National Aeronautics and Space Administration

NASA's recent progress toward quiet (and efficient) subsonic air transportation

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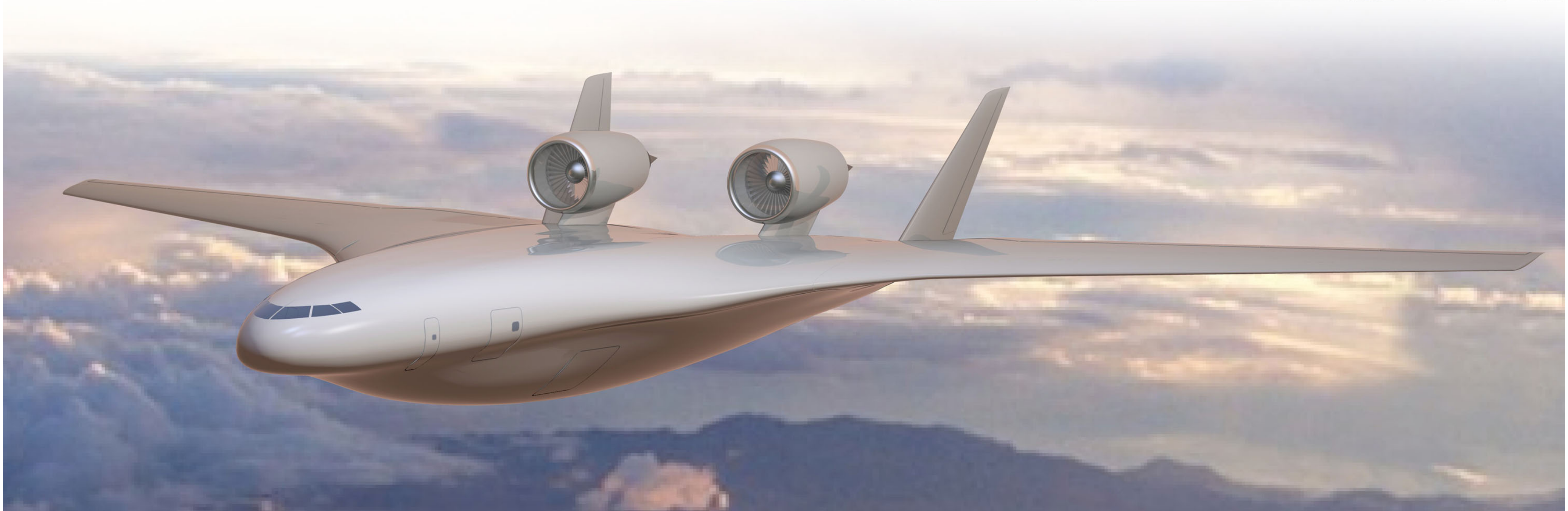


16th AIAA/CEAS Aeroacoustics Conference
Stockholm, Sweden
June 7-9, 2010

www.nasa.gov

Topics Addressed

- Motivation for the Environmentally Responsible Aviation Project
- ERA Goals, Objectives and System Level Metrics
- ERA Project Flow and FY11 President's Budget
- Technology Collectors - Aircraft Models for System Analysis
- Technical Approaches
- Vehicle Concept Study
- Progress Toward Noise Reduction Goals
- Questions

Motivation for the ERA Project

Fuel Efficiency

- In 2008, U.S. major commercial carriers burned 19.6B gallons of jet fuel. DoD burned 4.6B gallons.
- At an average price of $3.00/gallon, fuel cost was $73B

Emissions

- 40 of the top 50 U.S. airports are in non-attainment areas that do not meet EPA local air quality standards for particulate matter and ozone
- The fuel consumed by U.S. commercial carriers and DoD releases more than 250 million tons of CO_2 into the atmosphere each year

Noise

- Aircraft noise continues to be regarded as the most significant hindrance to NAS capacity growth.
- FAA's attempt to reconfigure New York airspace resulted in 14 lawsuits.
- Since 1980 FAA has invested over $5B in airport noise reduction programs

