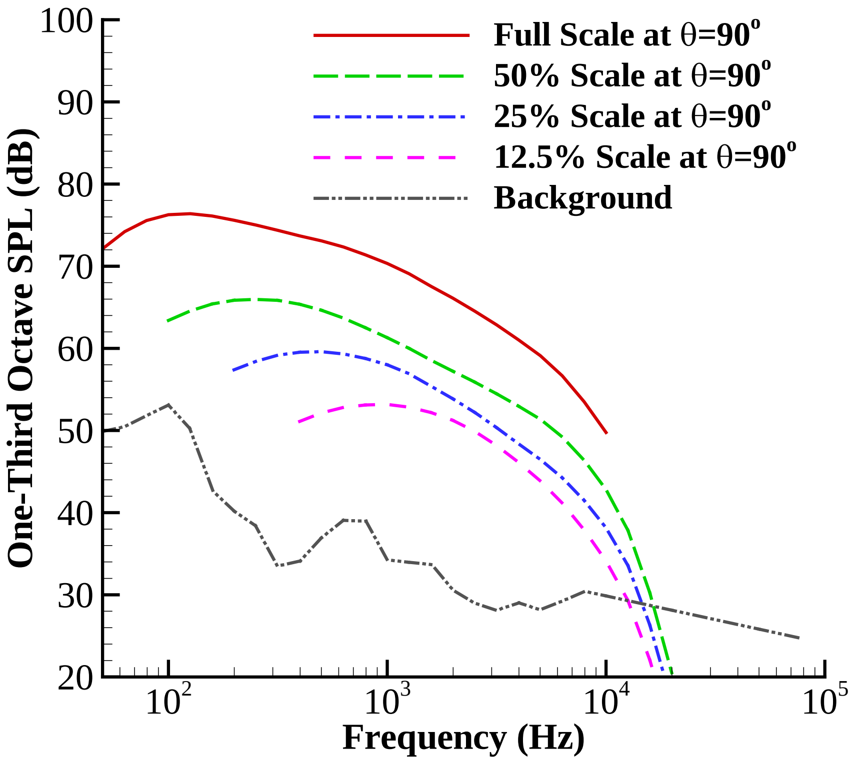


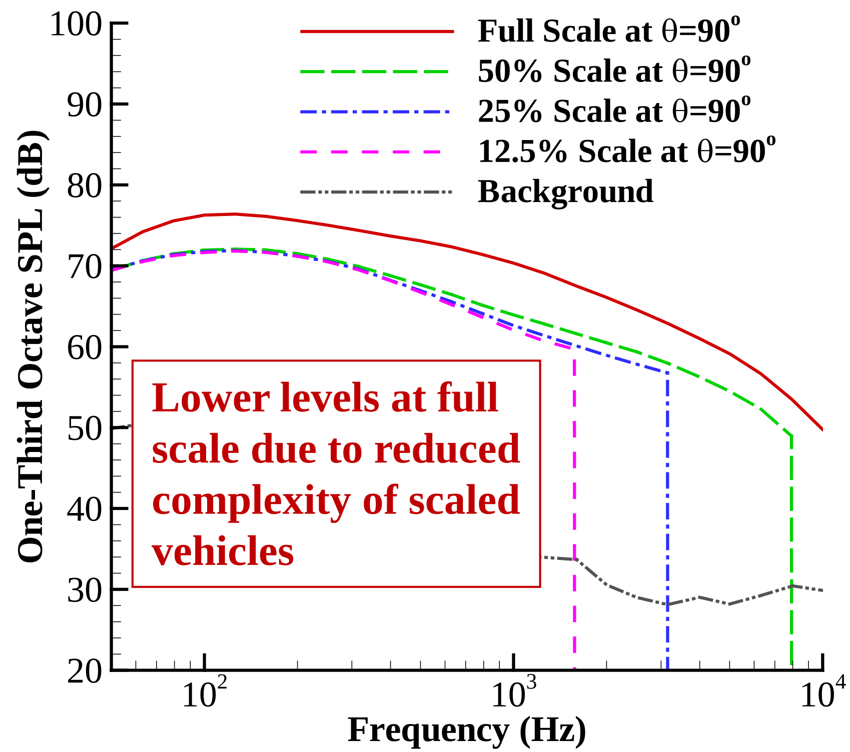
- Loss of Signal
- Background Noise Cutoff

Acknowledgments to Dr. Christopher Bahr and Dr. Patricio Ravetta for supplying background noise data

Realistically Scaled MFN

From AIAA-2018-3127





Realistically scaled (reduced geometric fidelity) as measured, propagation length of 396 ft.

Realistically scaled (reduced geometric fidelity) processed to full scale. Vertical lines indicate the frequency cutoff.

Subsonic X-Plane Study Summary

- An X-Plane focused system noise analysis process is essential to engage in:
  - X-Plane design requirements,
  - acoustic technical objectives,
  - flight research planning, and
  - analysis for application to prediction of the vision aircraft
- Highlights the interrelated issues of
  - scale
  - atmospheric absorption and background noise levels
  - geometric fidelity
  - source ranking
  - engine selection
  - instrumentation requirements

- X-Plane scale of 75% or more is most directly useful. Limitations become more severe as the scale factor approaches 50%.

- Selection of a UHB representative engine is valuable for prediction of engine system, PAA effects, and vision aircraft

Consider a Single Aisle Replacement, 160-230 pax, MFN Vision Vehicle

X-Plane Demonstrator B717 Hybrid Example

~45% for MFN301
~80% for a 160-230 pax

Consider a Single Aisle Replacement, 160-230 pax, MFN Vision Vehicle

X-Plane Demonstrator B717 Hybrid Example

~45% for MFN301
~80% for a 160-230 pax

Remarks on Future Low Noise Aircraft Prediction

Starts with excellent modeling teams for the engine and airframe

Combining experience in one team from:

- Acoustics Experimentation
- Noise Reduction Technology Development
- Prediction Method Development
- Aircraft System Noise

Experience from wide variety of technologies and concepts provides valuable perspective and insight

Advanced concepts require advanced methods

- PAA effects from scattering, flow interaction, BLI
- Noise reduction concepts such as Pod Gear, MDOF Liner, etc.

