PROGRESS TOWARD N+1 NOISE GOAL

Abstract

A review of the progress made towards achieving the Subsonic Fixed Wing project's noise goal for the next generation single aisle aircraft is presented. The review includes the technology path selected for achieving the goal as well as highlights from several in-house and partnership test programs that have contributed to this effort. In addition, a detailed, self-consistent, analysis of the aircraft system noise for a conceptual next generation single aisle aircraft is also presented. The results indicate that with the current suite of noise reduction technologies incorporated into the conceptual aircraft a cumulative noise reduction margin of 26 EPNdB could be expected. This falls 6 dB short of the N+1 goal, which is 32 EPNdB below Stage 4 noise standard. Potential additional noise reduction technologies to help achieve the goal are briefly discussed.

Progress Toward N+1 Noise Goal

Ed Envia
API for Acoustics

Contributors: Jeff Berton, James Bridges, Casey Burley,
Mike Jones, Mehdi Khorrami, and John Rawls

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System Level Metrics

.... technology for dramatically improving noise, emissions, & performance

CORNERS OF THE TRADE SPACE	N+1 (2015 EIS) Generation Conventional Tube and Wing (relative to B737/CFM56)	N+2 (2020 IOC) Generation Unconventional Hybrid Wing Body (relative to B777/GE90)	N+3 (2030-2035 EIS) Generation Advanced Aircraft Concepts (relative to user defined reference)
Noise	- 32 dB (cum below Stage 4)	- 42 dB (cum below Stage 4)	55 LDN (dB) at average airport boundary
LTO NOx Emissions (below CAEP 6)	-60%	-75%	better than -75%
Performance: Aircraft Fuel Burn	-33%**	-40%**	better than -70%
Performance: Field Length	-33%	-50%	exploit metro-plex* concepts

** An additional reduction of 10 percent may be possible through improved operational capability

* Concepts that enable optimal use of runways at multiple airports within the metropolitan areas

--- EIS = Entry Into Service; IOC = Initial Operating Capability

Approach

- Enable Major Changes in Engine Cycle/Airframe Configurations

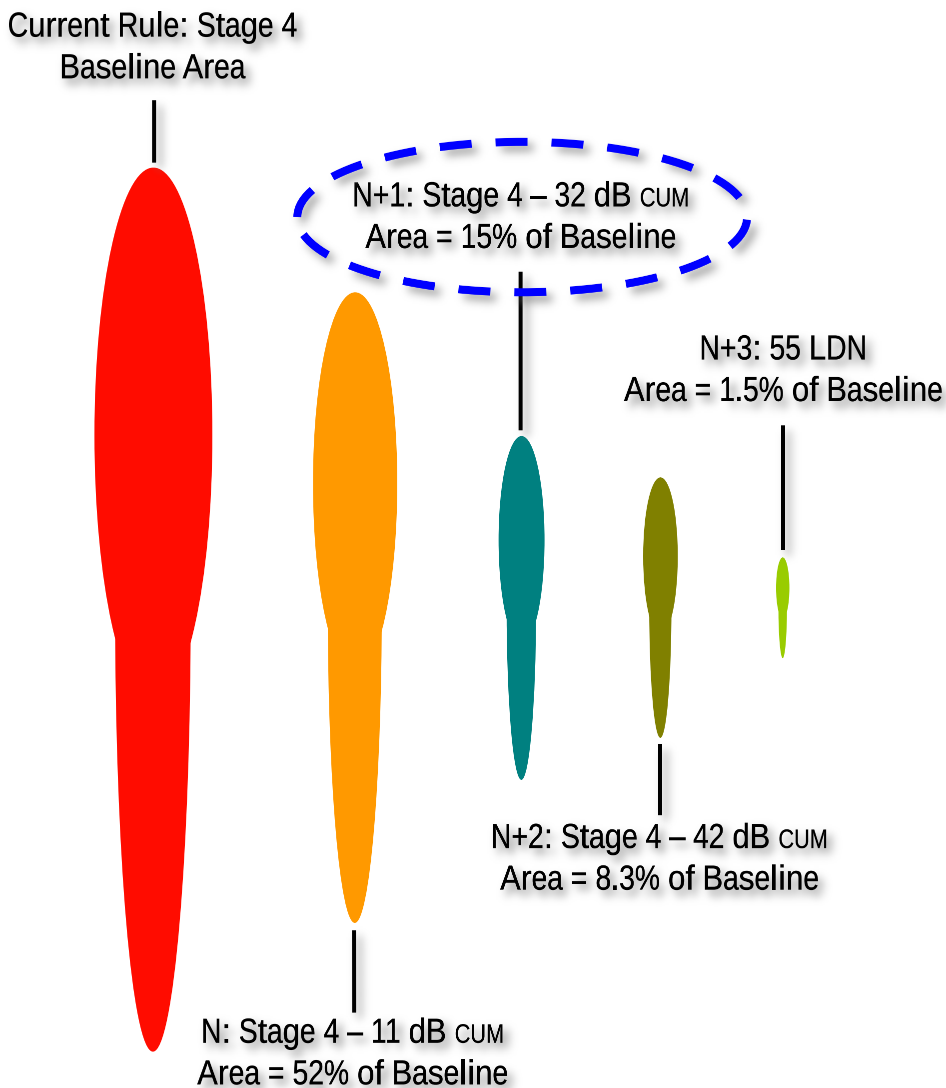
- Reduce Uncertainty in Multi-Disciplinary Design and Analysis Tools and Processes

