National Aeronautics and Space Administration

Integrated System Research Program
Environmentally Responsible Aviation (ERA) Project
A NASA Aeronautics Project focused on midterm environmental goals

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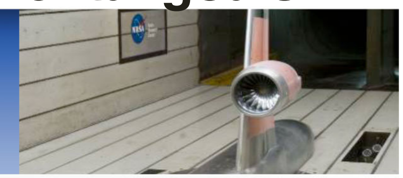


UTIAS /MITACS Aviation and Climate Change Workshop
MAY 27-28, 2010

www.nasa.gov

Topics Addressed

- ERA Goals, Objectives and System Level Metrics
- ERA Project Flow and FY11 President's Budget
- "Technology Collectors" – Current Set
- Technical Approach - Accomplishing N+2 Goals
- Vehicle Study
- Highlights

ERA Goals, Objectives & System Level Metrics

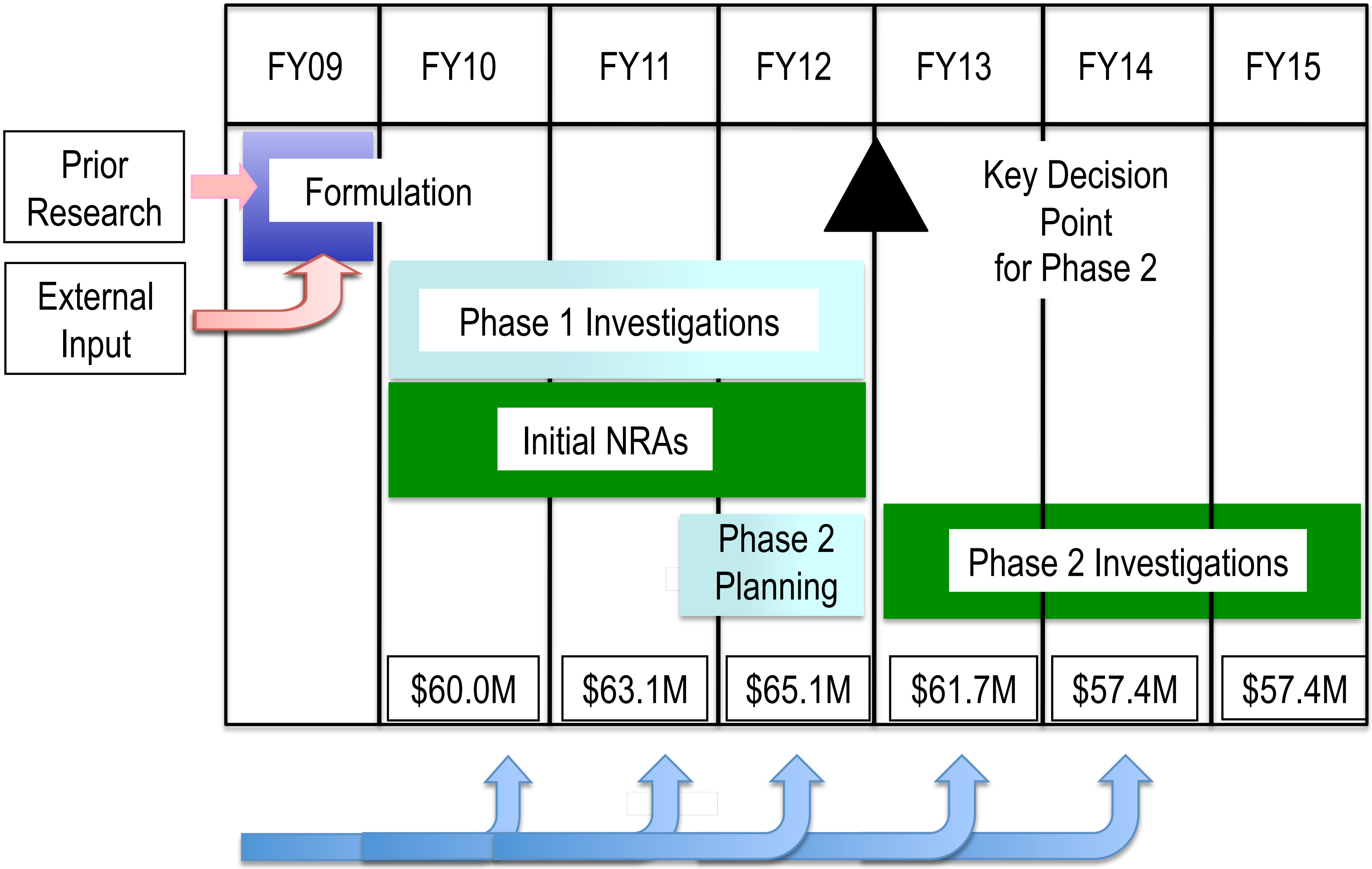
Over the next 5 years:

- Explore and mature alternate unconventional aircraft designs and technologies that have potential to simultaneously meet community noise, fuel burn, and NOX emission midterm goals as described in the National Aeronautics R & D Plan
- Determine potential impact of these aircraft designs and technologies if successfully implemented into the Air Transportation System
- Determine potential impact of these technologies on advanced "tube and wing" designs

CORNERS OF THE TRADE SPACE	N+1 = 2015*** Technology Benefits Relative To a Single Aisle Reference Configuration	N+2 = 2020*** Technology Benefits Relative To a Large Twin Aisle Reference Configuration	N+3 = 2025*** Technology Benefits
Noise (cum below Stage 4)	-32 dB	-42 dB	-71 dB
LTO NO_x Emissions (below CAEP 6)	-60%	-75%	better than -75%
Performance: Aircraft Fuel Burn	-33%	-50%**	better than -70%
Performance: Field Length	-33%	-50%	exploit metro-plex* concepts

***Technology Readiness Level for key technologies = 4-6. ERA will undertake a time phased approach, TRL 6 by 2015 for "long-pole" technologies
** RECENTLY UPDATED. Additional gains may be possible through operational improvements
* Concepts that enable optimal use of runways at multiple airports within the metropolitan area

