Quantification of Acoustic Scattering Prediction Uncertainty for Aircraft System Noise Assessment

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Outline

- Background and Motivation
  - ERA N+2 Vehicle Concepts
  - Assessment Objective
  - System Noise Assessment
- Acoustic Scattering Prediction: PAA-effect
- Quantification of Prediction Uncertainty
  - Reference data prediction test method
  - Results for system noise assessment
- Concluding Remarks

ERA Project Goal

NASA Subsonic Transport Metrics

v2013.1

TECHNOLOGY BENEFITS*	TECHNOLOGY GENERATIONS (Technology Readiness Level = 4-6)		
	N+1 (2015)	N+2 (2020**)	N+3 (2025)
Noise (cum margin rel. to Stage 4)	-32 dB	-42 dB	-52 dB
LTO NOx Emissions (rel. to CAEP 6)	-60%	-75%	-80%
Cruise NOx Emissions (rel. to 2005 best in class)	-55%	-70%	-80%
Aircraft Fuel/Energy Consumption‡ (rel. to 2005 best in class)	-33%	-50%	-60%

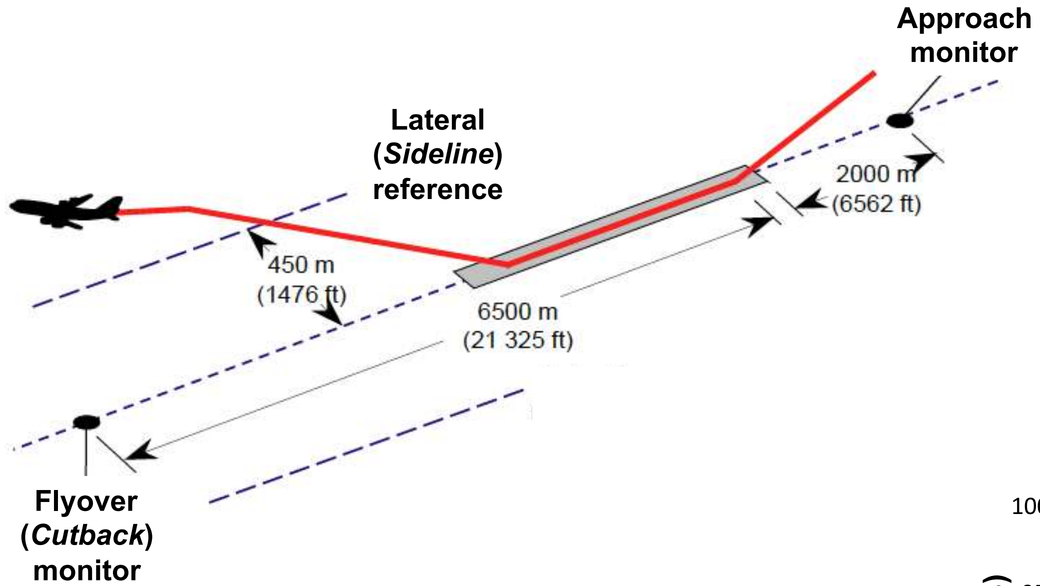
* Projected benefits once technologies are matured and implemented by industry. Benefits vary by vehicle size and mission. N+1 and N+3 values are referenced to a 737-800 with CFM56-7B engines, N+2 values are referenced to a 777-200 with GE90 engines

** ERA's time-phased approach includes advancing "long-pole" technologies to TRL 6 by 2015

‡ CO2 emission benefits dependent on life-cycle CO2e per MJ for fuel and/or energy source used

The ERA Project's goal is to identify and mature technologies and advanced configurations that, when integrated, can simultaneously meet the N+2 noise, LTO NOx, and fuel burn reduction metrics