- Develop/Test/ Analyze Advanced Multi-Discipline Based Concepts and Technologies

- Conduct Discipline-based Foundational Research

Representation of SFW Noise Reduction Goals

Change in noise "footprint" area for a single event landing and takeoff



- Relative ground contour areas for notional Stage 4 and SFW N+1, N+2, and N+3 aircraft
  - Independent of aircraft type/weight
  - Independent of baseline noise level
- Noise reduction assumed to be evenly distributed between the three certification points
- Simplified model: Effects of source directivity, wind, etc. not included

Technical Challenges

- Enabling Materials

  — Development of low-noise aircraft components and systems often requires the use of novel materials or structures. The Materials and Structures (M&S) discipline is focused on addressing this technical challenge based on the requirements defined by the Acoustics discipline.

- Engine/Airframe Integration

  — A noise optimized N+1 aircraft will pose more challenging nacelle/airframe integration issues than a current generation aircraft. Through partnerships with industry, SFW project is addressing this technical challenge.

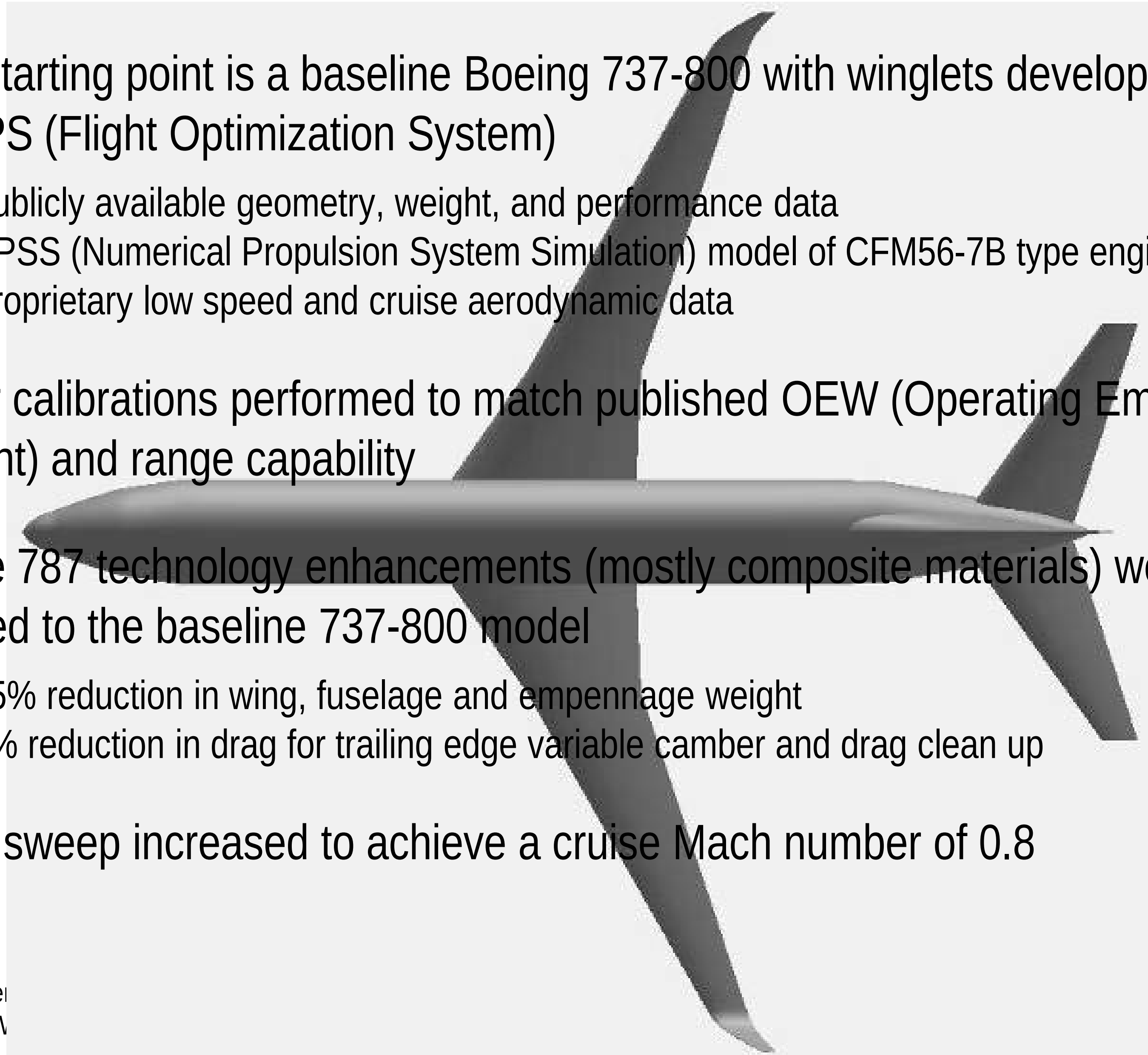
- Noise Reduction Technologies

  — Dramatic changes in engine cycle alone will not be sufficient to achieve the N+1 noise goal. It is necessary to augment the benefits of low-noise engine cycles with aggressive propulsion and airframe noise reduction technologies. Acoustics discipline is primarily focused on addressing this particular technical challenge.