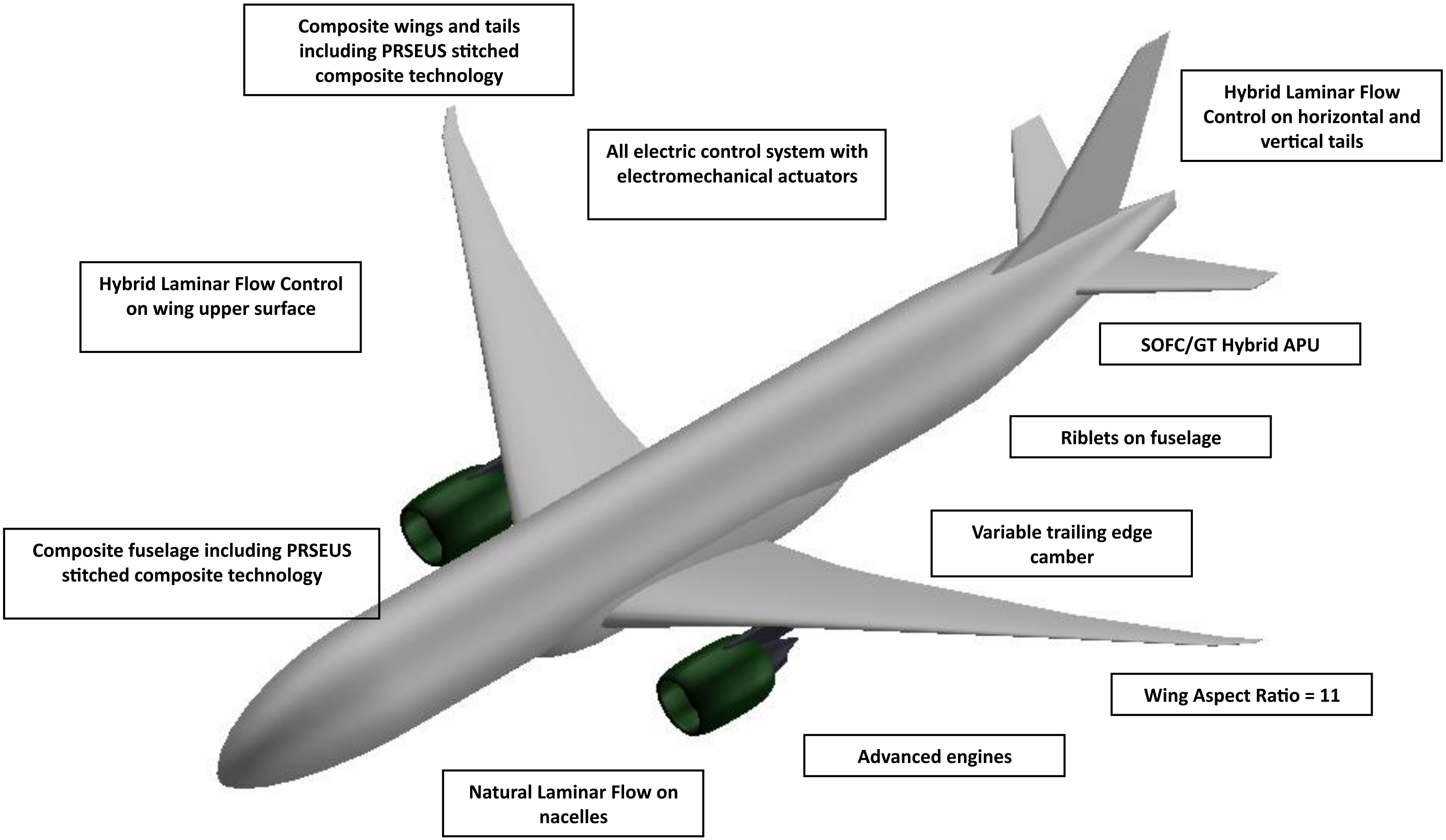
ERA Project Overview, Flow And Key Decision Point for Phase 2



Technical input from Fundamental Programs, NRAs, Industry, Academia, Other Gov't Agencies

2025 “Technology Collectors” – Current Set

Advanced Configuration 1
N+2 Advanced "tube-and-wing" 2025 Timeframe



Advanced Configuration 2A
N+2 Advanced HWB 2025 Timeframe

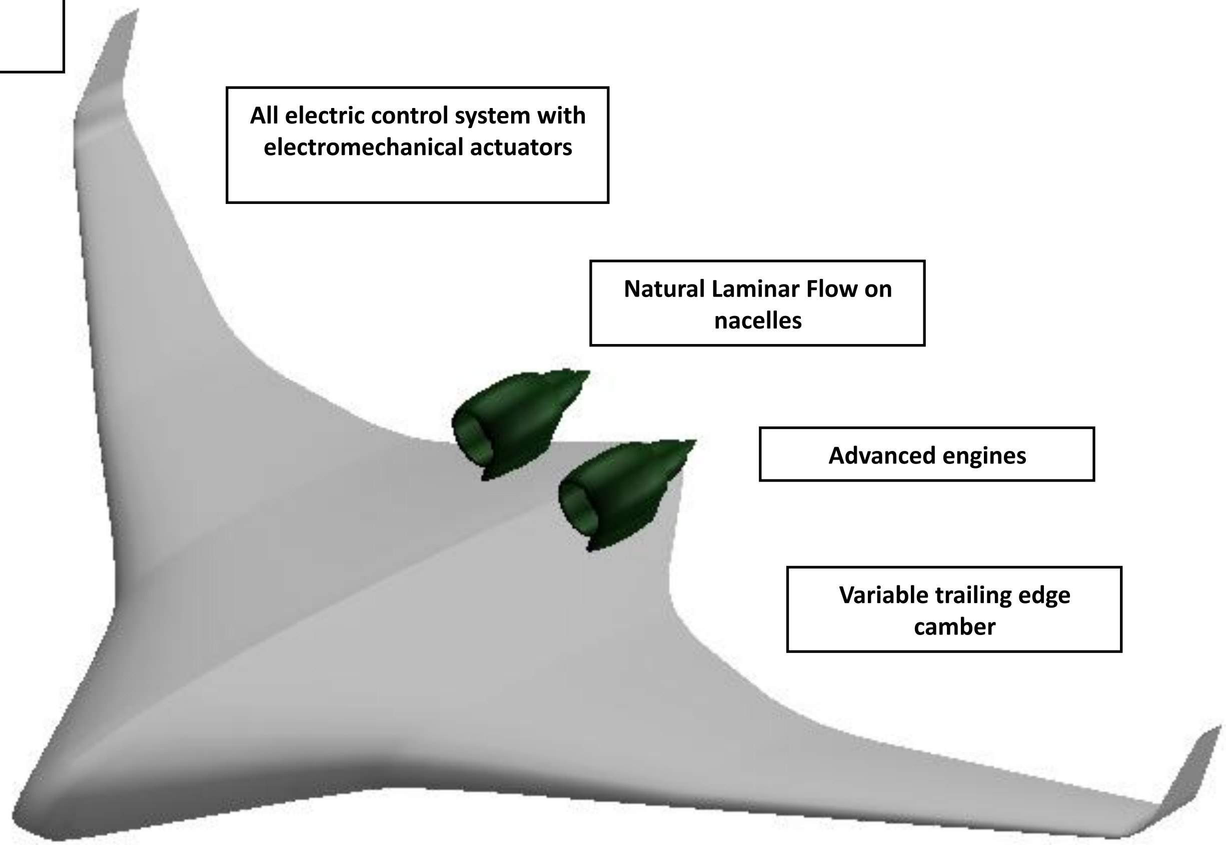
Composite centerbody and wings including PRSEUS stitched composite technology