Summary Remarks

HWB acoustics has matured considerably, 40 EPNL dB below St 4 is clearly achievable in the mid term

Credible far term technology roadmap developed to enable the HWB to reach 50.9 EPNL dB below St 4

MFN concept is a revolutionary and yet still tube-and-wing type vehicle capable of reaching 40.2 EPNL dB below St 4 enabling:

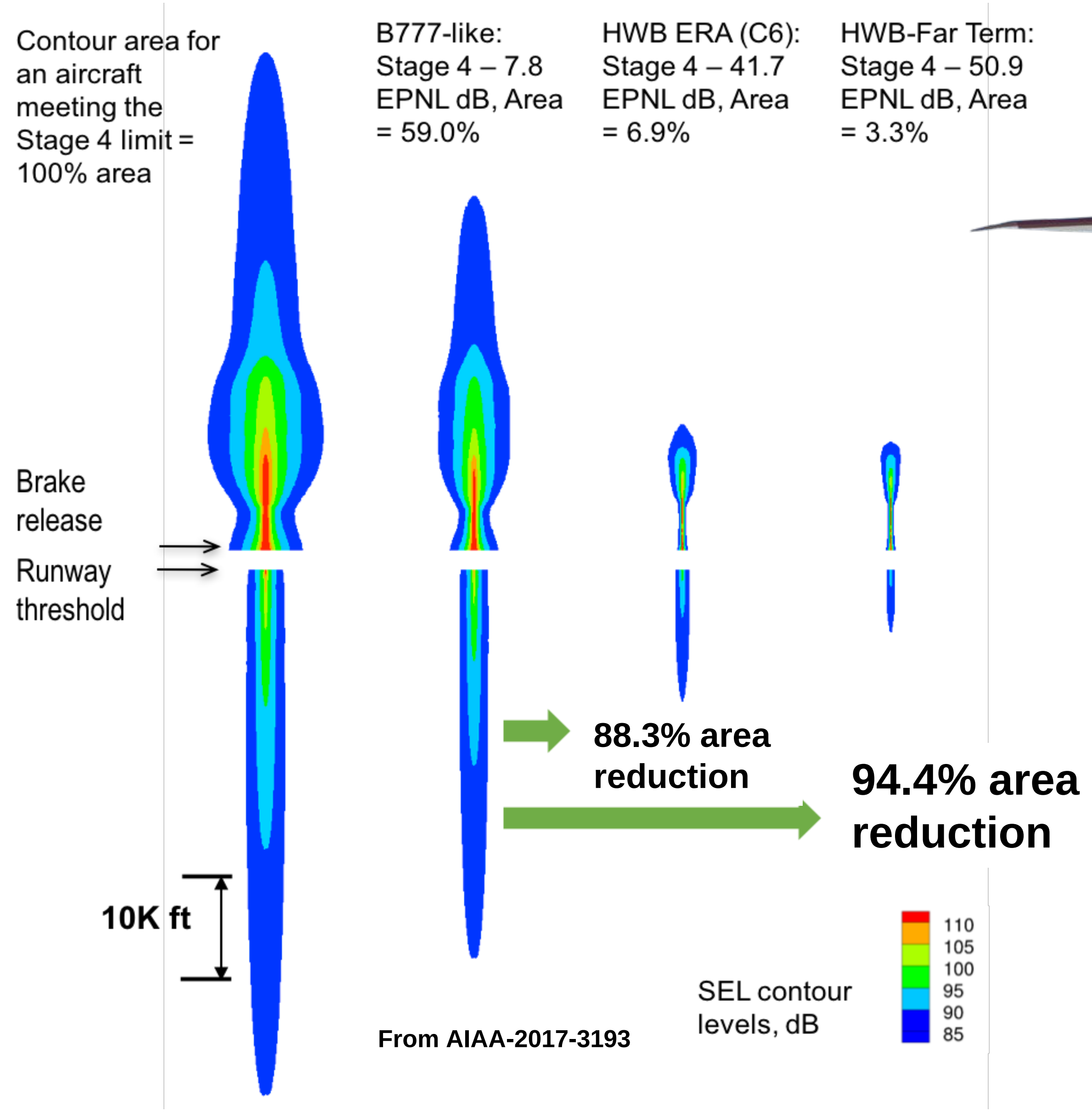
- shift from under to over-wing
- fundamentally quieter landing gear installation