Assessing Technologies for Meeting N+1 Noise Goal

- Objective
  - Define a technology path for meeting the N+1 noise goal using a notional next generation single aisle aircraft
- Strategy
  - Seek a noise-optimized solution that leverages the cycle noise benefits of an ultra high bypass (UHB) turbofan engine together with rig and wind tunnel/static engine/flight validated noise reduction technologies for engine and airframe components
- Methodology
  - Use analytical design tools, wind tunnel component noise data (where available), and measured benefits of various noise reduction technologies to develop a bottoms-up, self consistent system analysis of the noise levels of the notional aircraft
  - Continue development of propulsion and airframe technologies needed to achieve the N+1 noise goal at high technology readiness level

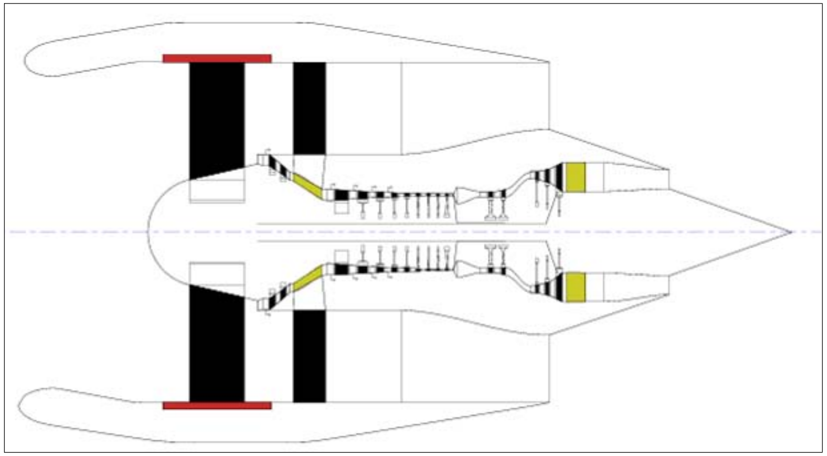
Notional Aircraft



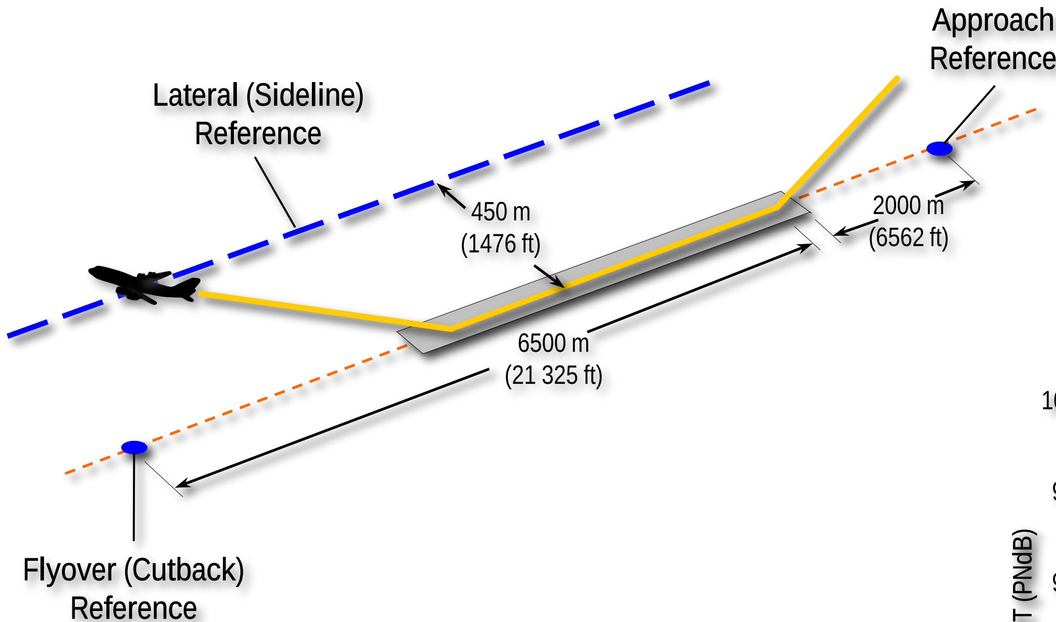
- The starting point is a baseline Boeing 737-800 with winglets developed in FLOPS (Flight Optimization System)
  - — Publicly available geometry, weight, and performance data
  - — NPSS (Numerical Propulsion System Simulation) model of CFM56-7B type engine
  - — Proprietary low speed and cruise aerodynamic data
- Minor calibrations performed to match published OEW (Operating Empty Weight) and range capability
- Some 787 technology enhancements (mostly composite materials) were applied to the baseline 737-800 model
  - — 15% reduction in wing, fuselage and empennage weight
  - — 1% reduction in drag for trailing edge variable camber and drag clean up
- Wing sweep increased to achieve a cruise Mach number of 0.8