All electric control system with electromechanical actuators

Hybrid Laminar Flow Control on outer wing sections

Natural Laminar Flow on nacelles

Advanced engines

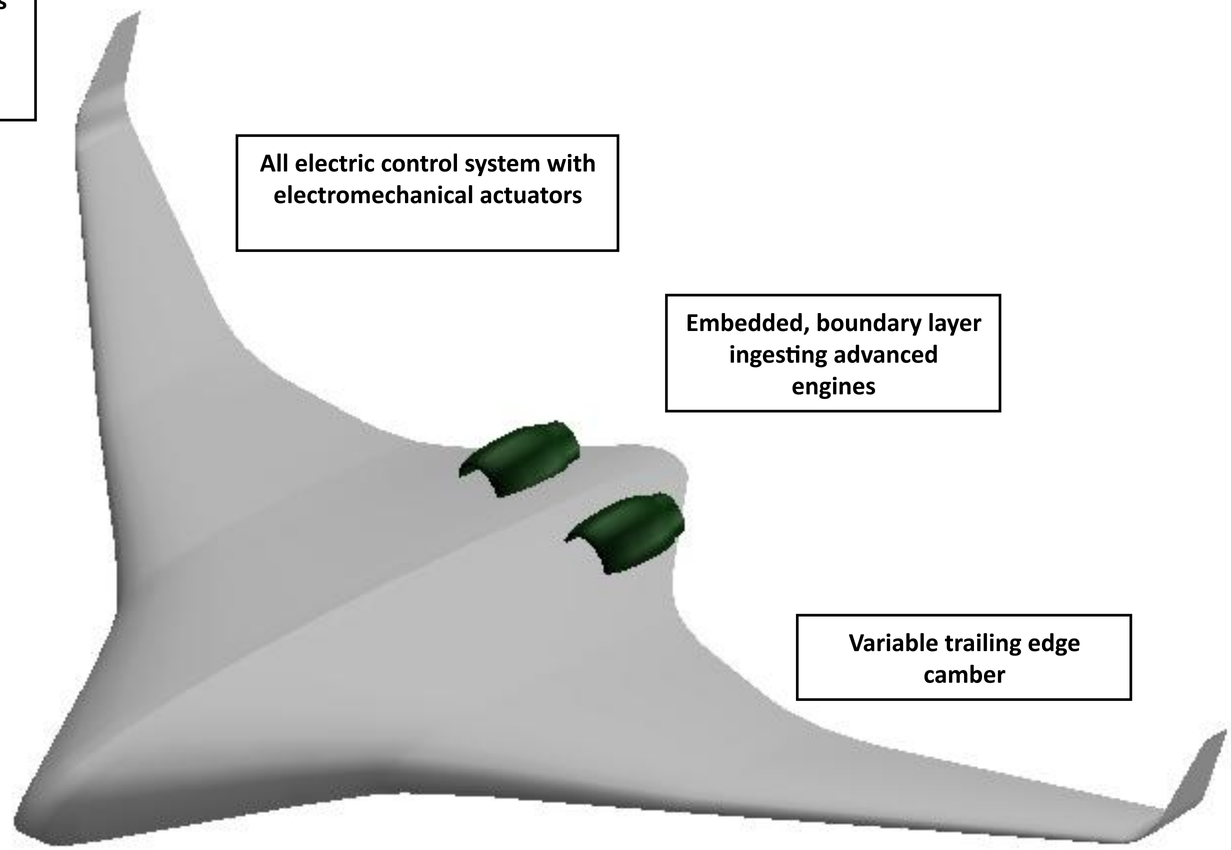


Variable trailing edge camber

Riblets on centerbody

SOFC/GT Hybrid APU

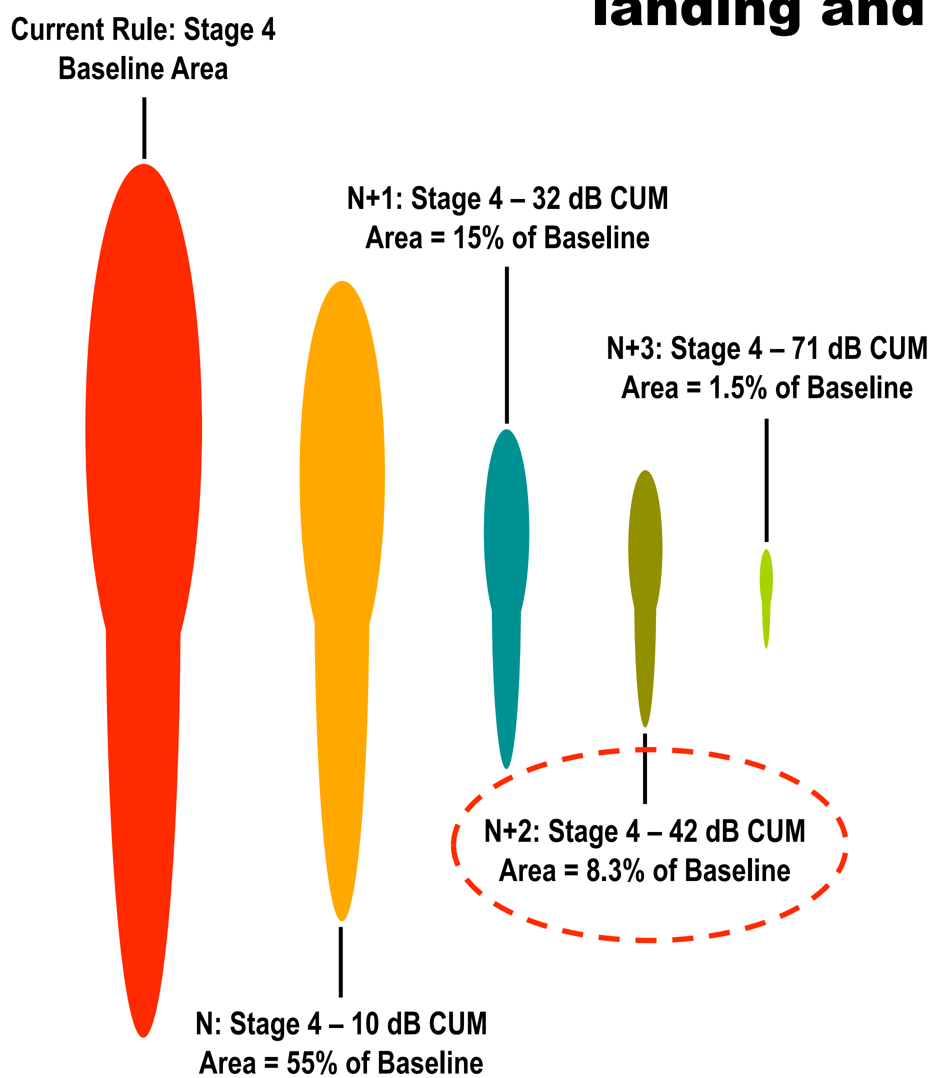
Advanced Configuration 2B
N+2 HWB300 2025+ Timeframe



Specific System Level Metrics and Technical Approaches

NASA's Noise Reduction Goals

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

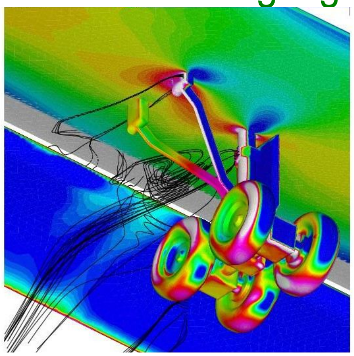


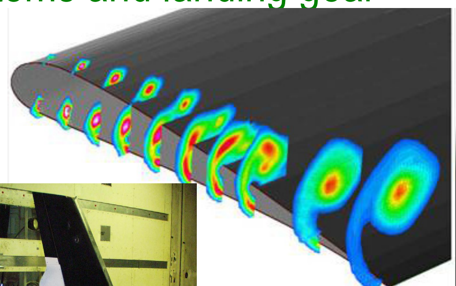
- Relative ground contour areas for notional Stage 4 and N+1, N+2, and N+3 aircraft
  - Independent of aircraft type/weight
  - Independent of baseline noise level
- Noise reduction assumed to be evenly distributed between the three certification points
- Simplified model: Effects of source directivity,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

Addressing Noise Reduction

Airframe Noise

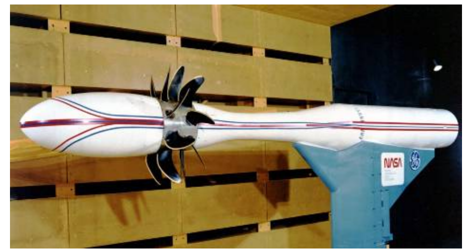
Addressing high-lift systems and landing gear





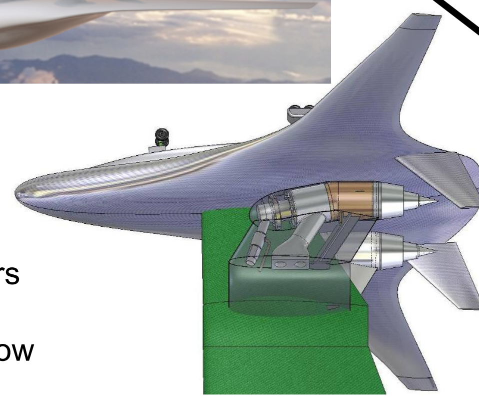
Propulsion Noise

Addressing fan, core, and jet noise



Open Rotor

UHB Turbofans



- Twin High Bypass Ratio Jet Simulators
- Simplified Fan Noise Simulator
- Instrumentation and Processing for Low Noise Levels