Flight testing of advanced configurations and technologies will be valuable step

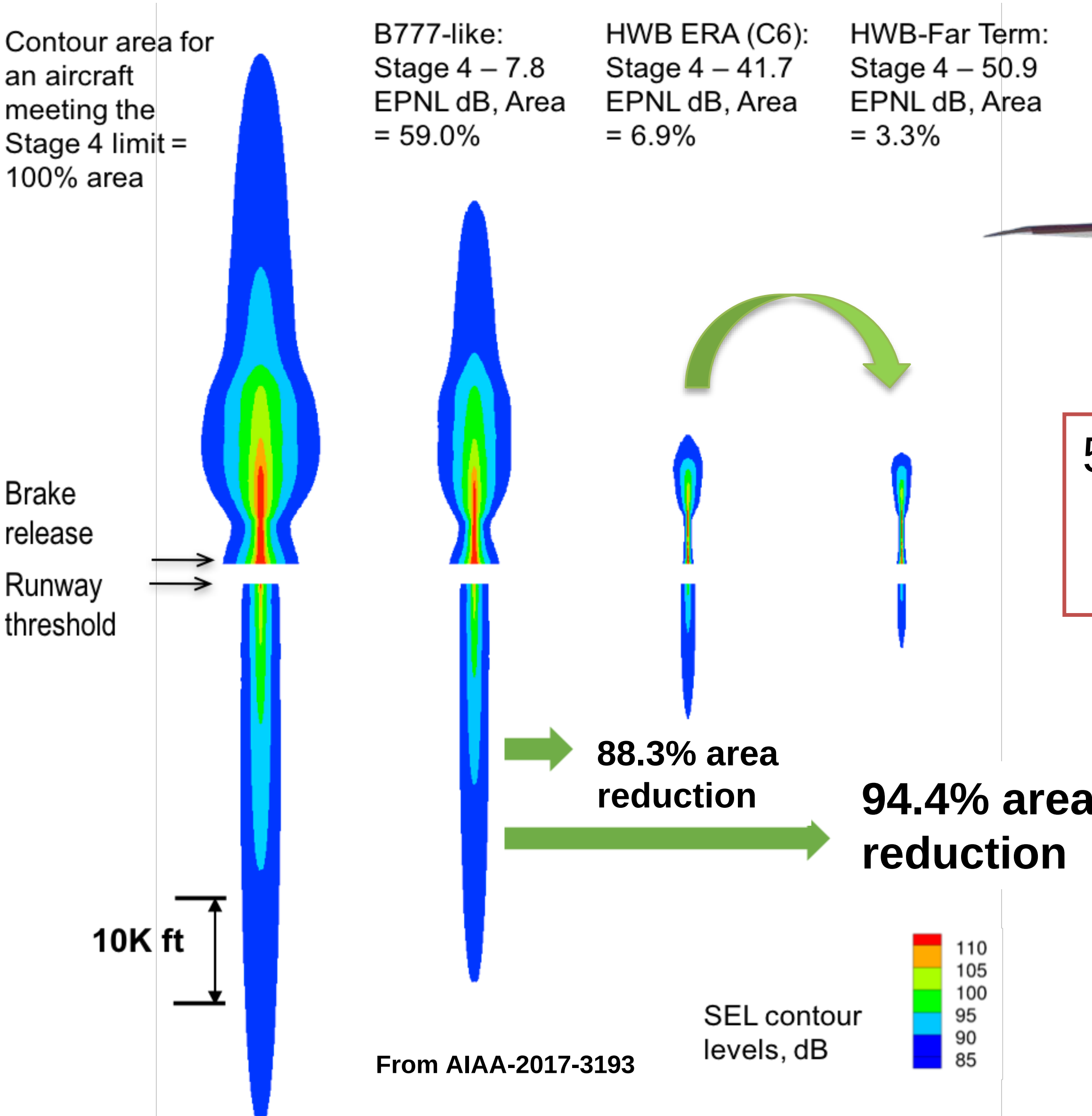
An X-plane subsonic demonstrator should be large scale (~75%) to produce the most directly useable community noise measurements

Portfolio of advanced concepts, missions, and technologies continues to expand and will require advanced methods, experiments and rigorous analysis

Grand Opportunity to Realize a Step Change in Aircraft Noise

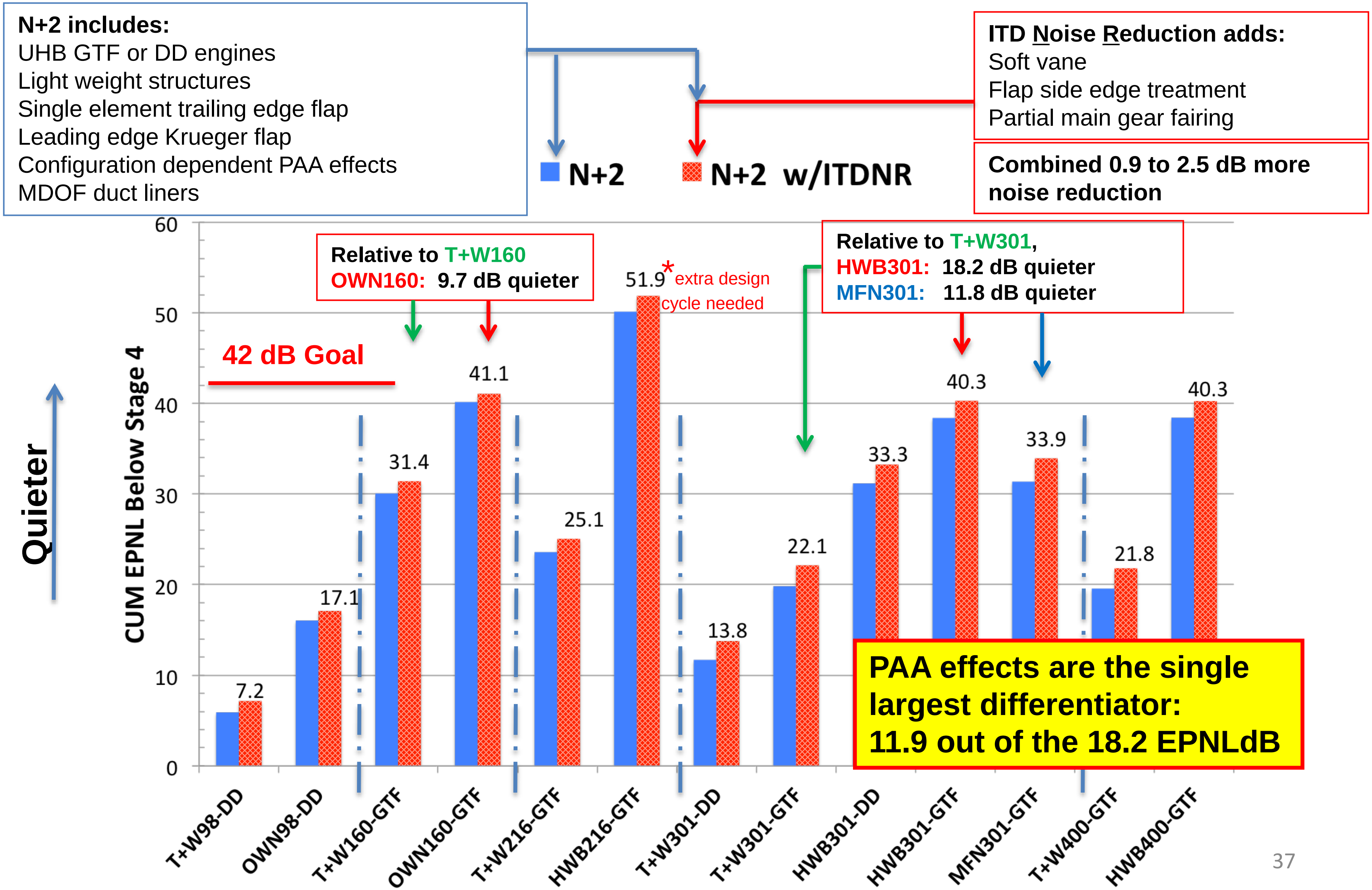


Grand Opportunity to Realize a Step Change in Aircraft Noise



52.2% reduction in area from HWB Mid Term to HWB Far Term

ERA Aircraft System Level Cumulative Noise Results from AIAA-2016-0863, January 2016