Notional Engine

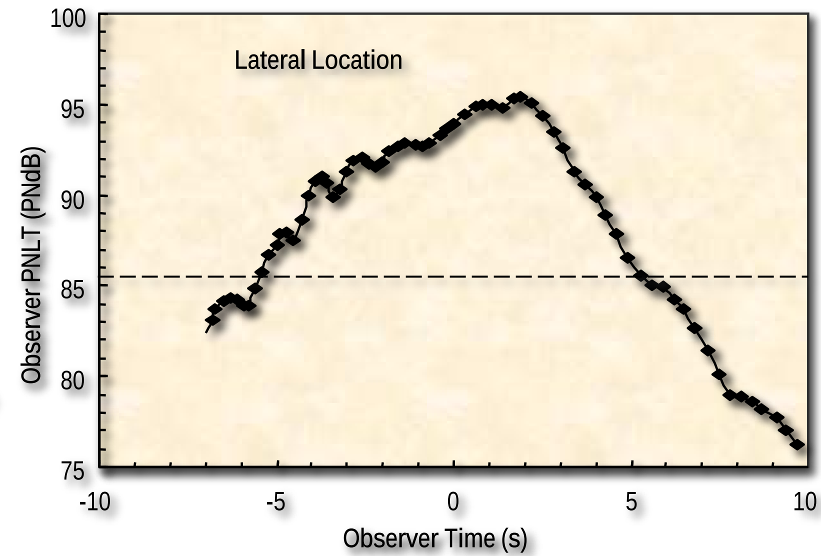
- The System Analysis, Design and Optimization group at NASA analyzed 48 engine designs within the design space covering a range of fan and overall pressure ratios, fan drive architectures and bypass nozzle geometry among other parameters
- Incorporated feedback obtained from P&W on approach and assumptions
  - Adjusted engine component efficiency assumptions
  - Ensured consistency between geared and direct drive engine cycles
  - Considered higher overall pressure ratios
- Assessed sensitivity of efficiency, emissions, and noise tradeoffs to engine architecture and mission requirements
- Selected a geared-driven, noise-optimized, UHB cycle with FPR = 1.4 & OPR = 42



Noise Metrics & Modeling Tools



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



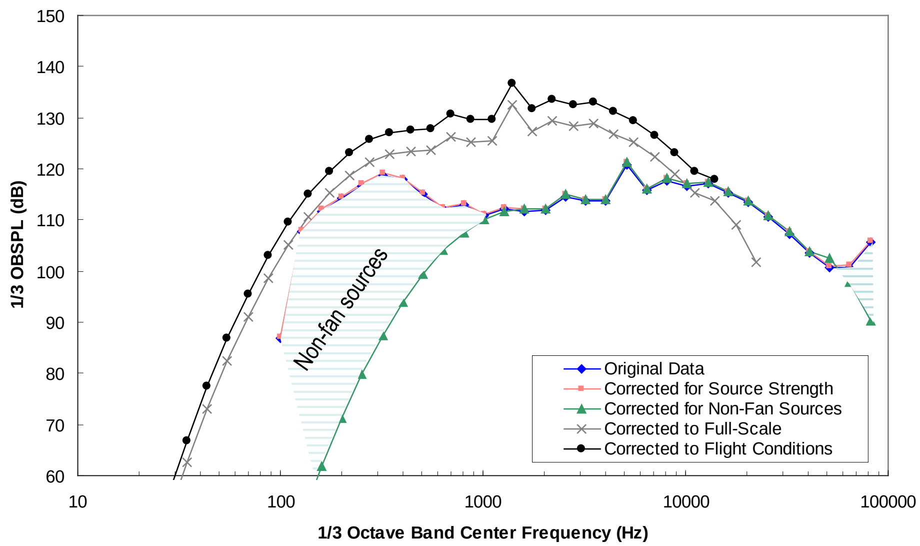
- Aircraft Noise Prediction Program (ANOPP)
- Source noise modeling
- Trajectory simulation
- Spectra propagation (spreading, atmospheric and lateral attenuation, ground effects, reflections)
- Frequency integration
- Tonal content and amplitude penalties
- Ground observer noise-time history

Time integration to
Effective Perceived Noise Level

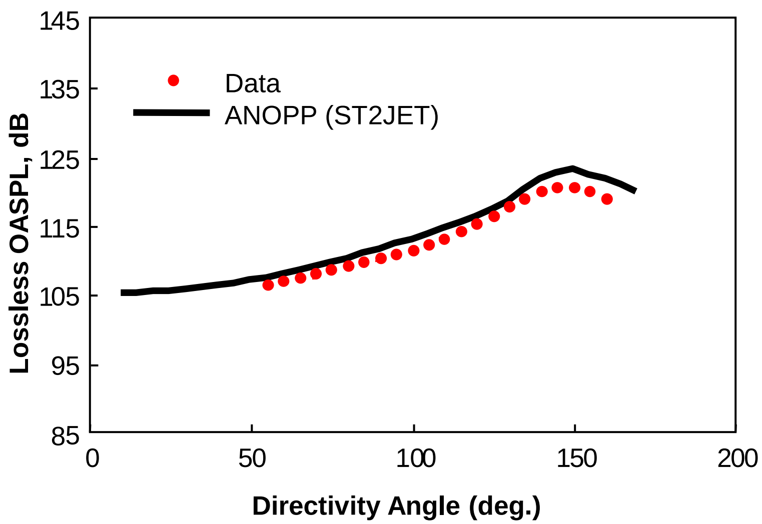
Component Noise Calculations

- For fan and liner components used scale model fan stage wind tunnel noise data to estimate full-scale noise contributions
- For other propulsion components[1] as well as airframe components[2] used ANOPP to estimate full-scale noise contributions