Propulsion Airframe Aeroacoustics

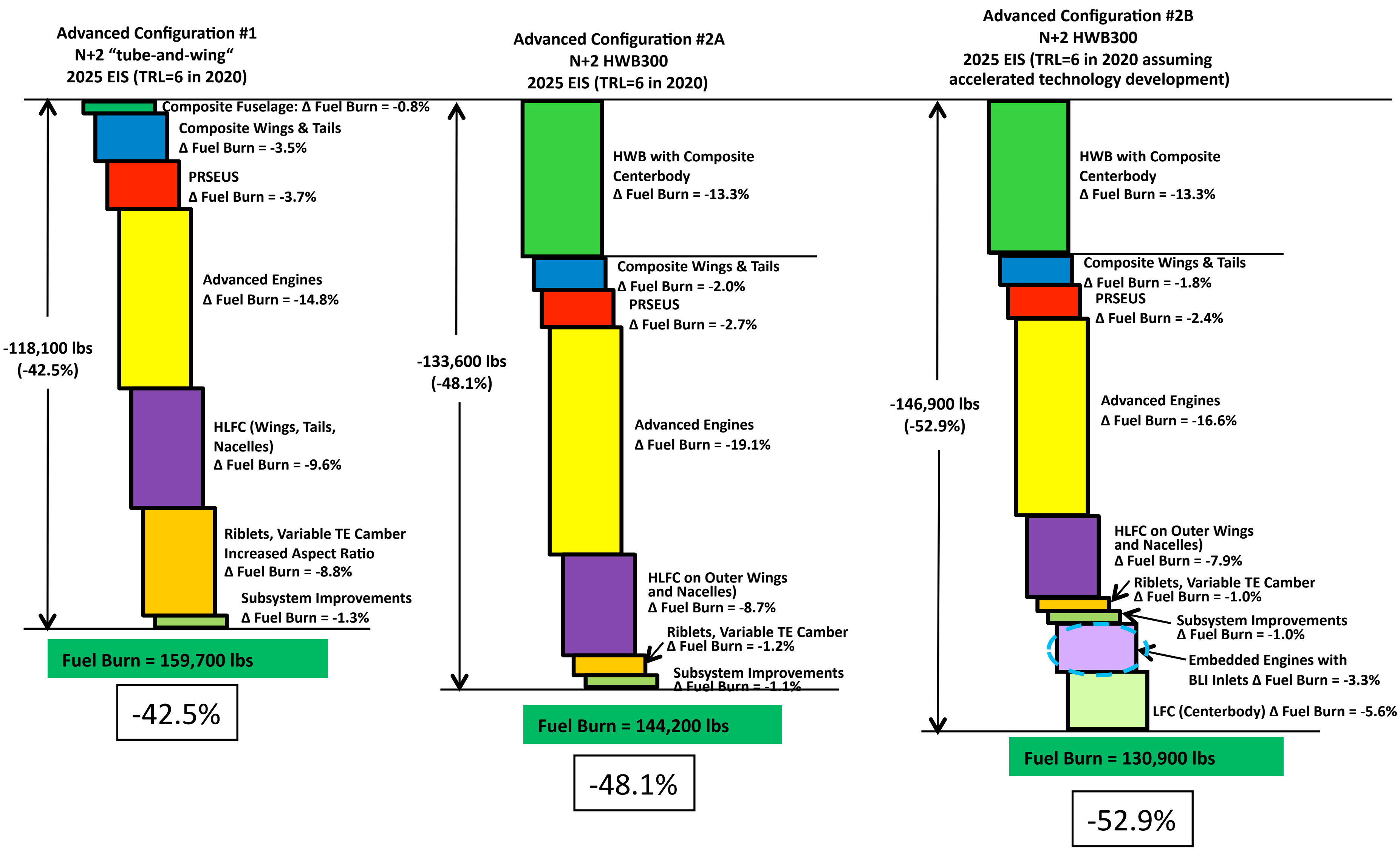
Addressing airframe/propulsion interaction - shielding

POTENTIAL REDUCTION IN FUEL CONSUMPTION

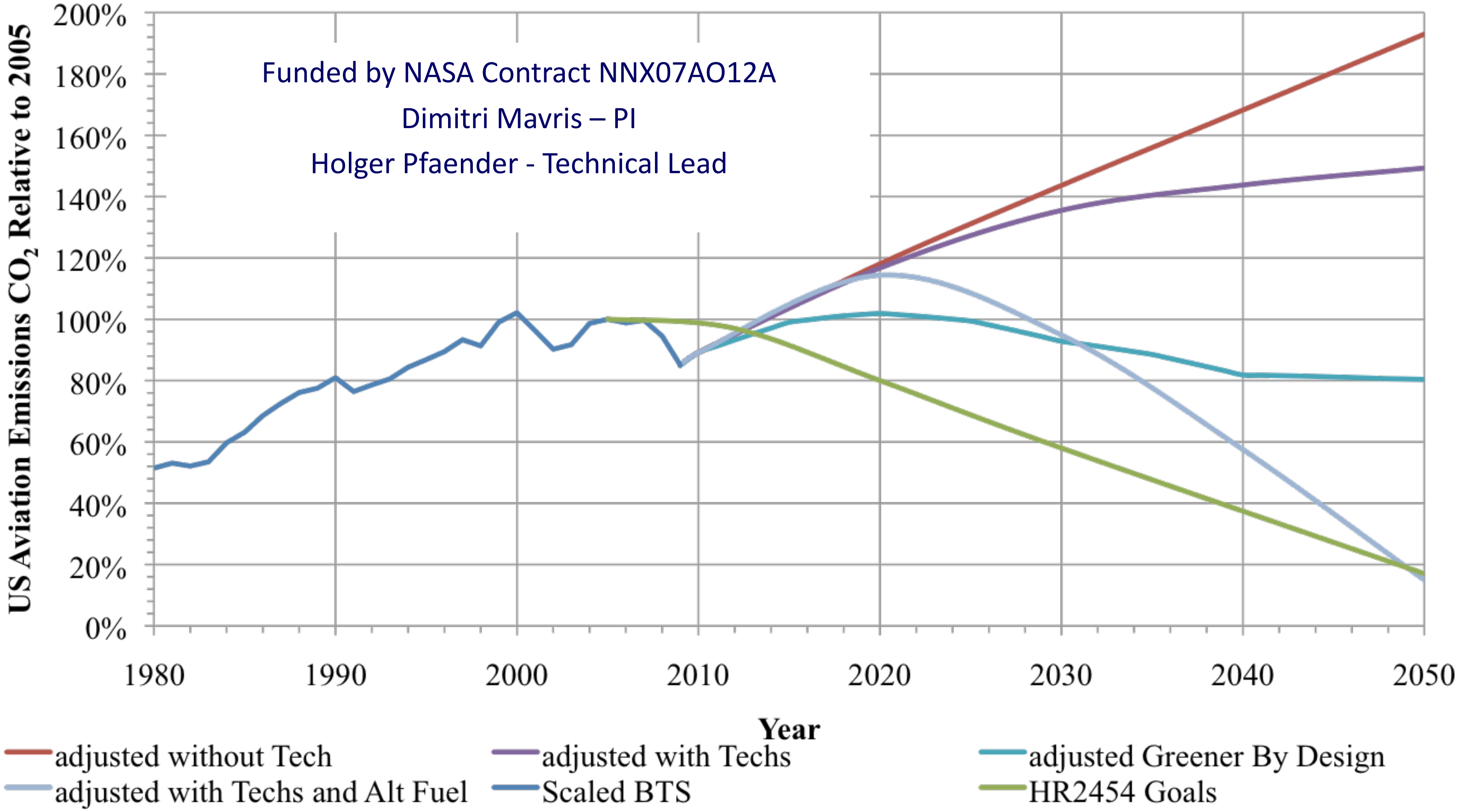
Advanced N+2 Configurations

Reference Fuel Burn = 277,800 lbs

"777-200LR-like" Vehicle



NASA Fuel Burned Goals – More Insight



Magnitude of emissions growth and gap is dependent upon aviation traffic growth assumptions