Noise Certification Measurement Points

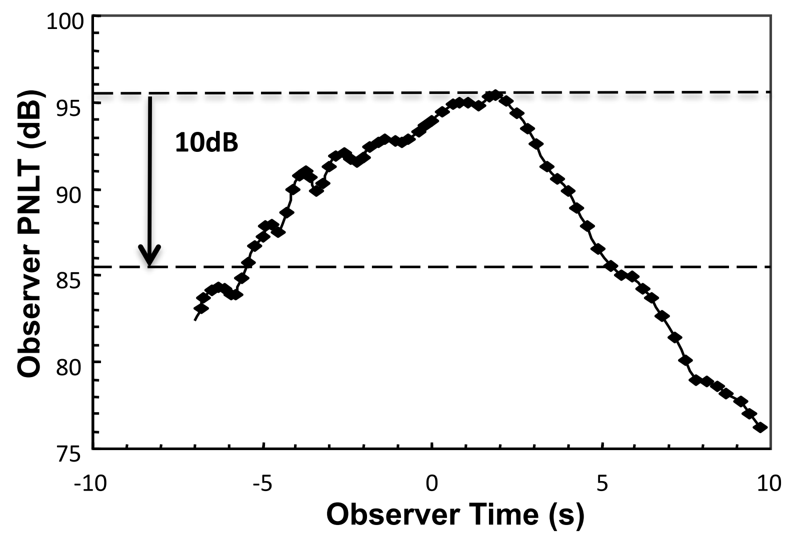


Noise certification points
- Lateral (Sideline)
- Flyover with Cutback
- Approach

Flight operation/trajectory simulation
Source noise modeling

Noise propagation to observers (accounting for spreading, atmospheric and lateral attenuation, ground effects, reflections)

Ground observer noise time history of PNLT metric (Frequency integration for each observer time accounting for tonal content with amplitude penalties)



Time integration to Effective Perceived Noise Level: EPNL

PNLT = tone corrected perceived noise level

ERA System Noise Prediction Process

ANOPP2

Aircraft Flight Definition

Source Noise (ANOPP-L31v3)
Jet: Stone (ST2JET + *AOA correction)*
Core: SAE (GECOR)
Fan: modified Heidmann (HDNFAN-Krejsa), (ACD:GTF-measured)
Duct Treatment: modified GE method (TREAT)
Landing gear (nose & main): (Guo-LG)
Flap-side-edge: Boeing (BAF-Flap)
Leading edge (Krueger): (Guo-Krueger)
Trailing edge: Fink (FNKAFM)

PAA Effects: engine noise installation effects (shielding, reflections) (GENSUP)

ITD noise technology: reduction through suppression of specific source noise (fan, gear, flap, Krueger) (GENSUP)

Propagation

Noise Metrics

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

Flight profiles that meet CFR 36
Aircraft geometries

FLOPS
MVL-aero

- Low speed aero (ITD 51A)
- Engine operating limits
- Airframe geometric definition
- Aircraft weights

Engine states and geometric parameters

NPSS

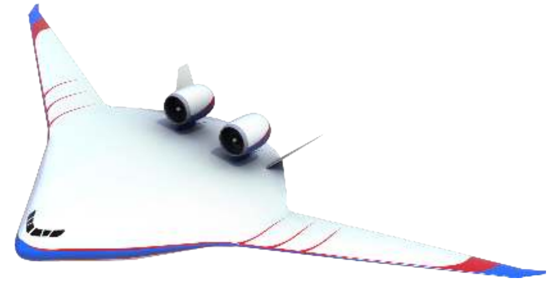
ITD 35A: Soft Vane fan noise reduction
GTF source fan noise and 'effects' data for cut-off, bifurcation, sweep & lean, rotor-stator-spacing
ITD 50A: Flap side edge noise suppression data for RJ & 3.0 dB suppression for all other vehicles
Partial main gear noise suppression data for all vehicles

Propulsion/Airframe Aeroacoustic (PAA) Effects Prediction:
14x22 N2A data (Phase I)
LSAF PAA data (Phase I)

Vehicle Assessment – Advanced N+2 (2025) Large Twin-Aisle Concepts

T+W301-GTF (Tube-and-Wing)

MFN301-GTF Mid-Fuselage Nacelle



HWB301-GTF Hybrid Wing Body

	T+W301-GTF	MFN301-GTF	HWB301-GTF
TOGW (lbs)	570,533	540,837	534,491
Payload (lbs)	118,100	118,100	118,100
Design Range (nm)	7500	7500	7500