Fan noise model data scaled up to engine size



Jet noise predicted using ANOPP



[1] Jet and core (combustor and turbine)

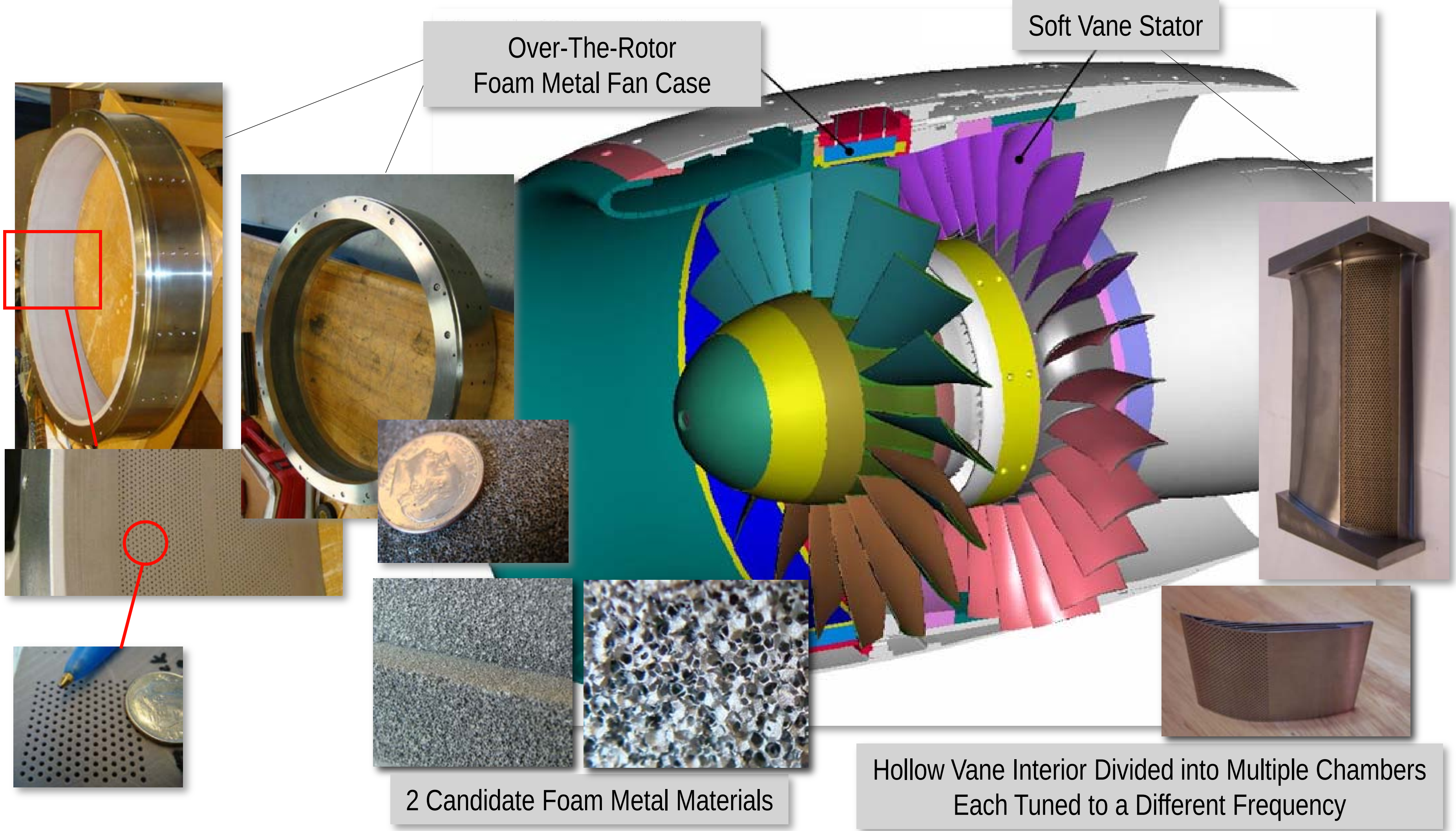
[2] Landing gear, flap, slat, wing, horizontal tail, and vertical tail

Propulsion Noise Reduction Technology Benefits

- Over-The-Rotor Noise Benefit: 3 dB (TRL3, TRL 6*)
- TRL 5 (UHB) Test Completed (October 22)

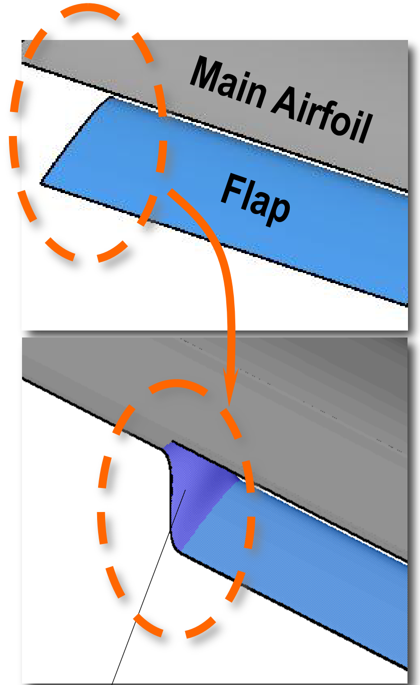
** Williams International FJ44-3A (Low BPR) Engine Test*