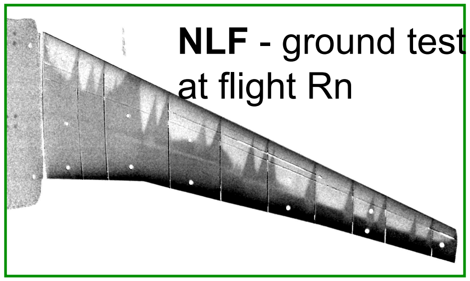
Addressing Fuel Burn (CO_2 Emissions)

DRAG REDUCTION via Laminar Flow

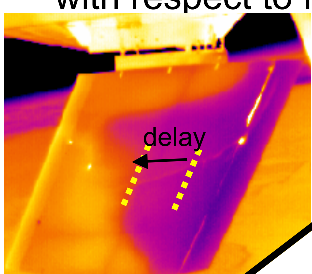
Addressing concepts & barriers
to achieving practical laminar flow on transport a/c

HLFC - revisit crossflow expt
- understand system weight

NLF - ground test
at flight Rn

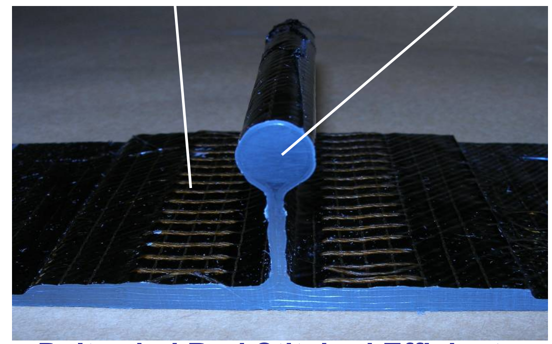


DRE - exploring the limits
with respect to Rn

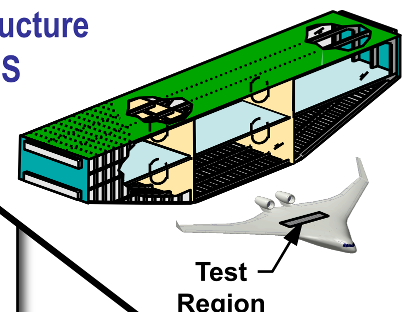


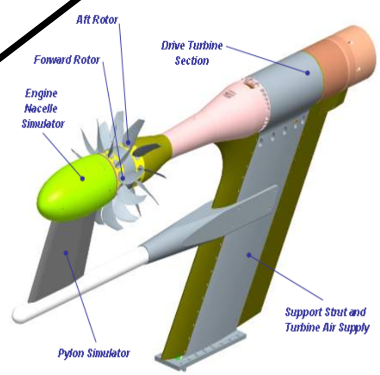
WEIGHT REDUCTION via Advanced Structures

Moving from "safe-life" to "fail-safe" design
with a lightweight composite structure