NASA-developed Concept Vehicles for UAM

NOT "BEST" DESIGNS; NO INTENT TO BUILD AND FLY

Passengers	50 nm trips per full charge/ refuel	Market	Type	Propulsion
1	1 x 50 nm	Air Taxi	Multicopter	Battery
2	2 x 50 nm	Commuter Scheduled	Side by Side (no tilt)	Parallel hybrid
4	4 x 50 nm	Mass Transit	(multi-) Tilt wing	Turboelectric
6	8 x 50 nm	Air Line	(multi-) Tilt rotor	Turboshaft
15			Lift + cruise	Hydrogen fuel cell
30			Vectored thrust	
			Compound	

Quadrotor "Air Taxi"

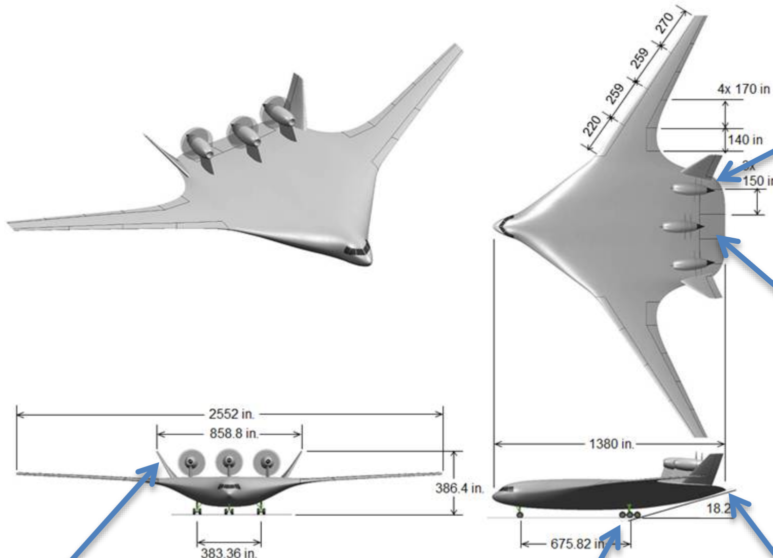
Side by Side "Vanpool"

Tilt wing "Airliner"

- Aircraft designed through use of NASA conceptual design and sizing tool for vertical lift, NDARC.
- Concepts described in detail in publication "Concept Vehicles for Air Taxi Operations," by W. Johnson, C. Silva and E. Solis. AHS Aeromechanics Design for Transformative Vertical Lift, San Francisco, Jan. 2018.

06 Feb 2018

Configuration and Parameter Changes for the OREIO Noise Assessment



Rotor installation distance x/D upstream of the trailing edge

NASA designed proof-of-concept airframe surface acoustic liner

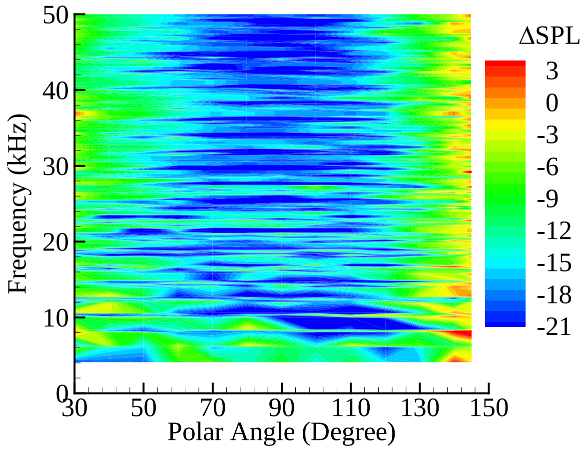
Vertical control surface cant angle

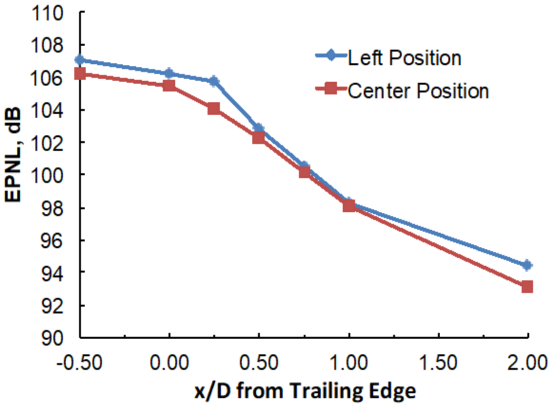
Projected landing gear noise reduction (NASA)

Center elevon deflection angle

AIAA 2014-0258, “System Noise Assessment and the Potential for Low Noise Hybrid Wing Aircraft with Open Rotor Propulsion”

NASA/Boeing Open Rotor PAA Experiment





Shielding in the flyover plane for interaction tones at takeoff power

Upstream on airframe

"Open Rotor Aeroacoustic Installation Effects for Conventional and Unconventional Airframes," Czech and Thomas, AIAA-2013-2185