- Soft Vane Noise Benefit: 1.5 dB (TRL 3)
- TRL 5 (UHB) Test Completed (October 22)

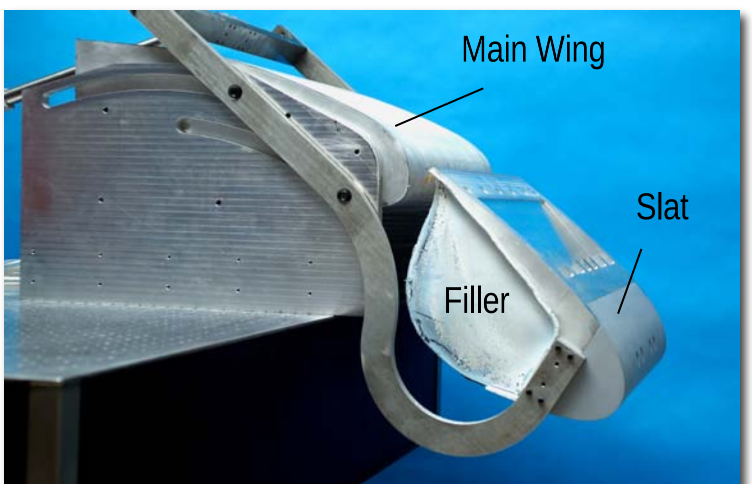


Airframe Noise Reduction Technologies

- Incremental airframe noise reduction technologies
  - — Higher TRL
  - — Includes gears fairings, slat cove filler, and flap porous tips
- Aggressive airframe noise reduction technologies
  - — Lower TRL
  - — Includes gear spoilers and fairings, aggressive slat cove filler, flap continuous mold-line link, and trailing edge treatments (e.g., serrated edges, brushes, etc)



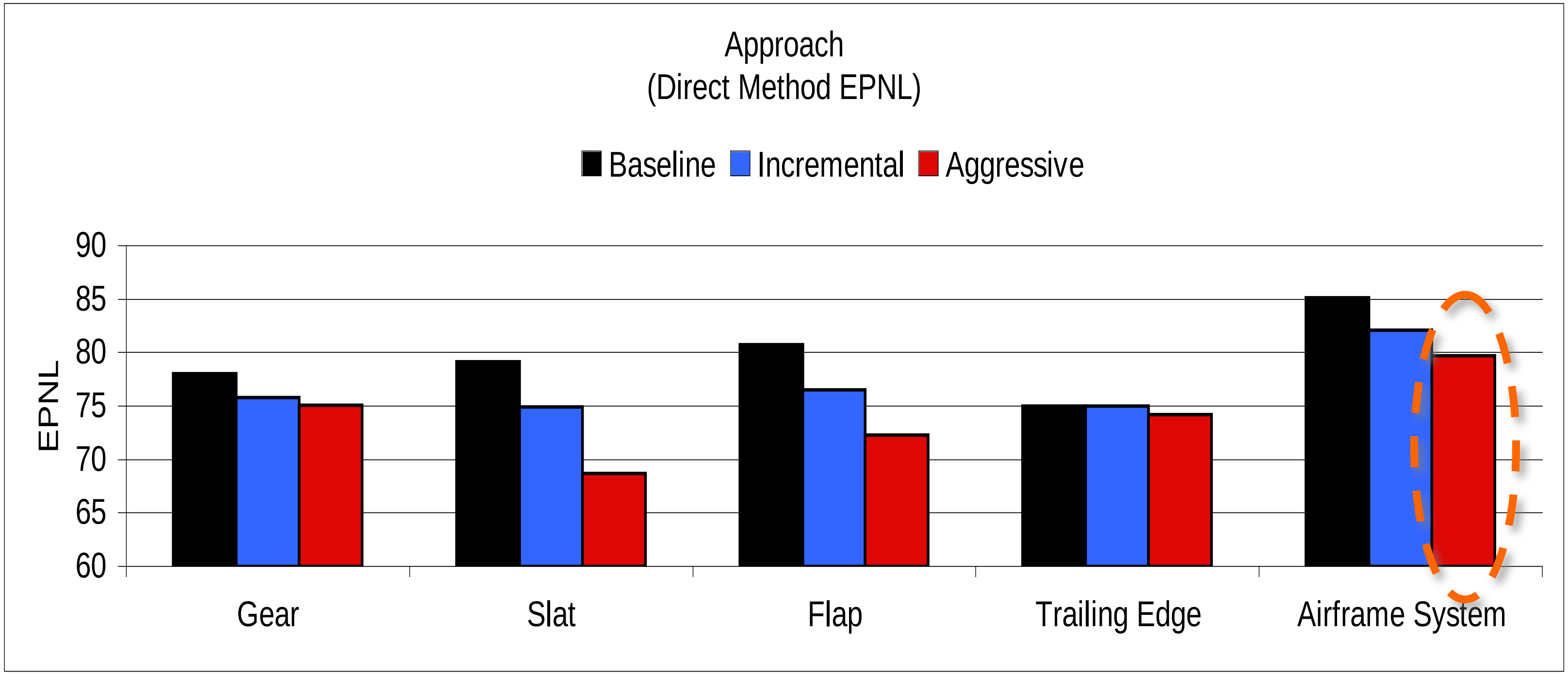
Continuous Mold-Line Link (CML)