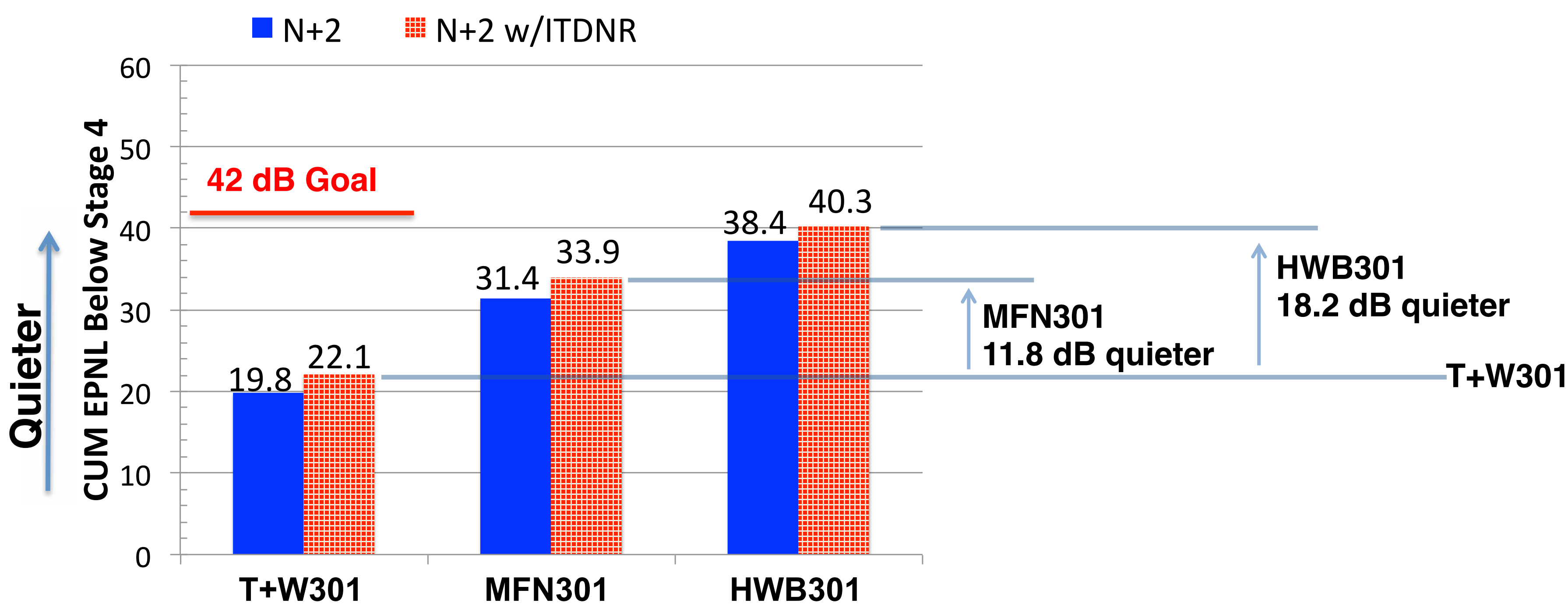
Same mission, different configuration and aero-performance

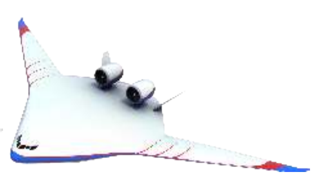
Aircraft Cumulative Noise Results

N+2 includes:
UHB GTF or DD engines
Light weight structures
Single element trailing edge flap
Leading edge Krueger flap
Configuration dependent PAA effects
Multi-degree of freedom duct liners (MDOF)

Integrated Technology Demonstration Noise Reduction (ITDNR) adds:
Soft Vane (SV)
Flap Side Edge Treatment (FSET)
Partial Main Gear Fairing (PMGF)

ITDNR combined 0.9 to 2.5 dB noise reduction





Acoustic Scattering Prediction of Propulsion Airframe Aeroacoustic (PAA) Interaction Effects

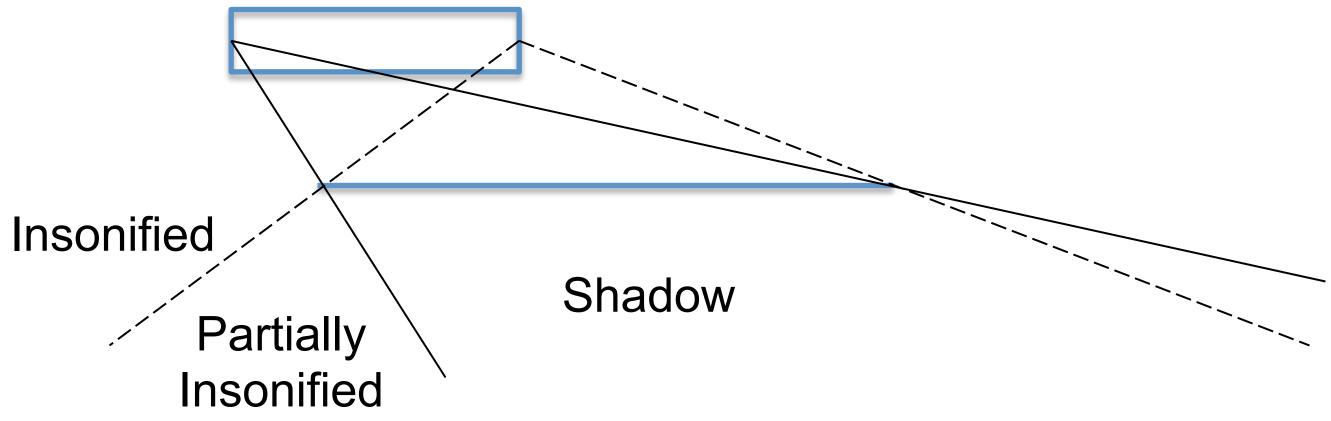
- Multi-parameter analysis of the most closely matched datasets coupled with theoretical analysis, computational and analytical modeling.