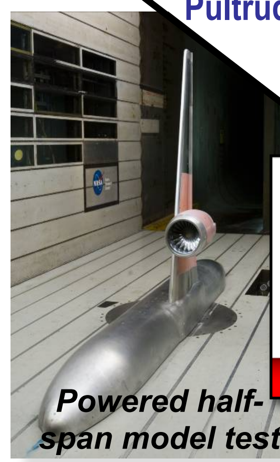


Pultruded Rod Stitched Efficient
Unitized Structure
PRSEUS

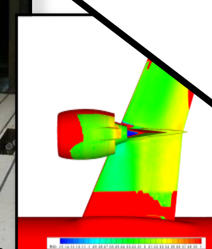




Open Rotor Propulsion Rig



Powered half-span model test

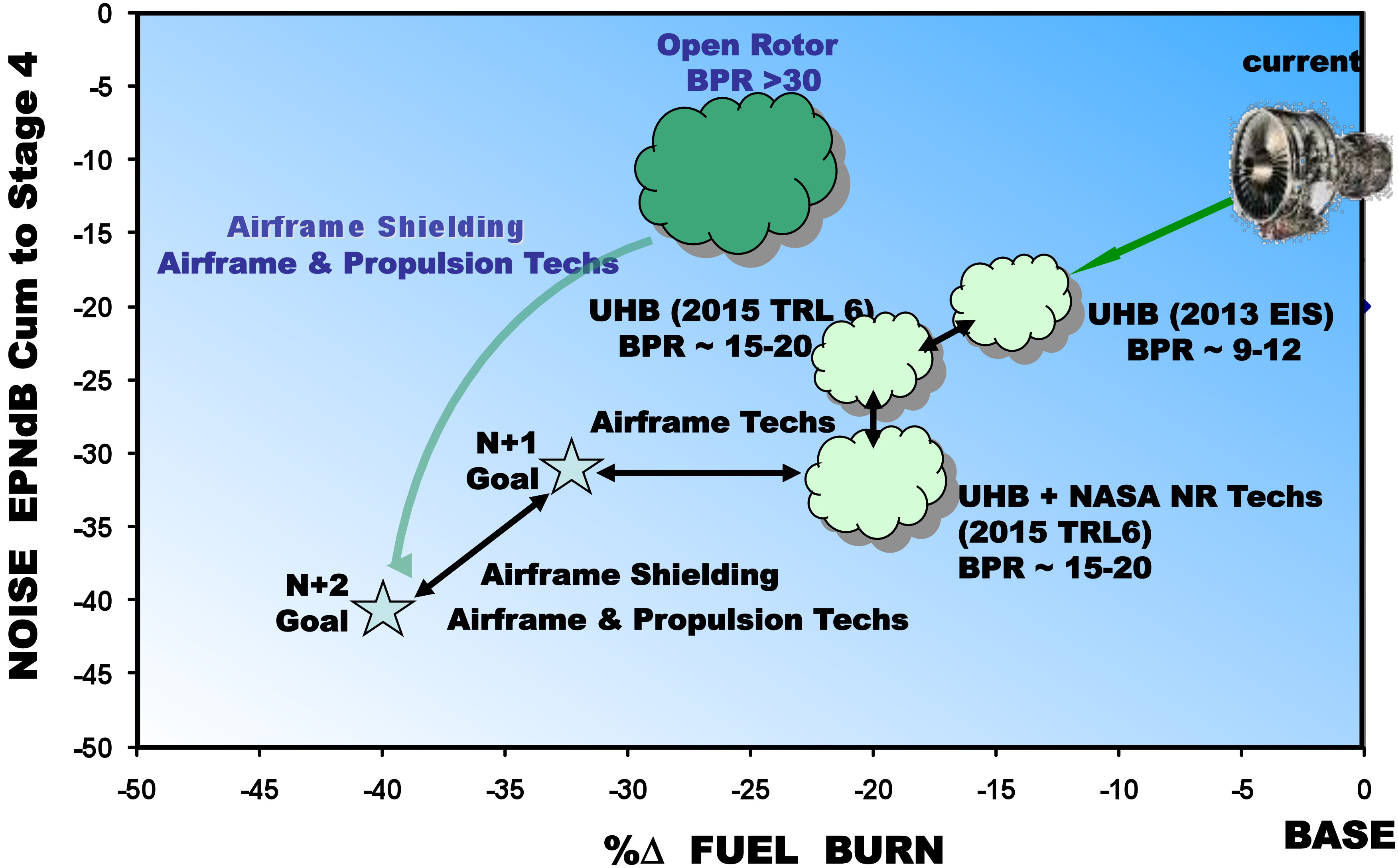


PSP Results

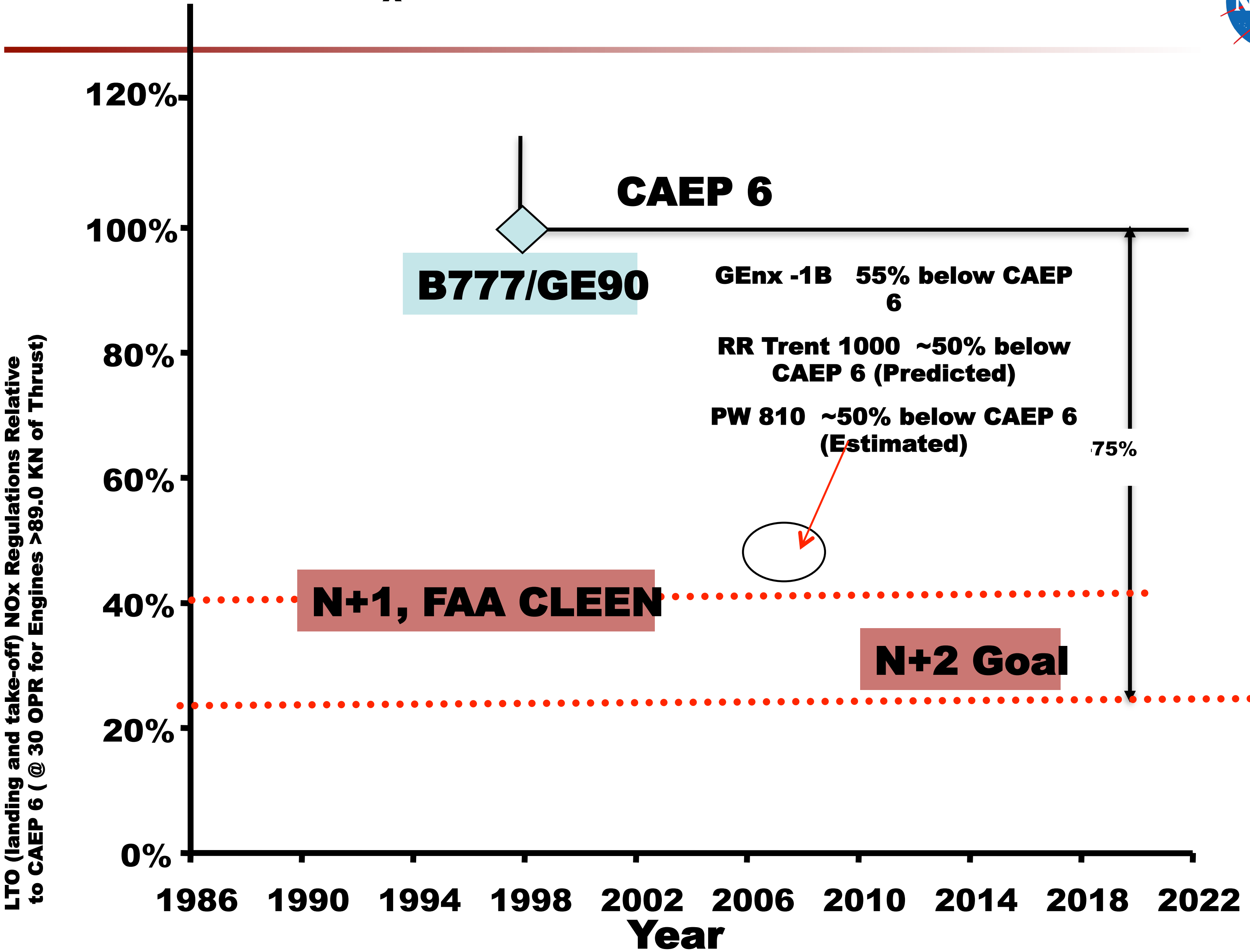
SFC REDUCTION via UHB

Addressing multidisciplinary challenges from subcomponent to installation
to achieve ultra-high by-pass ratio

Propulsor Technology Roadmap



N+2 LTO NO_x Reduction Goal – More Insight

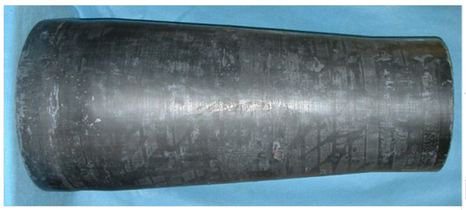


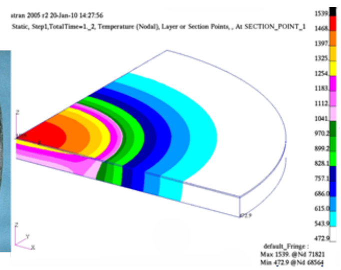
Addressing Reduced LTO NO_x Emissions

ERA CMC Combustor Liner

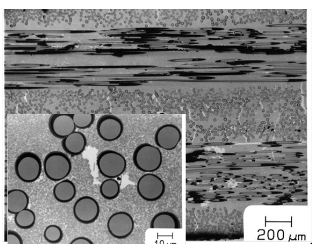
CMC combustor liner enables new engine designs incorporating higher engine temperatures and reduced cooling air flows

CMC combustor liner



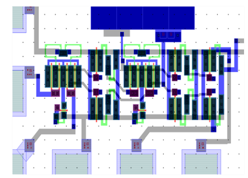


SIC CMC – enable higher temperature engine



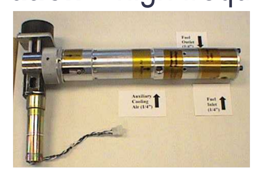
Active Combustion Instability Control

Demonstrating the capability to suppress combustor instabilities for low emission combustors

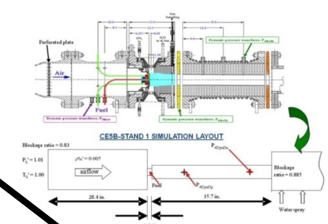


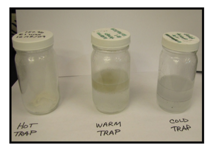
High Temperature SiC electronics circuits and dynamic pressure sensors

Fuel Modulation – high frequency fuel delivery systems

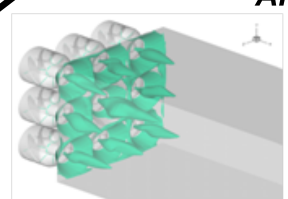


Instability Models and Control Methods

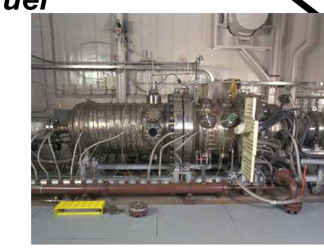




Alternative fuel



Innovative Injector Concept



ASCR Combustion Rig

Low Nox, Fuel-Flexible Combustor

- **High Bypass Ratio/High Pressure Combustor**
- **Superior Alternative Fuel properties**
- **Enhance Fuel/Air Mixing**
- **Advanced Ignition**

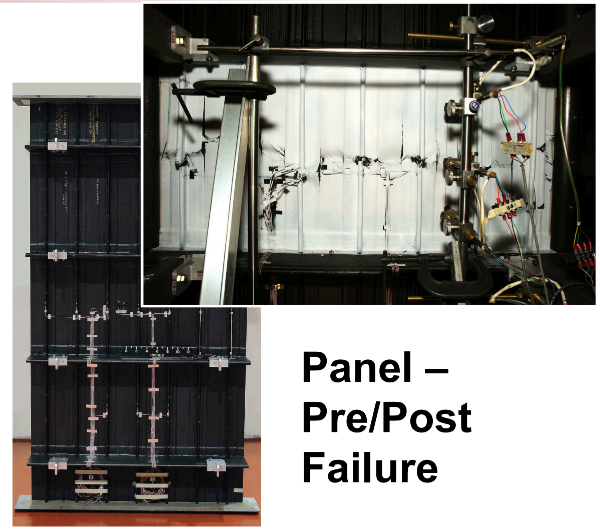
Vehicle Study

- NASA intends to release a BROAD solicitation within the month to:
  - Seek up to 4 subsonic transport vehicle concepts capable of simultaneous achievement of the N+2 noise, NOX and fuel burn system level metrics
  - Develop 15-year technology maturation roadmaps – addressing propulsion and airframe and integration requirements
  - Determine initial system readiness levels, and plot expected system readiness maturation with execution of the 15-year technology roadmaps
  - Explore two additional options -
    - Option 1 – Select up to 2 of subsonic transport vehicle concepts to develop preliminary designs (of sufficient scale to demonstrate goals)
    - Option 2 – Identify risk reduction testing and assessment programs associated with the scaled vehicles.
  - Period of performance is 27 months