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

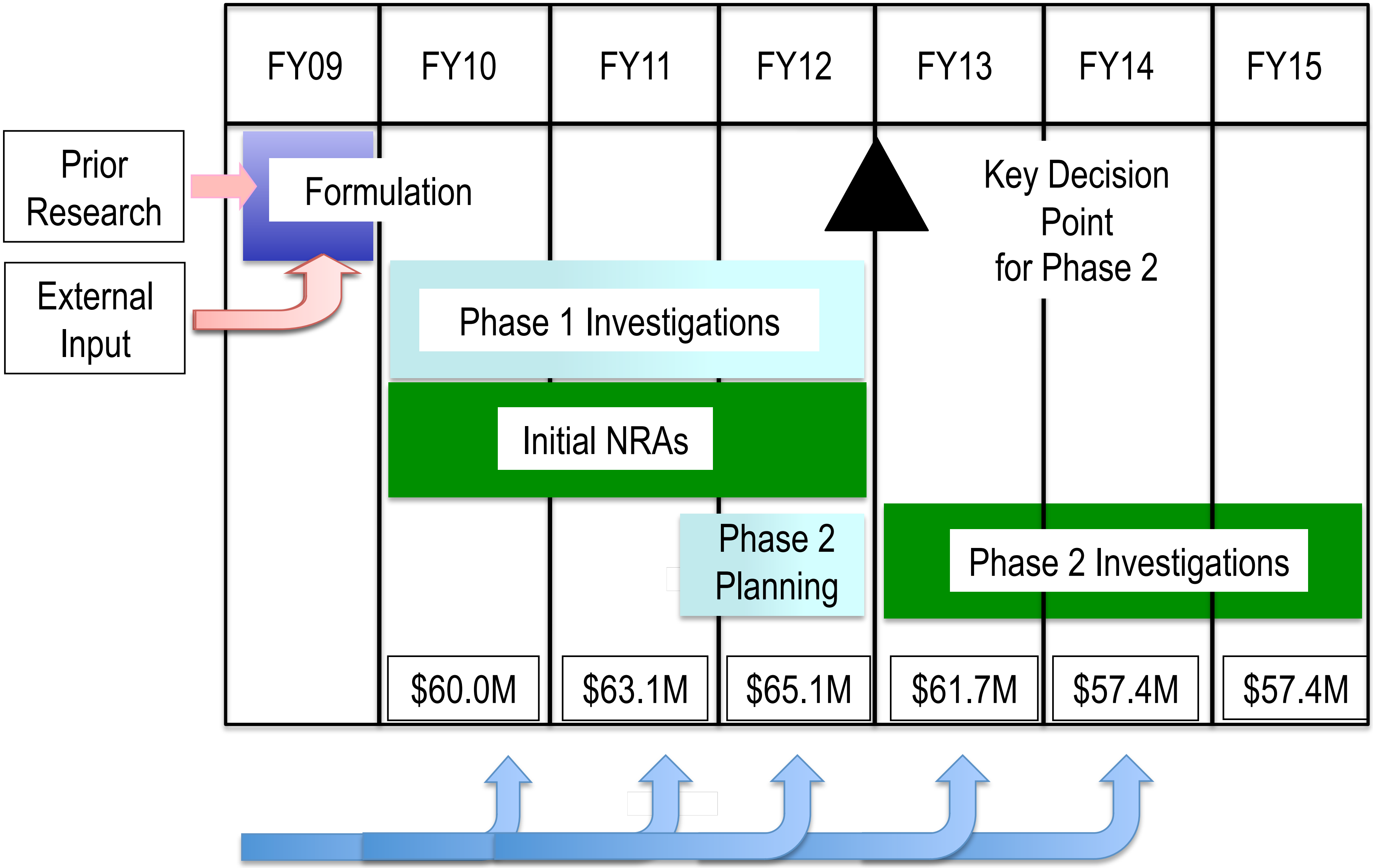
CORNERS OF THE TRADE SPACE	N+1 = 2015*** Technology Benefits Relative To a Single Aisle Reference Configuration	N+2 = 2020*** Technology Benefits Relative To a Large Twin Aisle Reference Configuration	N+3 = 2025*** Technology Benefits
Noise (cum below Stage 4)	-32 dB	-42 dB	-71 dB
LTO NO_x Emissions (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

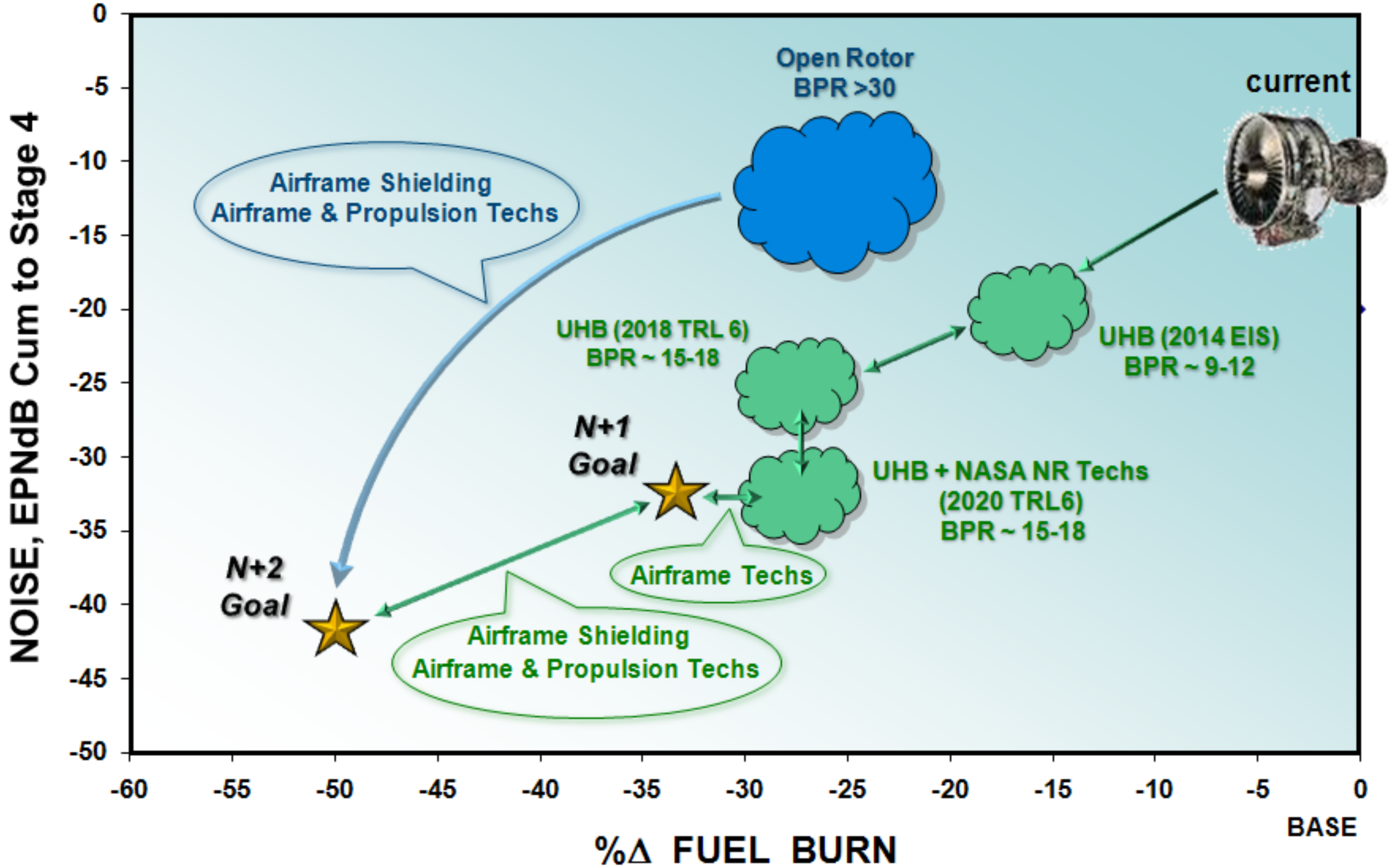
* Concepts that enable optimal use of runways at multiple airports within the metropolitan area