- Datasets
  - LSAF and 14x22 aeroacoustic test campaigns
  - HWB and conventional tube-and-wing configurations with variations in source noise definition: distributed and point broadband sources, jet
  - Operational parameters defined for approach and takeoff conditions
  - Acoustic data as function of configuration, power condition, frequency and both polar & azimuthal directivity.

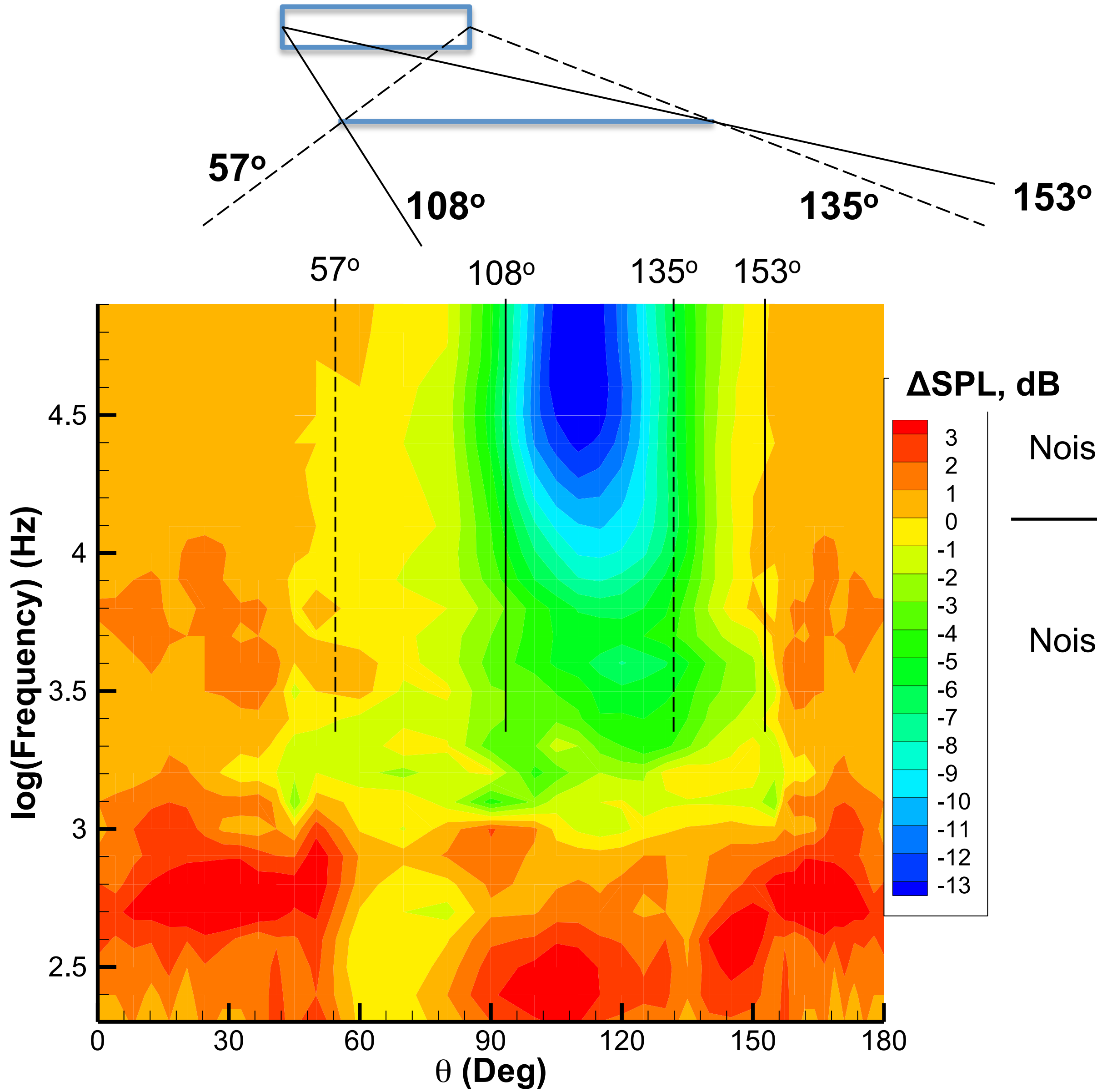
- Computational and analytical modeling
  - Account for effects not fully represented in the datasets such as reflections from horizontal tails, or specific full aircraft configurations with multiple engines
  - Extend frequency and directivity angle definitions to required full-scale ranges