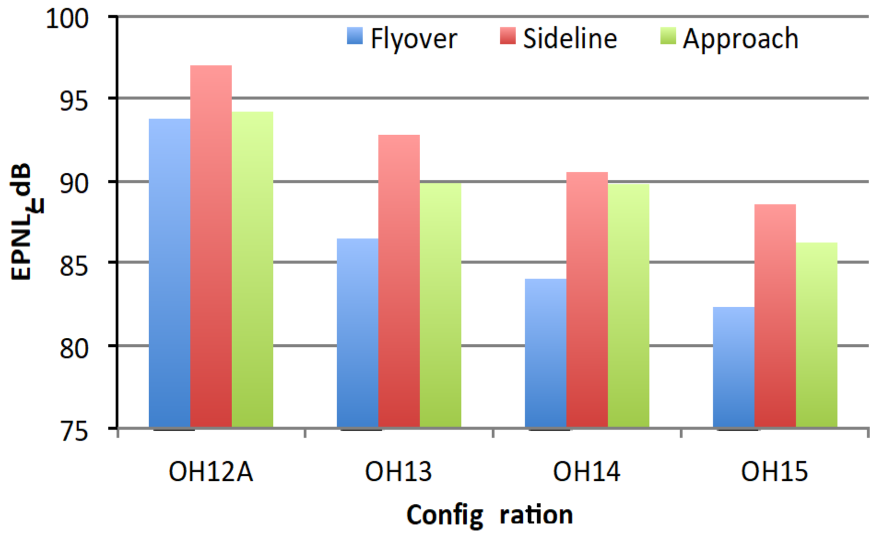
Methods for application of PAA experimental effects to a future rotor of arbitrary design:

"Open Rotor Tone Shielding Methods for System Noise Assessments Using Multiple Databases," Bahr et al., AIAA Paper 2014-0367.

"Open Rotor Noise Shielding by Blended Wing Body Aircraft," Guo and Thomas, AIAA Journal Vol 54 No 1, January 2016.

Open Rotor HWB Aircraft System Level Results

Cumulative EPNLdB rel Stage 4	-10.3	-26.0	-30.8	-38.0



AQR = Advanced Quiet Rotor, 2025 Projection

Isolated AQR, Baseline Airframe, No Shielding

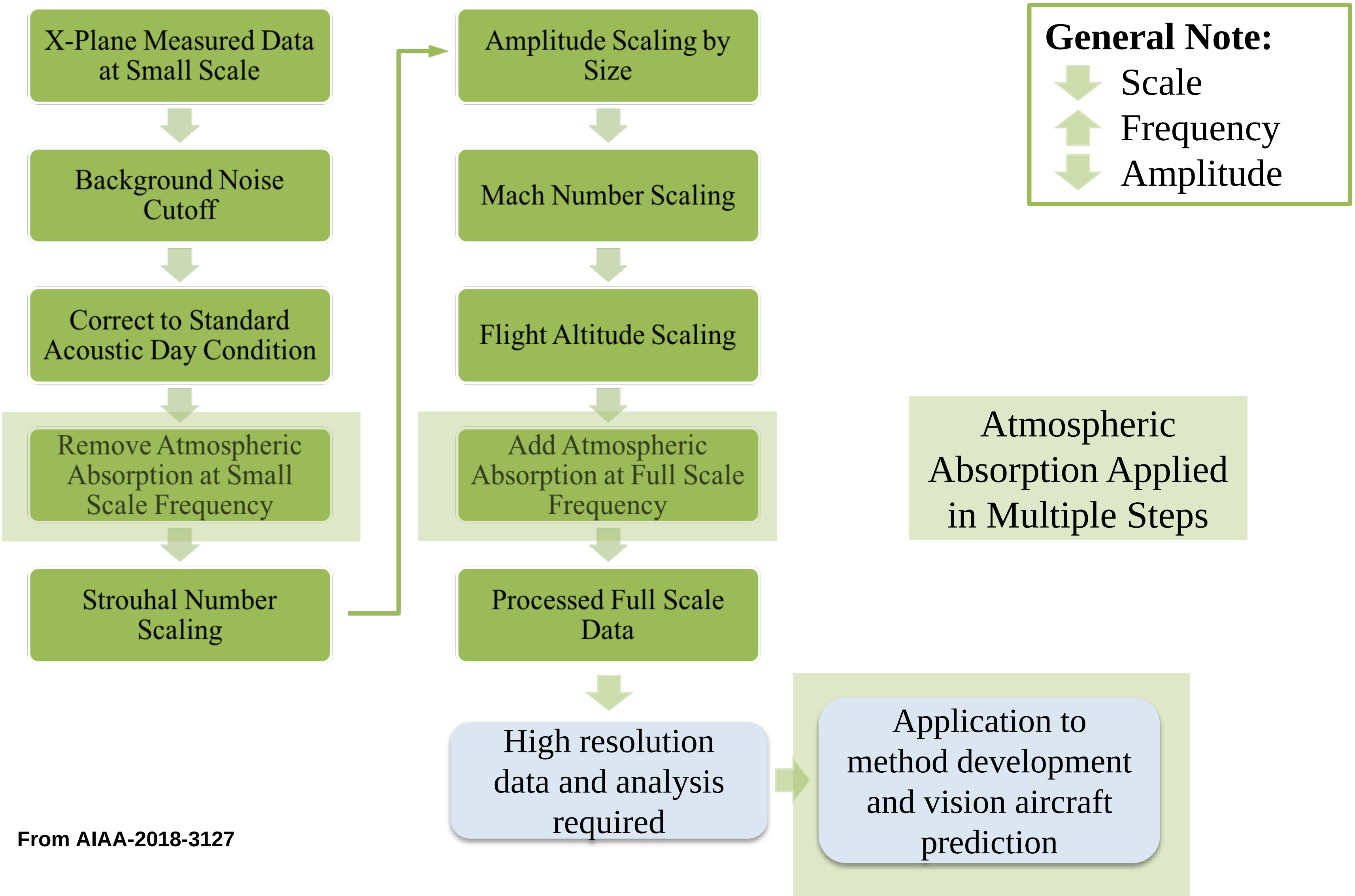
OREIO, AQR at 1D, Airframe w/ Noise Reduction (NR) Techs

OREIO, AQR at 1.5D, Airframe w/ NR

OREIO, AQR at 1.5D, Airframe w/ NR + Additional Possible Approaches

AIAA 2014-0258, “System Noise Assessment and the Potential for Low Noise Hybrid Wing Aircraft with Open Rotor Propulsion”