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



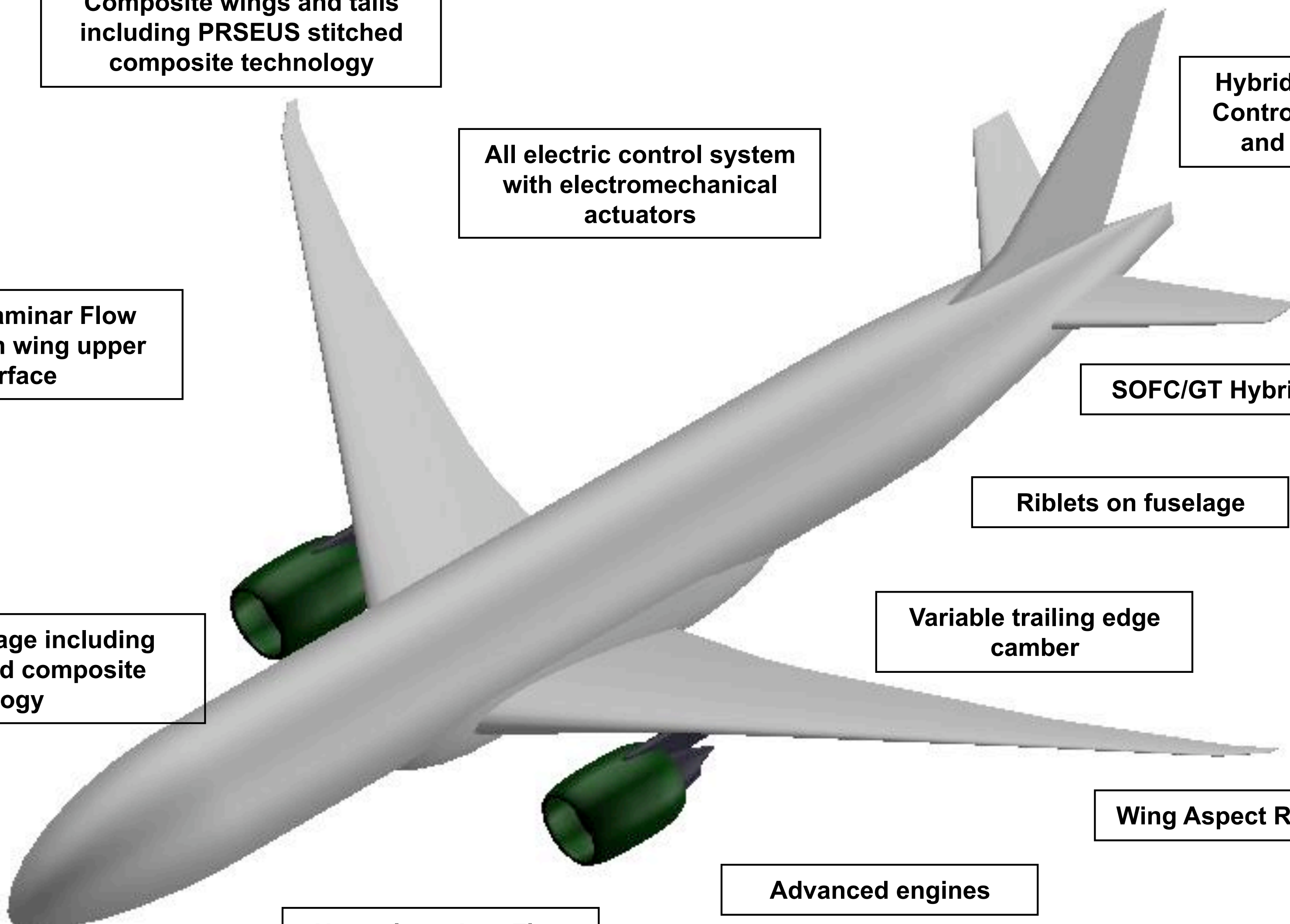
Technical input from Fundamental Programs, NRAs, Industry, Academia, Other Gov't Agencies