Slat-Cove Filler Pneumatic Concept (Bench-Top Model)

Airframe Noise Reduction Technology Benefits

- Approach condition with ground effects included



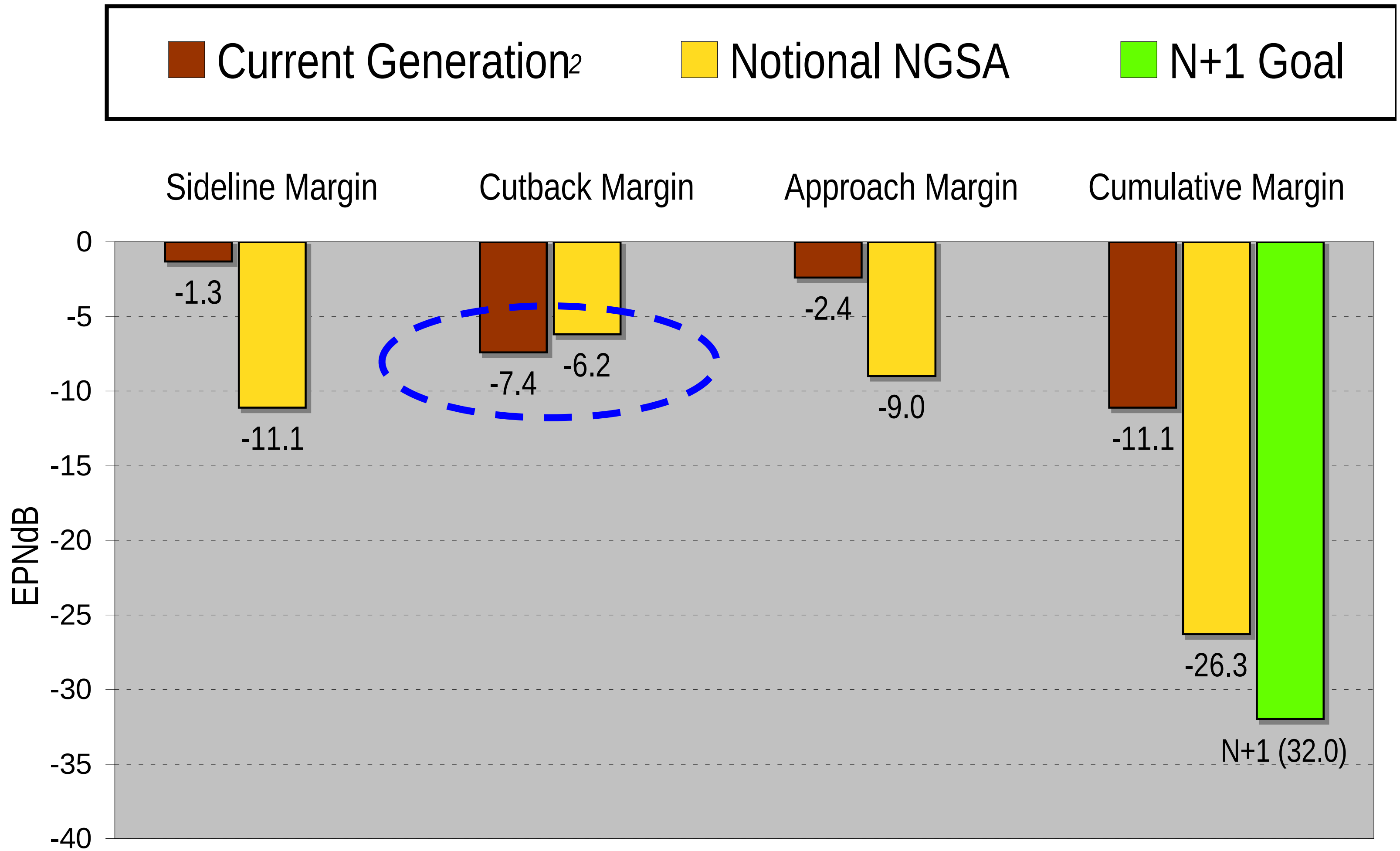
Estimated Noise Levels for Notional Aircraft

Sources	Certification Point Noise Levels (EPNdB)		
	Sideline	Cutback	Approach
Fan*	77.5	76.7	85.8
Jet	72.0	66.5	61.1
Core	75.2	74.8	76.4
Engine (Fan + Jet + Core)	81.6	80.1	86.8
Airframe**	71.8	75.9	79.7
Aircraft	82.2	81.8	88.1

* Liner suppression and fan noise reduction technologies benefits included at all three certification points
** Aggressive airframe noise reduction benefits included for the approach condition only

Estimated Noise Margins for Notional Aircraft

(All numbers relative to Stage 4 noise limit[1])



[1] Stage 4 "certification point limits" calculated by subtracting 3.33 EPNdB from the corresponding Stage 3 noise limits
[2] Current generation is represented by a certified A318-111 with CFM56-5B8/P engines

Observations & Comments

- An in-depth, bottoms-up, self-consistent systems analysis study of an engine and airplane system using accepted NASA tools and methods was conducted
- The result is a “low-noise” corner of the trade space
- Status: Current prediction is -26 EPNdB cum below Stage 4 noise limit
- Perspectives
  - This is 6 cum EPNdB short of the N+1 goal
  - P&W’s estimate for a B737 replacement with GTF engines is reported to be 20 EPNdB cum relative to Stage 4 without benefits of noise reduction technologies included