Processing of Predicted "Flight Test" Data

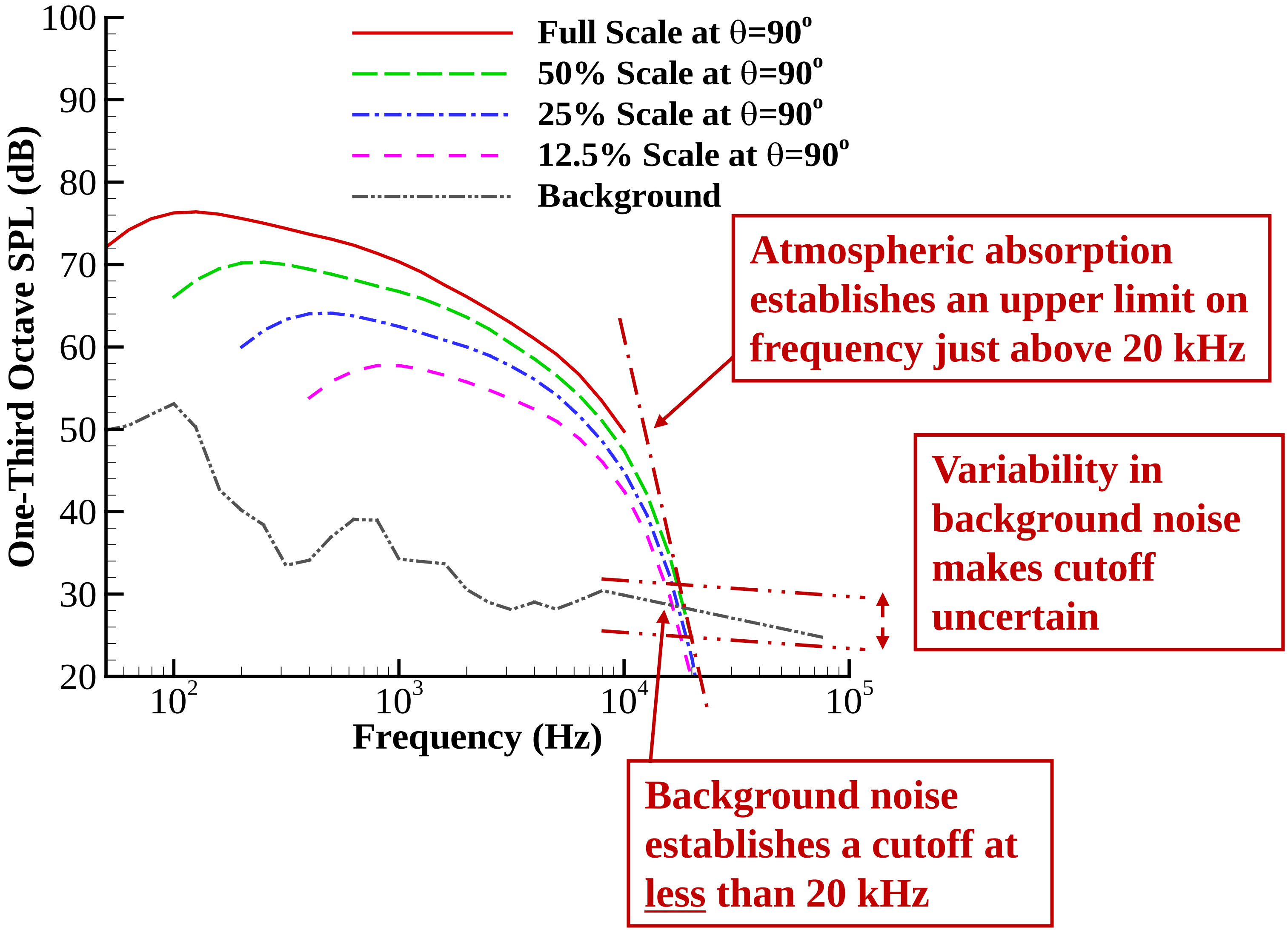


From AIAA-2018-3127

Limitations on Measuring High Frequencies

From AIAA-2018-3127

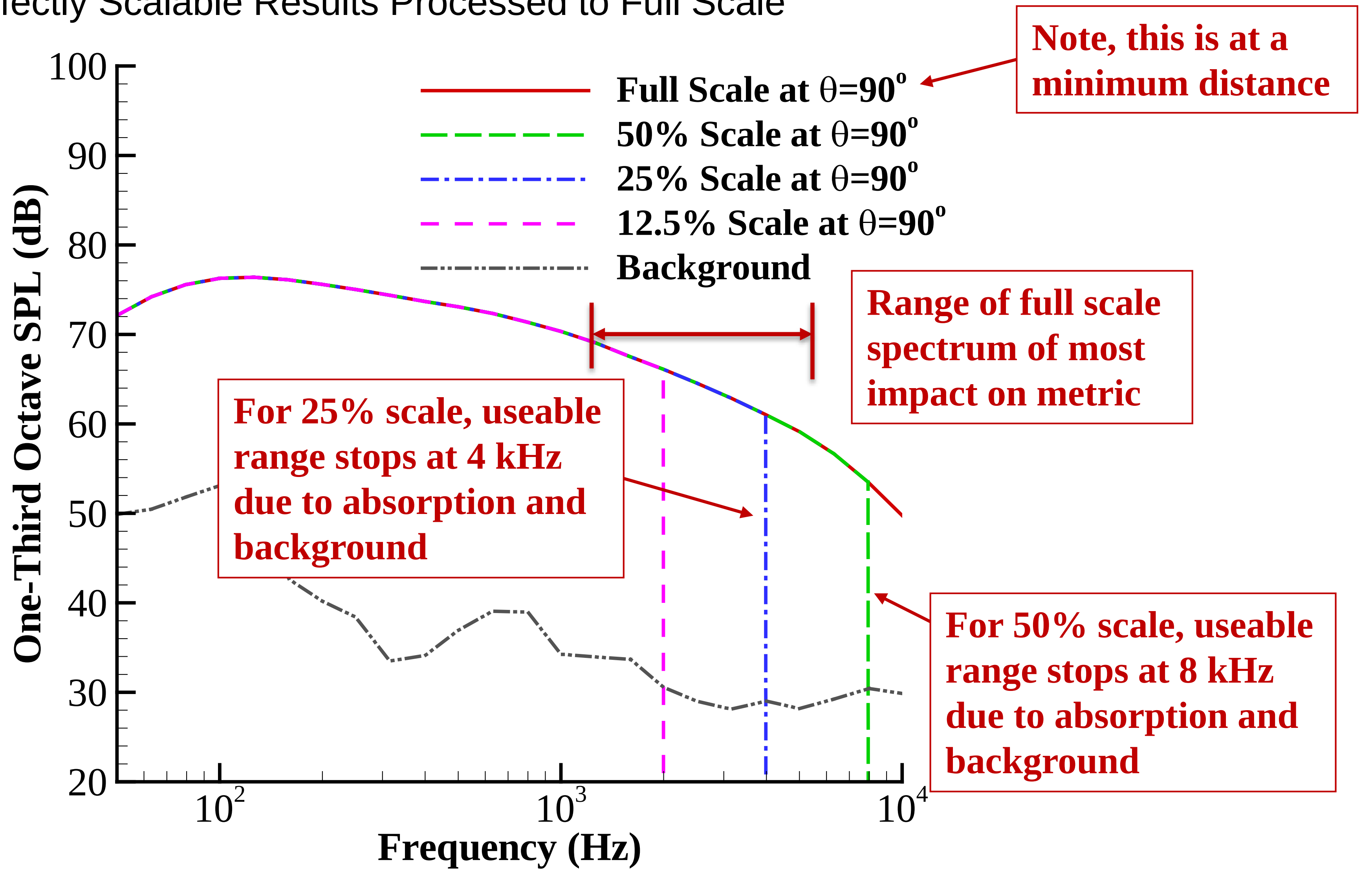
Perfectly Scalable Aircraft



Loss of Signal Impacts Full Scale Result

From AIAA-2018-3127

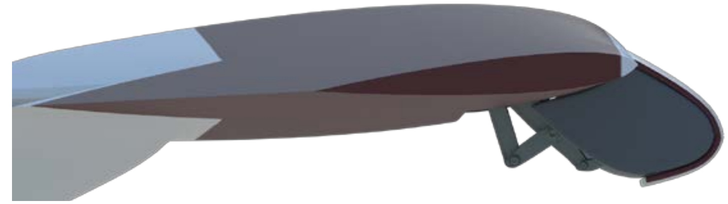
Perfectly Scalable Results Processed to Full Scale