Vehicle System Integration Technology Roadmap



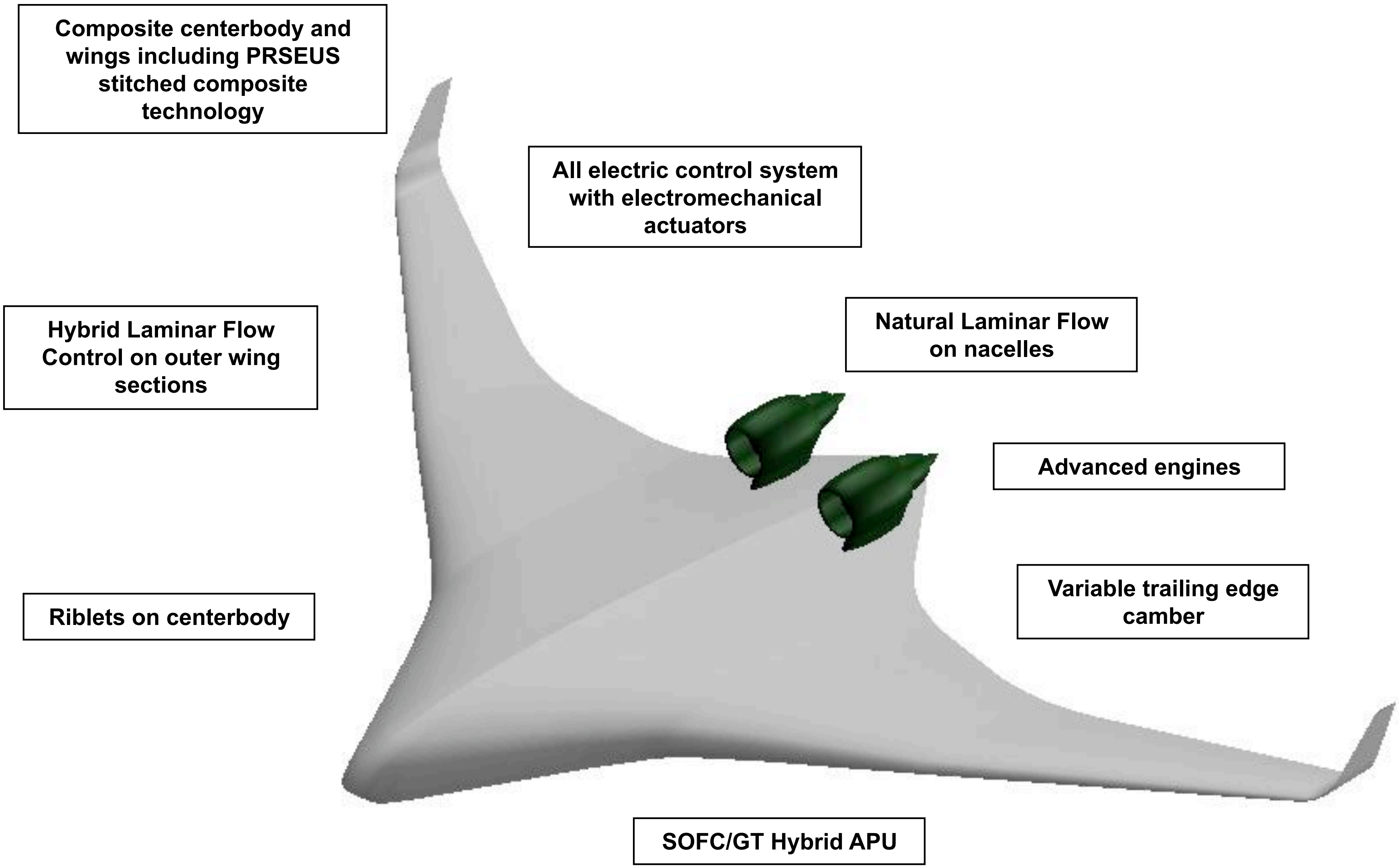
2025 “Technology Collectors” – Current Set