Assessment Results / Implications

- Why the shortfall from the N+1 goal?
  - The original -32 EPNdB goal analysis had incorporated benefits of continuous descent approach (credited at 2 EPNdB), which is inappropriate
  - Unexpectedly small noise reduction margin at cutback. Alternative lapse, trajectory and throttle modeling could result in further 1-2 EPNdB reduction
  - Tools, methods and assumptions have an error margin of 1 EPNdB
- This result indicates that a greater reliance on noise reduction technologies may be needed to achieve the N+1 goal
- Possible path to -32 dB goal could include more aggressive technologies, e.g.
  - Core (and airframe?) noise reduction technologies
  - Advanced liners (zero-splice, etc.)
  - Low-count stator technology
  - Architecture changes
  - …

Propulsion Technology Development Effort
Partnership with Pratt & Whitney

- Fan Cycle and Fan Noise Reduction Technology Tests
  - Scale model UHB cycle noise benefits test completed in November 2006. Cycle benefits demonstrated.
  - Fan noise reduction technology validation test completed in October 2008. Results being analyzed.
  - Aerodynamic integration study test completed in May 2008. Nacelle-wing integration investigated.

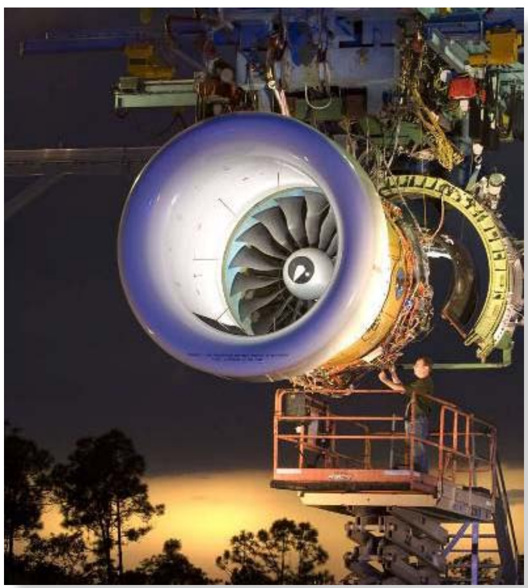
P&W GTF Model Scale Fan in 9'x15' Acoustic Wind Tunnel ('06)

Fan Noise Reduction Technology Test-bed in 9'x15' Acoustic Wind Tunnel ('08)

Powered Half-Span Model in 11' Transonic Wind Tunnel ('08)

Propulsion Technology Development Effort
Partnership with Pratt & Whitney

- Static Engine and Flight Demonstrator Tests
  - Full scale geared turbofan (GTF) test completed in April 2008. Fan noise scaling laws validated.
  - Flight demonstration of GTF engine on P&W 747 test-bed completed in July 2008. Flight test on Airbus A340 currently underway.



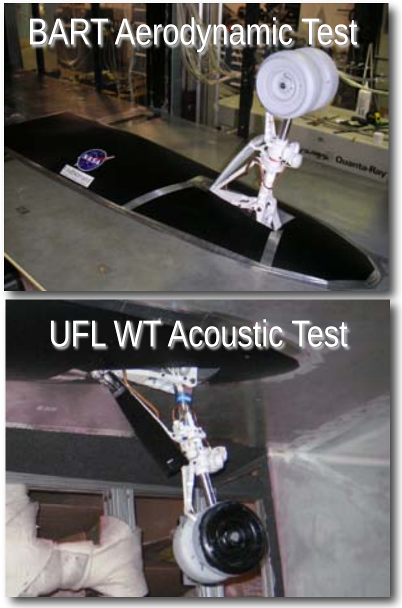
P&W GTF Demonstrator Engine Ground Test ('08)

GTF Demonstrator Engine Installed on P&W 747 Test-bed Aircraft ('08)

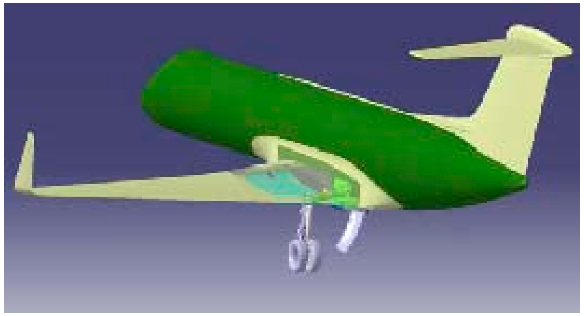
Airframe Noise Investigation Effort
Partnership with Gulfstream

- Airframe Noise Source Investigation and Mitigation Study
  - First flight test of G550 aircraft completed in October 2006. Benchmark airframe noise data acquired.
  - Wind tunnel aero and acoustic tests of the scale model nose gear completed in 2007 & 2008. Sub-scale / full-scale data comparisons carried out.
  - Half-span model of airframe to be tested in wind tunnel in 2009 (aero) and 2010 (acoustic) followed by a second flight test in 2011.

Flight Test of G550 Aircraft ('06)



Nose Gear Model Tests ('07, '08)



Half-Span G550 Sub-Scale Model Tests in 14'x 22' Acoustic Wind Tunnel ('09, '10)