MFN Vision Vehicle and Airframe Noise Reduction Technologies

From AIAA-2018-3127

Mid Term MFN Aircraft Concept



Dual Use Krueger Fairing (fills cove and fairs the brackets)

Continuous Mold Line (CML) Flap

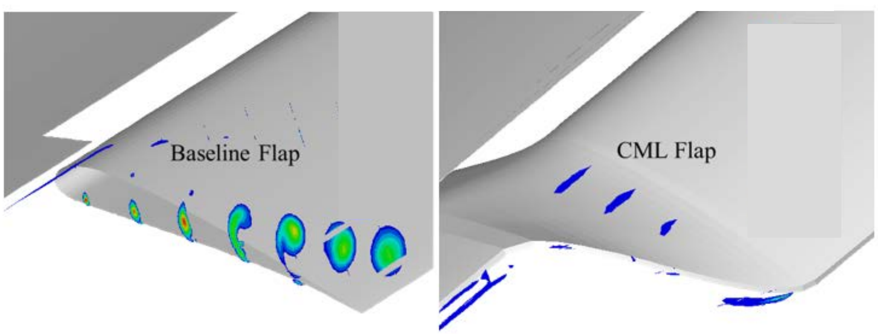


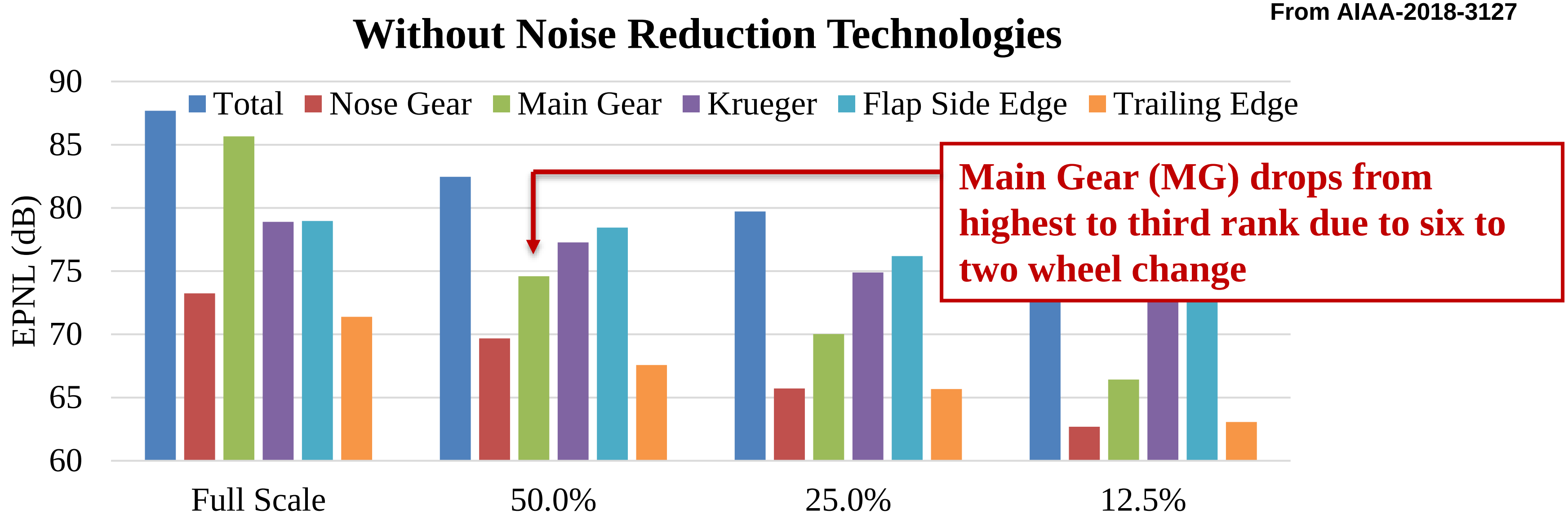
Figure 7 Illustration of continuous mold line technology