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



Examined With Various Noise Reduction Applications

Advanced Configuration 2A
N+2 Advanced HWB 2025 Timeframe



Examined With Various Noise Reduction Applications

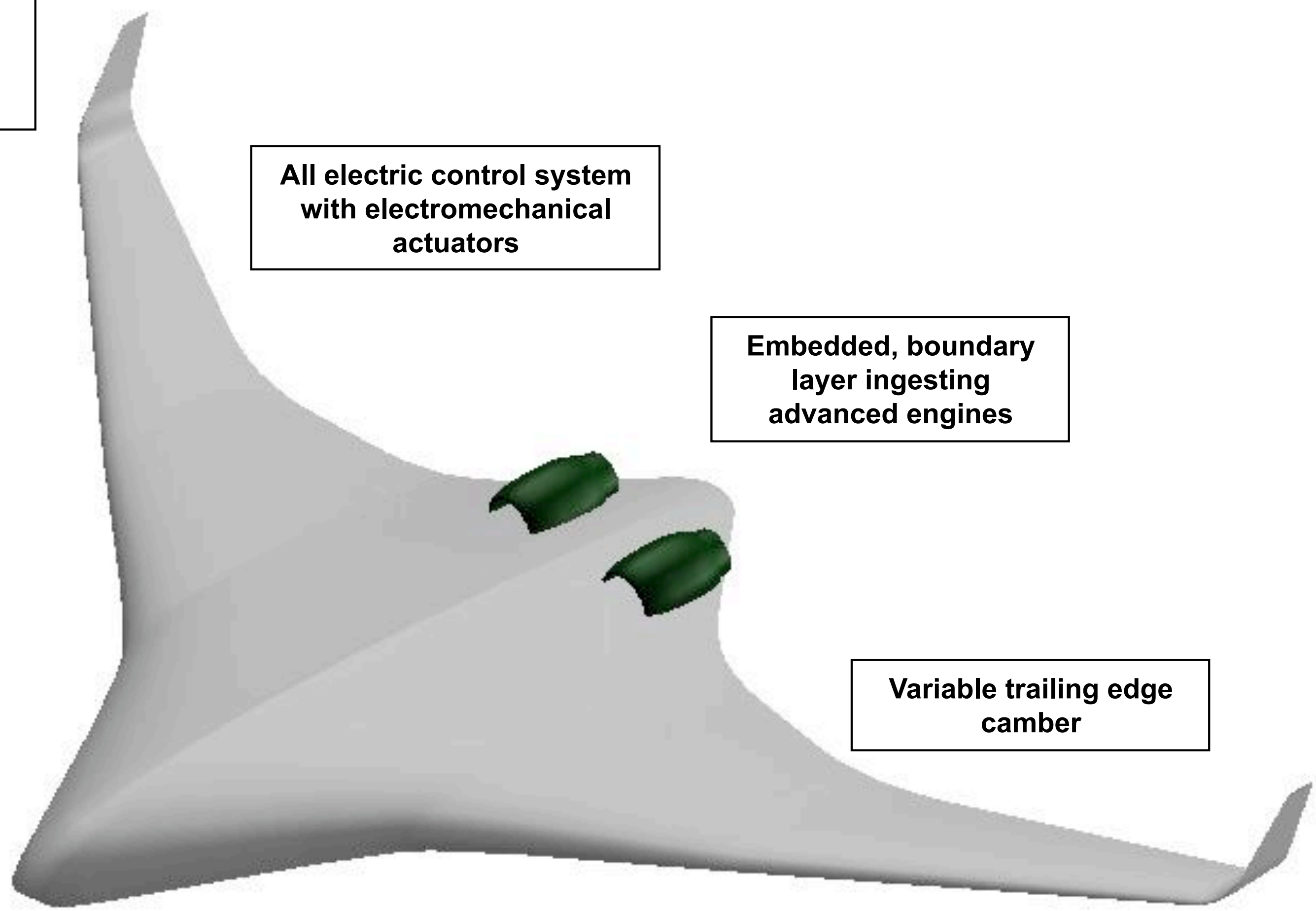
Advanced Configuration 2B
N+2 HWB300 2025+ Timeframe