Shielding Characteristics

- Angular zones
  - Insonified: slight noise increase due to edge diffraction
  - Partially insonified: noise reduction by half of the direct radiation but slight increase due to diffraction
  - Shadow: no direct radiation and diffraction as noise floor
- Boundaries of angular zones predicted by geometry and vary with engine/wing configuration
- Diffraction amplitudes determined by source/edge distance and frequency



Noise Scattering Map Prediction



Noise increase

Noise decrease

Acoustic Scattering Prediction of Propulsion Airframe Aeroacoustic (PAA) Interaction Effects

- Modification to engine source noise components
  - "Suppression/Attenuation"

$$S(f,\theta,\phi) = \frac{P_{rms}^2(f,\theta,\phi)_{shielded}}{P_{rms}^2(f,\theta,\phi)_{unshielded}} = 10^{\left(\frac{\Delta dB}{10}\right)}$$

- Applied to engine source noise to account for installation effects due to
  - Shielding / reflection from airframe
  - Modification of source level and directivity due to change in flow field from free stream

Shielding is dependent on noise source characteristics and directivity, source/airframe positioning, airframe shape, control surface deflection, and frequency

Uncertainty Quantification of System Noise Prediction

- **Companion paper presents framework and process for establishing aircraft noise prediction uncertainty**

- **The uncertainty on EPNL prediction is computed in a direct Monte Carlo process**
  - 10,000 EPNL simulations: $EPNL_i = f$ (prediction $element_i$)
  - Source prediction elements: Engine (fan, jet, etc.), airframe (gear, etc.), PAA-effects

- **New uncertainty framework/process outlines four methods for determination of prediction element uncertainty**
  - I. Reference data prediction test method
  - II. Formulation method
  - III. Fixed by aircraft level method
  - IV. Inferred method
- **Reference data prediction test method: "Reference Dataset" hierarchy**
  1. Full-scale, full-fidelity aircraft flight data
  2. Model-scale, higher fidelity integrated system experimental data
  3. Model-scale, high fidelity sub-system experimental data
  4. Isolated component experimental data

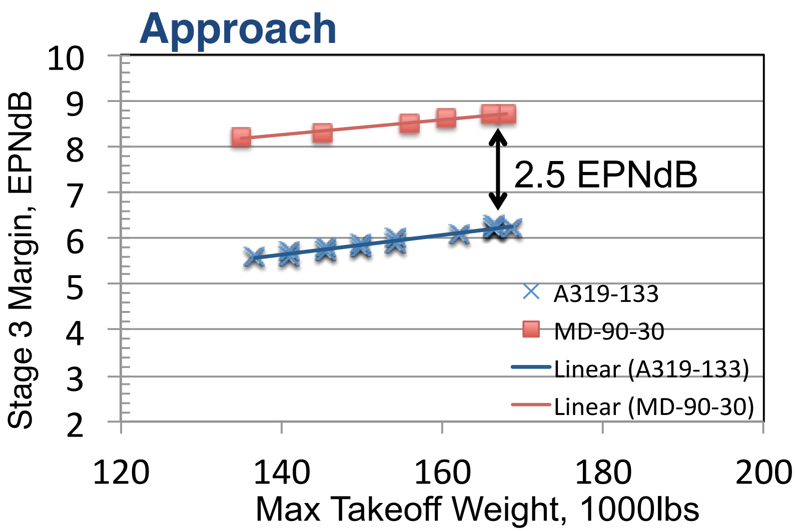
Full-Scale Propulsion Airframe Aeroacoustic (PAA) "Reference Dataset"