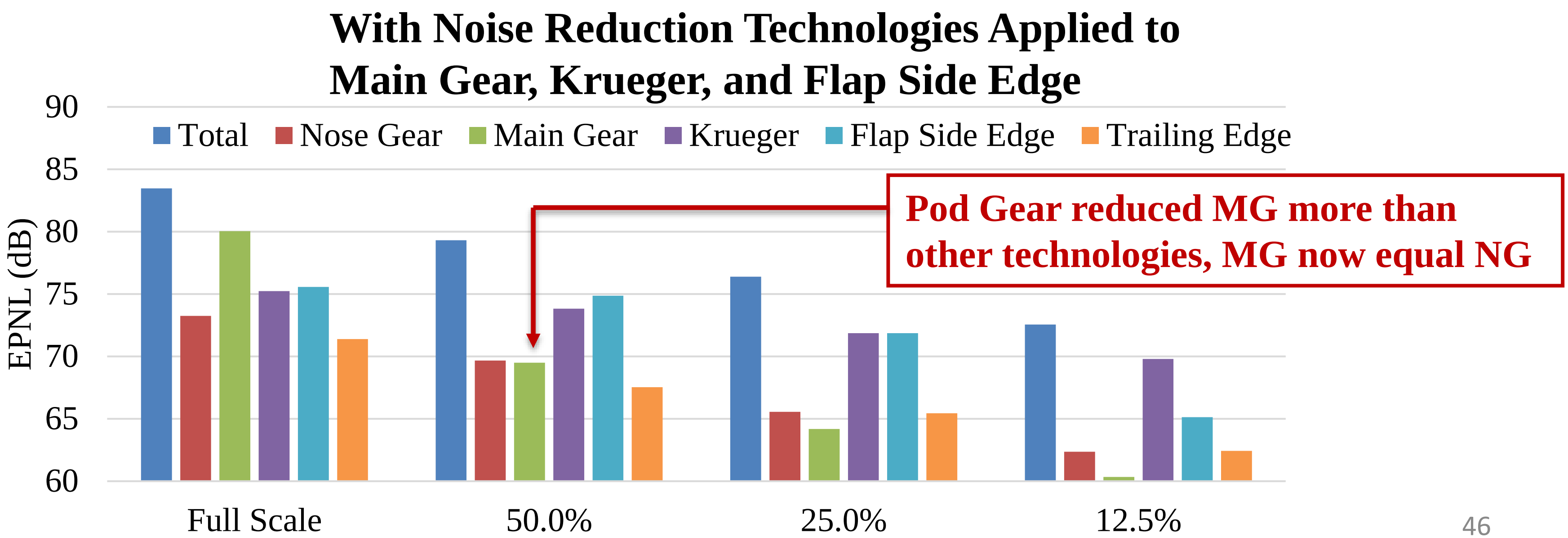
Far Term MFN Aircraft Concept

MFN Concept Redesigned with Pod Gear Concept

Realistically Scaled MFN with Technologies

From AIAA-2018-3127

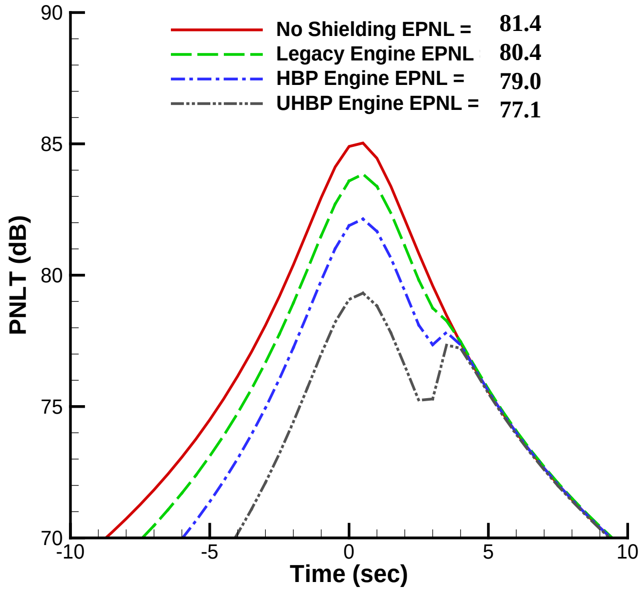




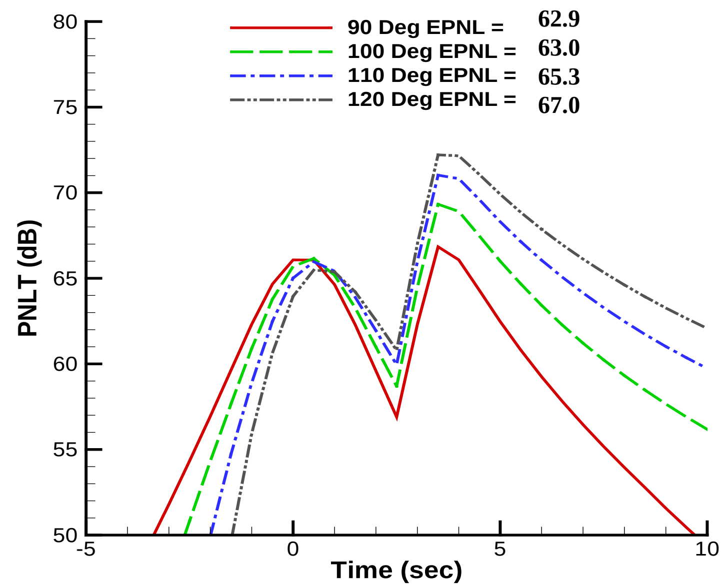
Impact of Engine Selection on PAA Effects

From AIAA-2018-3127

Engine Class	BPR	Dominant Source
Legacy	6-9	Jet
Current EIS HBP	9-12	Fan and Jet
UHBP Vision Engine	15+	Fan



Effect of Engine Source Ranking on Shielding



Effect of Engine Source Directivity on Shielding

Isolated engine characterization, engine source ranking, and analysis required to apply X-Plane Engine and PAA results to Vision Vehicle