Composite centerbody and wings including PRSEUS stitched composite technology

All electric control system with electromechanical actuators

Hybrid Laminar Flow Control on outer wing sections

Embedded, boundary layer ingesting advanced engines



Variable trailing edge camber

Laminar flow control on centerbody

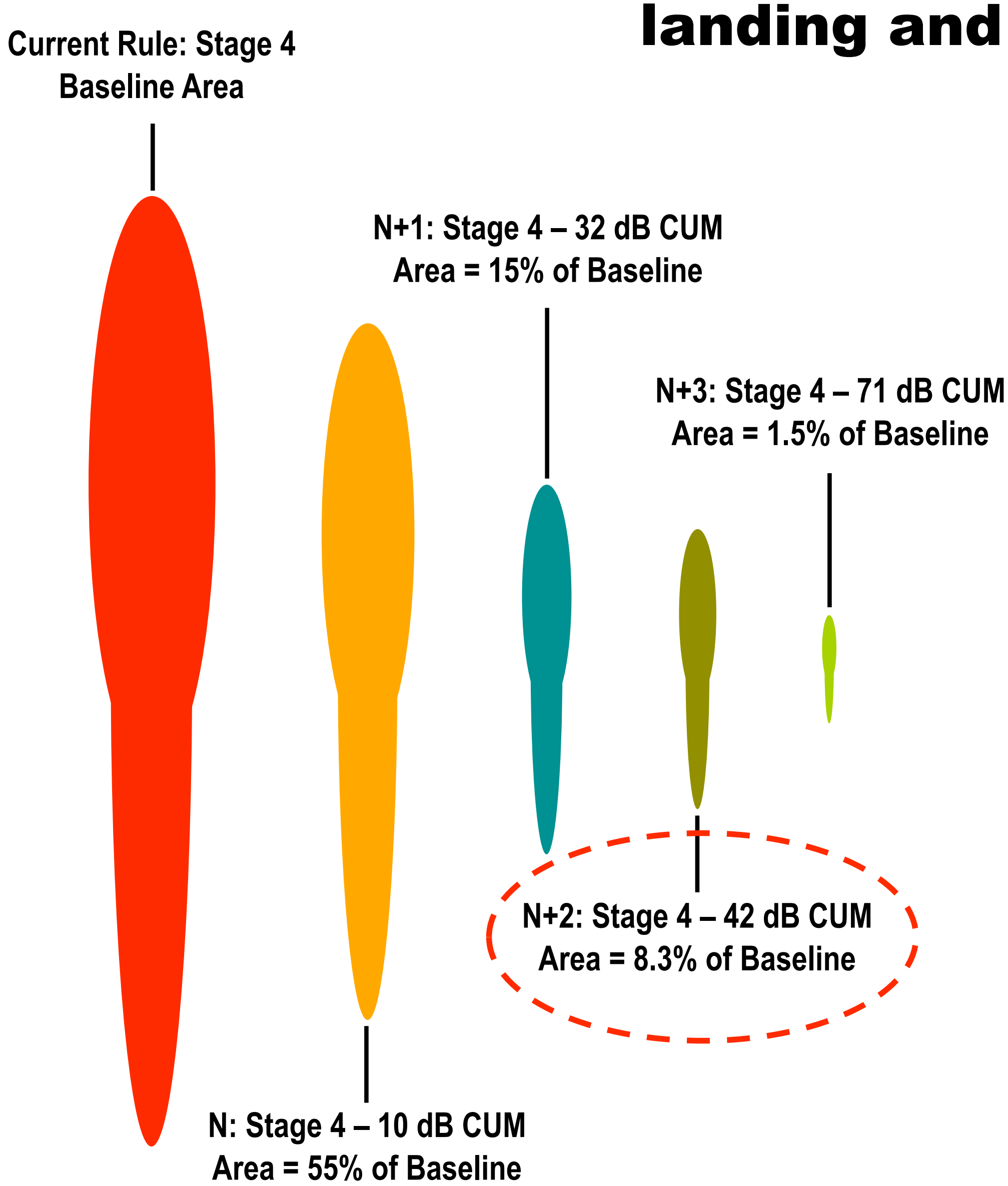
SOFC/GT Hybrid APU

Examined With Various Noise Reduction Applications

Specific System Level Metrics and Technical Approaches

NASA's Noise Reduction Goals – Idealized Impact

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

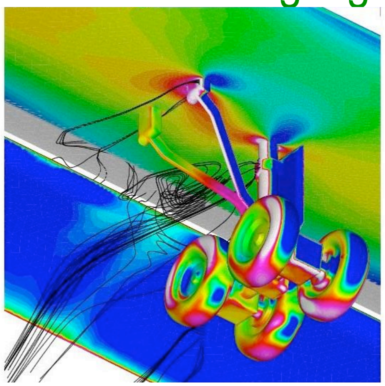


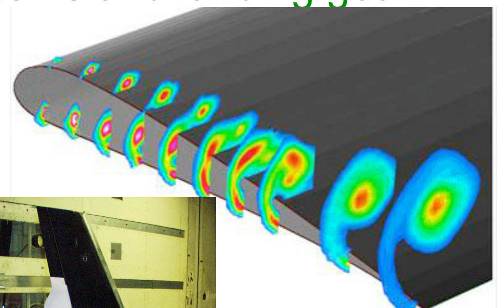
- Relative ground contour areas for notional Stage 4 and N+1, N+2, and N+3 aircraft
  - Independent of aircraft type/weight
  - Independent of baseline noise level
- Noise reduction assumed to be evenly distributed between the three certification points
- Simplified model: Effects of source directivity,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

Addressing Noise Reduction

Airframe Noise

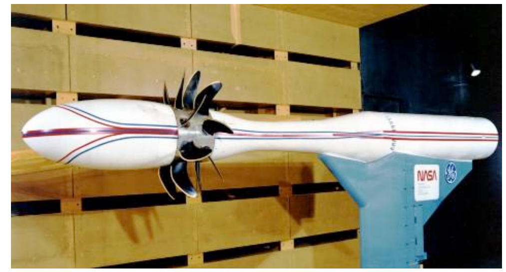
Addressing high-lift systems and landing gear