PAA integration effects from a similar engine installed on similar sized but different aircraft configurations –likely PAA effects are acoustic shielding by wing and fuselage for tail mount while the under-wing mounting increases noise from reflection and jet-flap interaction (*Ron Olsen, Boeing)*

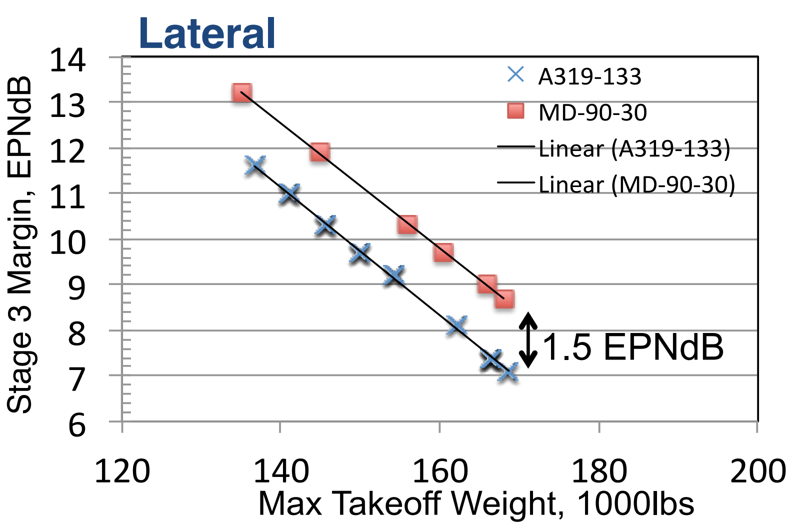
Boeing MD-90-30		**Airbus A319-133**		**(relative to MD-90-30)**
Engine IAE 2528-D5		Engine IAE 2527M-A5		
Thrust (lbs)	28,000	Thrust (lbs)	26,500	–1,500 lbs
MTOW (lbs)	166,000	MTOW (lbs)	166,400	+400 lbs
MLW (lbs)	142,000	MLW (lbs)	137,800	–4,200 lbs
Noise Certification (EPNdB):				
Approach	91.9	Approach	94.4	+2.5
Lateral	91.0	Lateral	92.5	+1.5
Flyover	82.6	Flyover	84.2	+1.6
Cumulative Margin Relative to Stage 3 = – 23.5 EPNdB		**Cumulative Margin Relative to Stage 3 = – 17.9 EPNdB**		**+5.6**

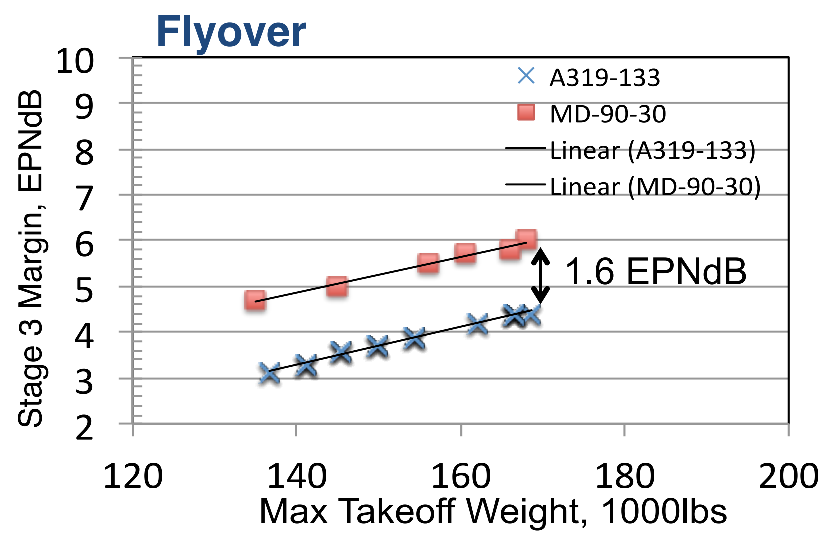
Data from www.faa.gov and ICAO noisedb website

Certification Noise Margins Relative to Stage 3



- Noise certification data (ref. EASA (European Aviation Safety Agency)
- Nearly linear function with Max Takeoff Weight
- Difference in EPNL invariant with MTOW