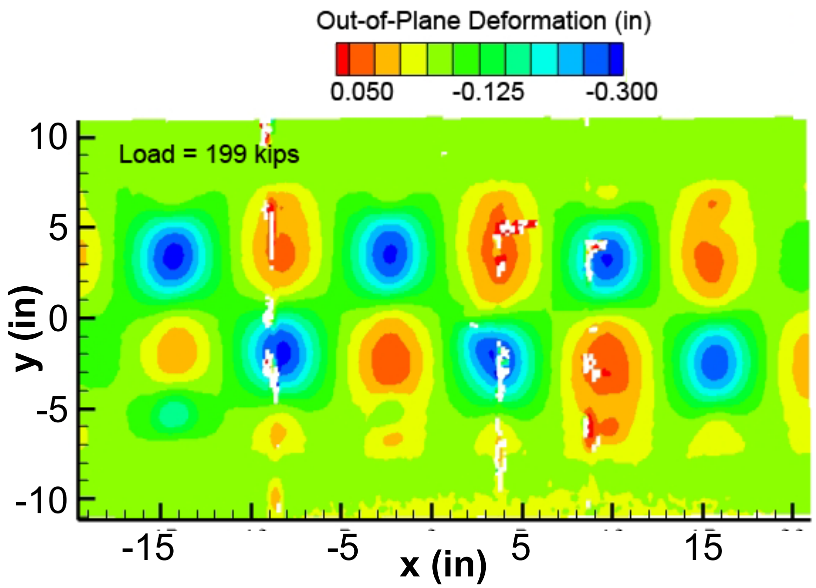
ERA Airframe Technology Highlight

02.01.02 – Boeing-NASA PRSEUS Collaboration (Apr 2010)

- **Objective:** Overcome the limitations of primary composite structure designed like "black aluminum" to enable weight reduction for 50% fuel burn reduction.
- **Approach:** Use stitched composites for light weight, and fail safe damage tolerance. Develop failure prediction and weight estimation design capability.
- **7-Stringer Pultruded Rod Stitched Efficient Unitized Structure (PRSEUS) panel tested to compression failure**
  - Fabricated by Boeing, tested at LaRC
  - Loaded in compression to design limit load, fatigue cycled and then loaded to failure.
  - Skin buckling between stringers observed within 1% of prediction of 93 kips
  - Failure observed at 200 kips compared to 205 kips prediction through "barely visible damage" impact site
  - NDE indicated no damage growth from impact damage sight inflicted prior to test



Panel – Pre/Post Failure

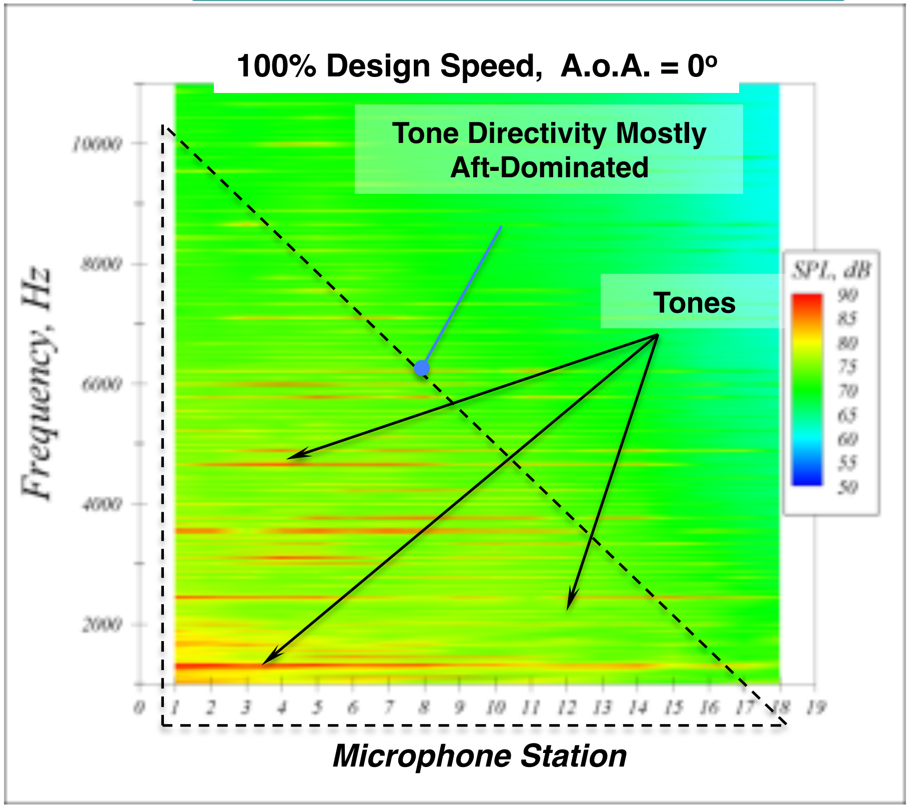


Deformation near failure – note the buckles in the thin-skin bays

ERA Propulsion Technology Highlight
03.02.01 – GE-NASA Open Rotor Collaboration (Apr 2010)

- **Objective:** Explore the design space for lower noise while maintaining the high propulsive efficiency from a counter-rotating open rotor system.
- **Approach:** A low-noise open rotor system is being tested in collaboration with General Electric. Candidate technologies for lower noise are being investigated as well as installation effects such as pylon and fuselage integration.

- *Historical Baseline Blade Set*



- **Open Rotor Collaboration Progress:**
  - Isolated aero and acoustic testing 95% complete.
  - Advanced Concepts testing continuing.
  - Preliminary acoustic results are favorable
  - Data integrity checks are ongoing
  - Amended SAA in process to give NASA access to data from all GE designed blade sets
  - Testing featured on AvWeek Dec 14 cover: “Blade Runner”, March Aerospace America, April Popular Science
  - Open Rotor gridding capability task initiated

ERA Airframe Technology Highlight
2.02 Flight Dynamics and Control

Objective: Evaluate low-speed S&C for HWB and derivative configurations in free-flight through flight control algorithms, test, and prediction methods for unique control effector and propulsion combinations

Approach

- Wind tunnel (LaRC 30x60) and free-flight experiments (DFRC WATR) with HWB 8.5% scaled X-48B
- Conduct wind tunnel (LaRC 30x60) and flight experiments (DFRC WATR) demonstrating flight control and handling qualities on derivative HWB with airframe noise shielding configuration of turbofan propulsion (X-48C)
- Demonstrate single surface PID and intelligent/adaptive control approaches to enhance vehicle performance and manage unique HWB flying qualities challenges (ride quality, gust load alleviation, etc.)