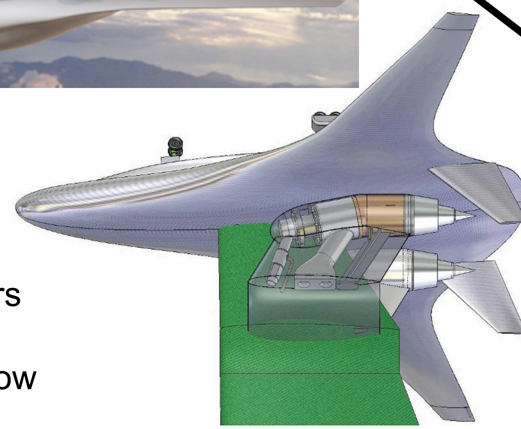
Propulsion Noise

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

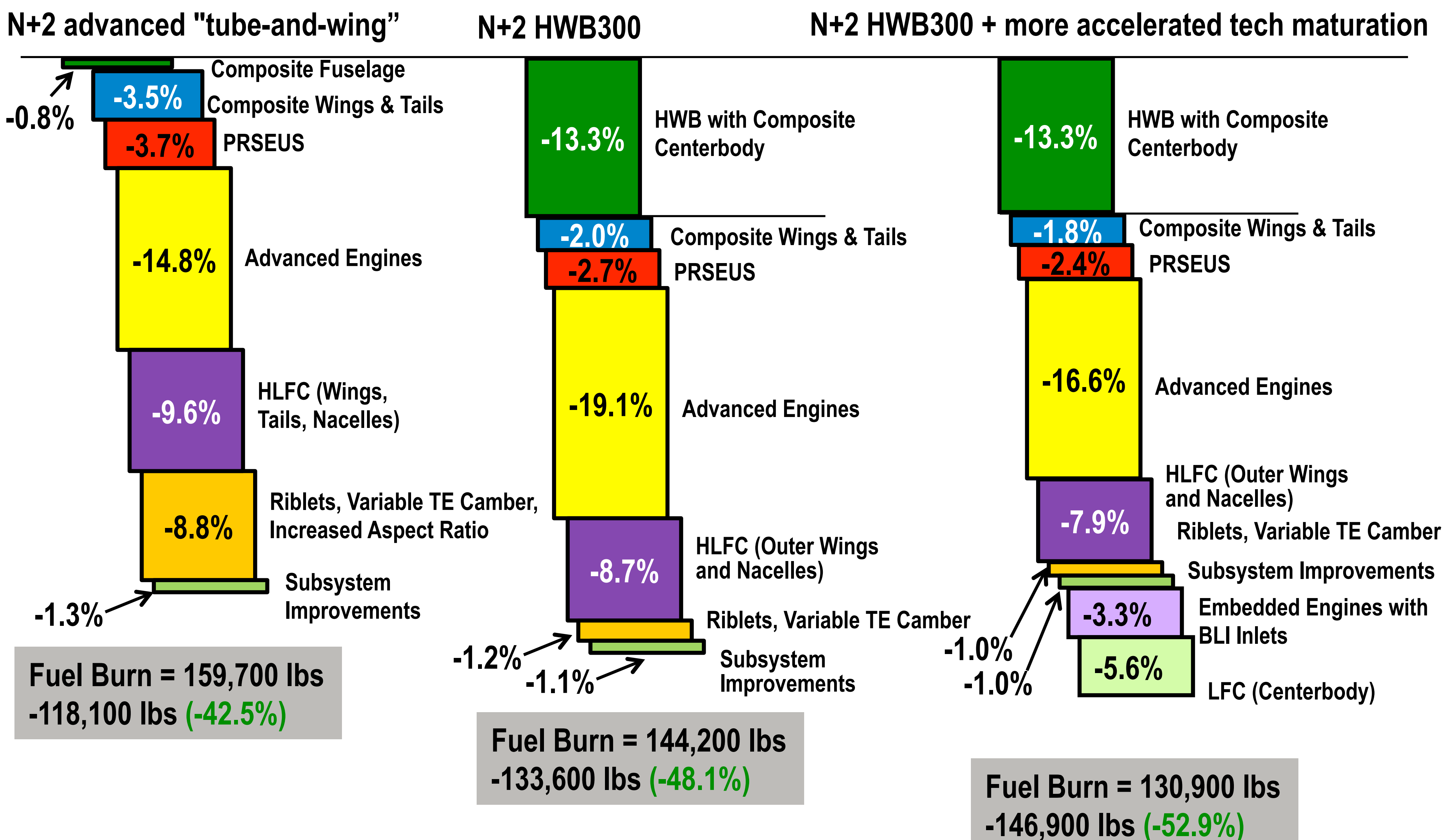
Propulsion Airframe Aeroacoustics

Addressing airframe/propulsion interaction - shielding

Potential Reduction In Fuel Consumption

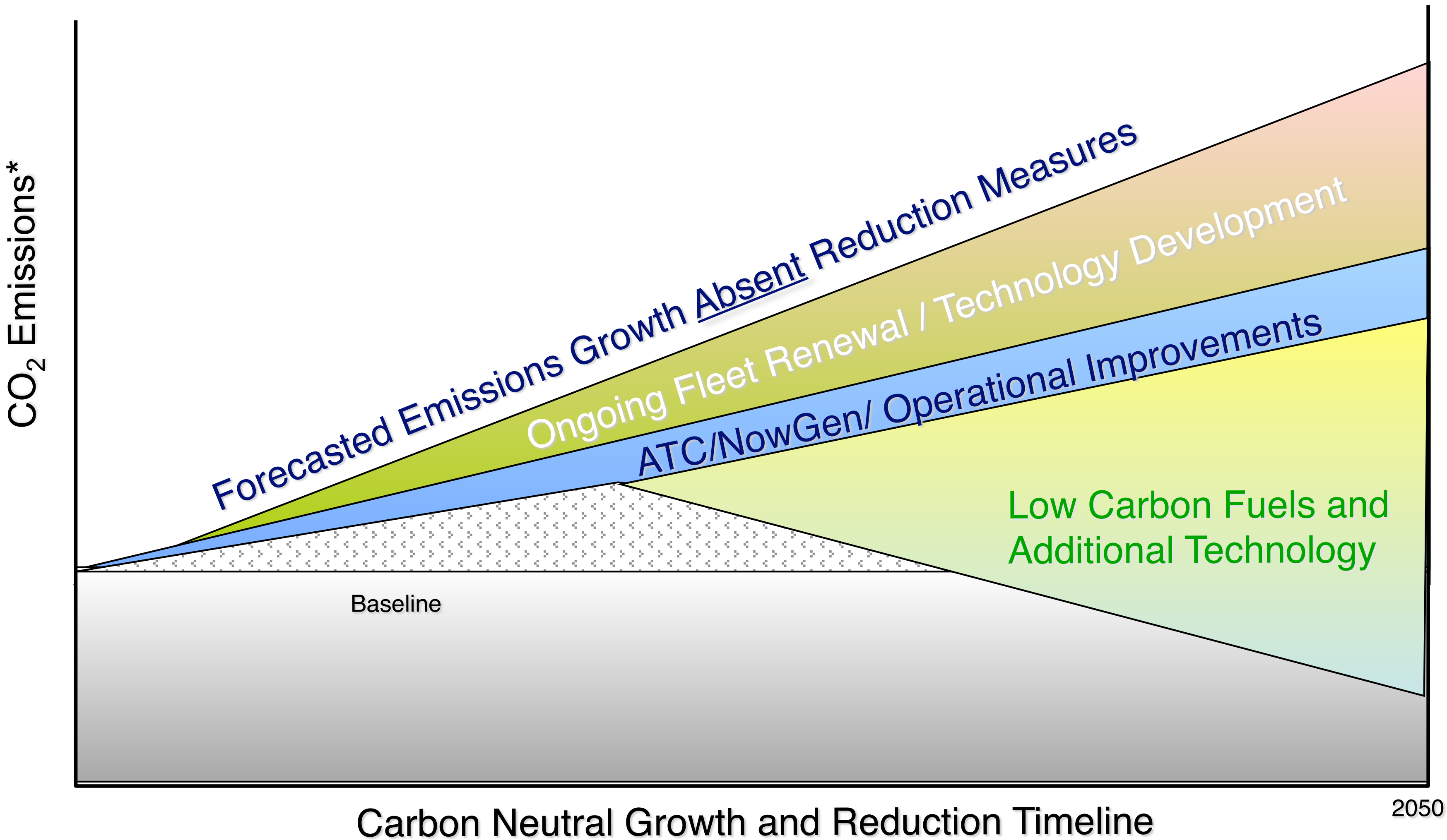
2025 EIS (TRL = 6 in 2020)

Technology Benefits Relative to Large Twin Aisle (Reference: 777-200LR “like” Vehicle



Reference Fuel Burn = 277,800 lbs

Motivation to reduce fuel burn



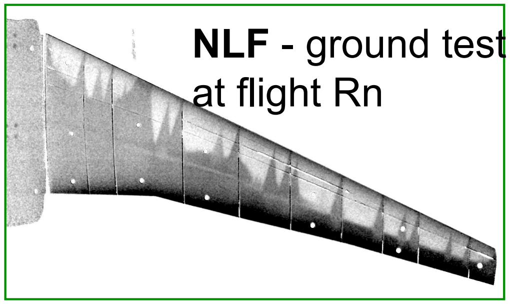