PAA-Effect Prediction Uncertainty Process

- Simulate configurations of MD-90-30 and A319-133 with NASA model of 737-800 with CFM56 engines

	Boeing MD-90-30	Airbus A319-133	Boeing 737-800
Engine/airframe Configuration	Empennage-mounted	Under-the-wing	Under-the-wing
Engine	IAE 2528-D5	IAE 2527M-A5	CFM56-7B
Thrust	28,000	26,500	26,000
BPR	4.8	4.7	5.2
MTOW (lbs)	166,000	166,400	174,000

- Predict PAA-effect for the both configurations
  - Broadband engine noise scattering
  - Jet noise scattering

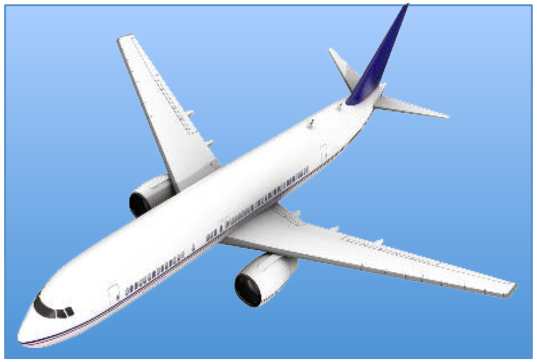
- Compare difference in EPNL at each certification noise point to Reference Dataset differences

- Match Reference Dataset result by “adjusting” PAA-effect prediction

Noise Simulations of PAA Configurations

- Engine represented by NPSS NASA model of CFM56-7B
- Airframe and certification flight path determined from FLOPS aero-performance analysis of NASA 737-800 like aircraft
- Noise Scattering (PAA-effect) Prediction

Under-the-wing



- Aft engine sources: wing reflection
- Jet: reflected from wing
- Observers directly in sight of both engines

Empennage-mounted

- Inlet engine sources: wing shielding
- Jet: reflected from horizontal tail
- Sideline observers: one engine shielded, but engine noise reflected from fuselage

Prediction Compared to Reference Dataset

	Under-the-wing engine	Empennage-mounted engine	ΔEPNL Prediction	ΔEPNL Reference Dataset
Approach (EPNdB)	96.4	94.8	1.6	2.5
Lateral (EPNdB)	95.1	91.4	3.7	1.5
Flyover (EPNdB)	86.3	85.5	0.8	1.6

- Discrepancy between ΔEPNL results from prediction and Reference Dataset is indirect measure of prediction uncertainty
  - Approach and Flyover: underprediction of shielding effect
  - Lateral: overpredict noise shielding

Noise Scattering Prediction Map Adjustment (ΔSPL, dB)

- Engine noise scattering prediction uncertainty
  - Dependent on engine source, geometry, flight condition & data available
    - Representative jet source: nozzle geometries, flow and cycle conditions
    - Turbomachinery (broadband) source: representative nacelle with ‘impinging-jet” source

- Empennage-mounted engine configuration PAA-effect prediction adjusted
  - Uniformly applied spectrally at each polar and azimuthal directivity angle
    - Lateral: reduced “shielding” effect
    - Approach and Flyover: increased “shielding” effect

Engine Source/ PAA map source	Approach	Lateral	Flyover
fan & core / Broadband (dB)	-1.0	+3.3	-1.5
Jet / Jet (dB)	0.0	+1.5	0.0