Progress

- X-48B Phase 1 and 1.5 complete (80 flights)
- Partners AFRL, Boeing R&T, Cranfield Aerospace
- X-48C flight tests in preparation

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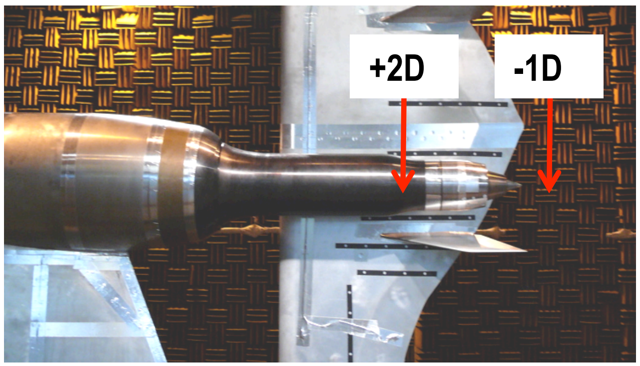
ERA Vehicle System Integration
Noise Reduction – Technical Highlight

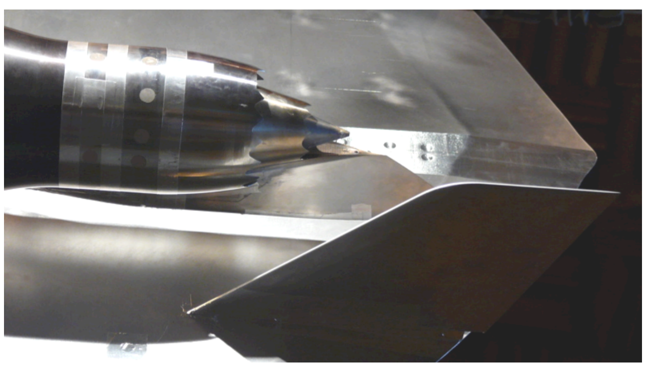
Config 1: Baseline Nozzle/Pylon at Keel, Baseline BWB -1D, Vert

Config 2: Baseline Nozzle/Pylon at Keel, Aft Shielding +2D, Vert

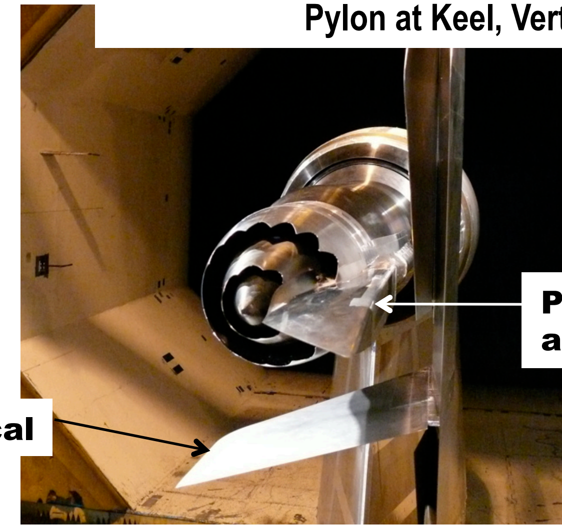


Config 3: +2D, Chev2, Pylon at Keel, Vert

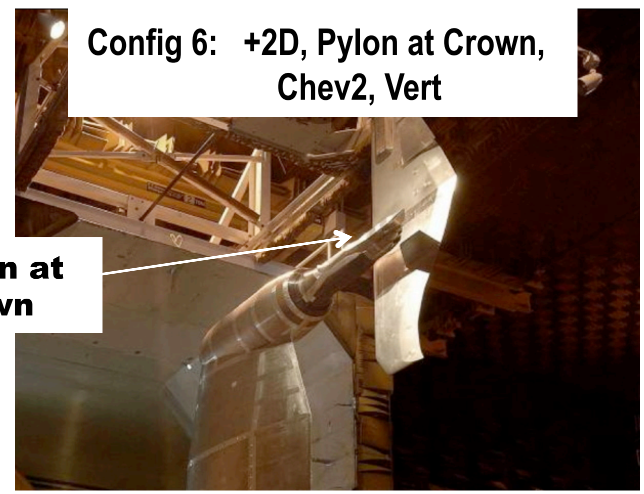
Config 4: +2D, Chev2, Mod Active Pylon at Keel, Vert



Config 5: +2D, Chev2, Agg Active Pylon at Keel, Vert, Elevons*



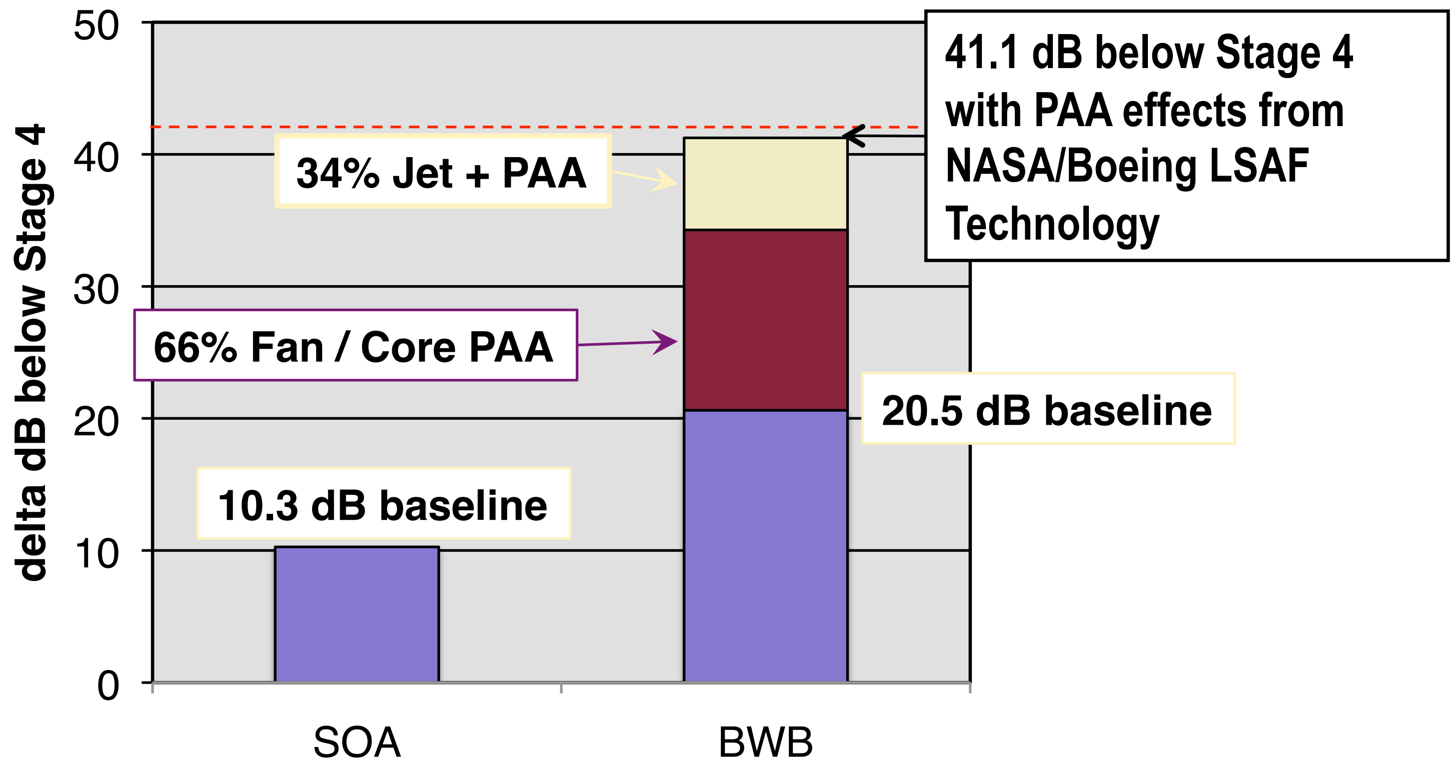
Config 6: +2D, Pylon at Crown, Chev2, Vert



***Effect not included at this stage**

ERA Vehicle System Integration
Noise Reduction – Technical Highlight

Assessment Result : 41.1 dB Cumulative



NASA