Predicted PNLT and EPNL With Adjusted Noise Scattering Maps

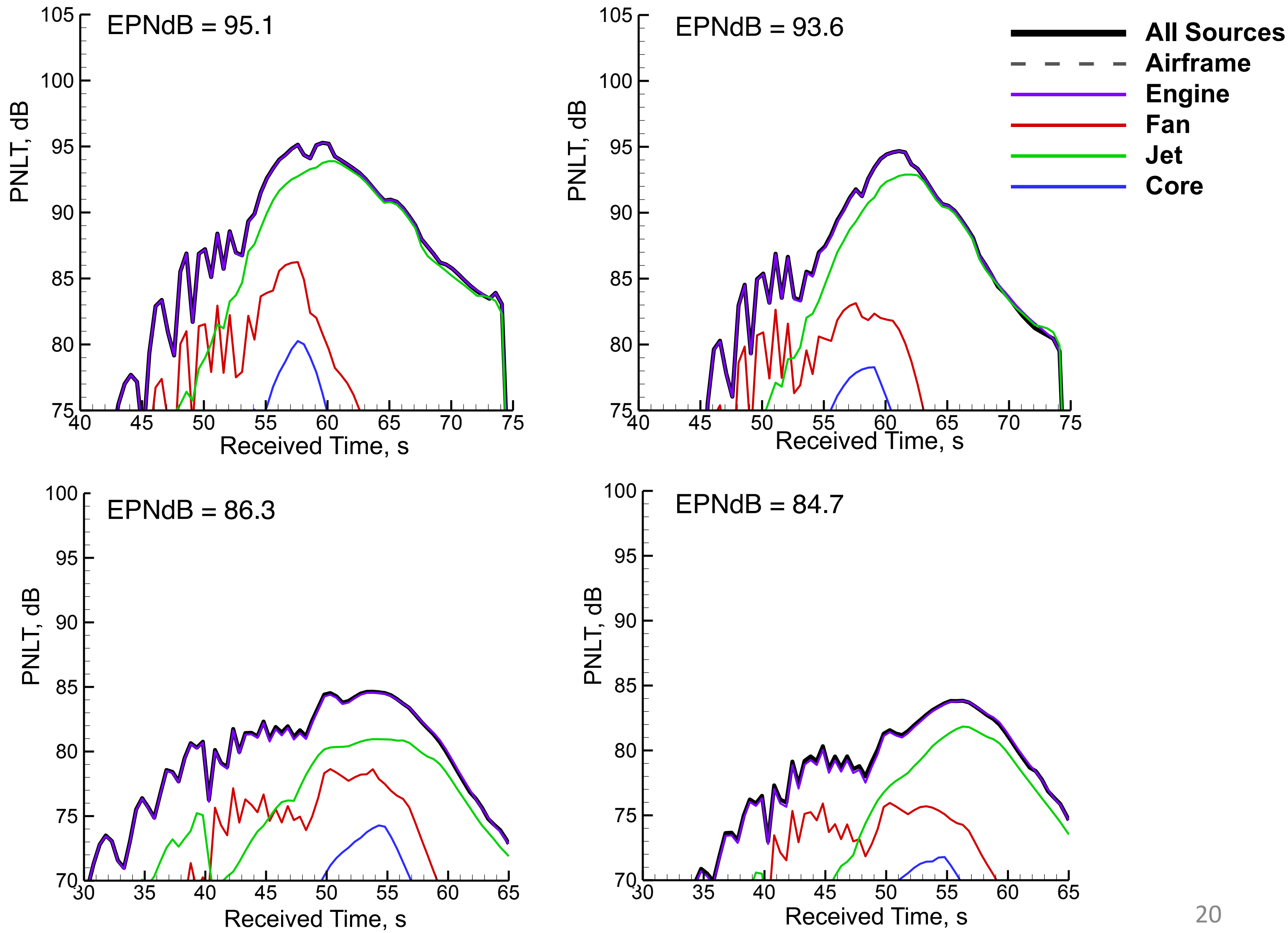
Under-the-wing engines | **Empennage-mounted engines**

Lateral

ΔEPNdB=1.5

Flyover

ΔEPNdB=1.6



Acoustic Scattering Prediction Uncertainty

- Established through deductive inference and additional considerations
  - **If** Reference Dataset quantifies the PAA-effect between aircraft configurations
  - **And** the PAA-effect difference can be computed through simulation whereby only change is the engine noise scattering prediction
  - **Then** the discrepancy between results from Reference Dataset and simulation is measure of prediction uncertainty

  - Additional considerations include fidelity of PAA-effect prediction method datasets and modeling, and their range of validity for vehicles in flight

Engine Source/ PAA map source	95% Confidence Level	Standard Deviation
Fan & Core / Broadband (dB)	± 4	2
Jet / Jet (dB)	± 2	1

Concluding Remarks

- Described a process to quantify the uncertainty of the “acoustic scattering prediction element” utilized in full-scale, full-fidelity aircraft system noise simulations

- Scattering prediction element uncertainty quantified using the “Reference data prediction test method” with full-scale, full-fidelity aircraft flight data

- Quantification of the “acoustic scattering prediction element” is a valuable contribution to establishing aircraft noise prediction uncertainty for both conventional and unconventional configurations.

- Acoustic scattering prediction uncertainty can be improved, particularly for installed turbomachinery sources, through dedicated campaigns:
  - Higher fidelity flight acoustic “Reference Dataset”
  - Large-scale wind tunnel PAA tests with representative source
  - Development and validation of physics-based computational methods