Addressing Fuel Burn (CO_2 Emissions)

DRAG REDUCTION via Laminar Flow

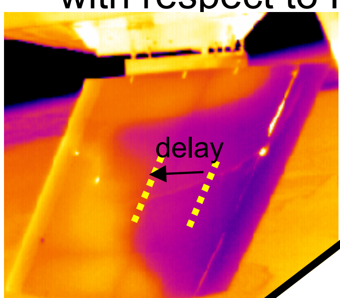
Addressing concepts & barriers
to achieving practical laminar flow on transport a/c

HLFC - revisit crossflow expt
- understand system weight

NLF - ground test
at flight Rn

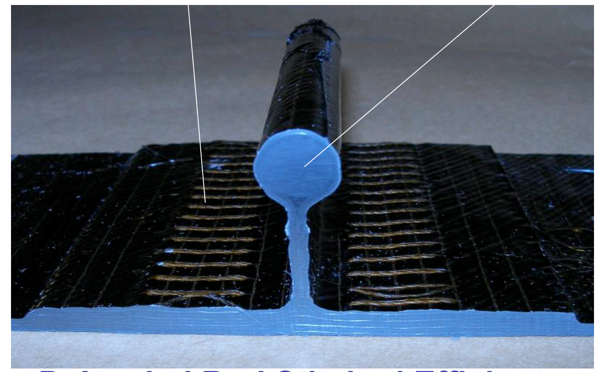


DRE - exploring the limits
with respect to Rn

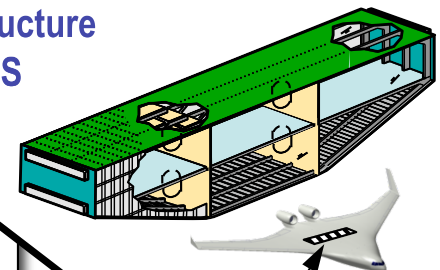


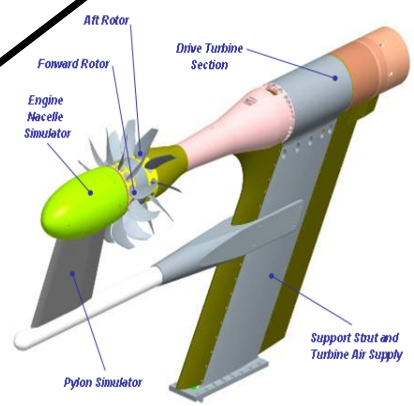
WEIGHT REDUCTION via Advanced Structures

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

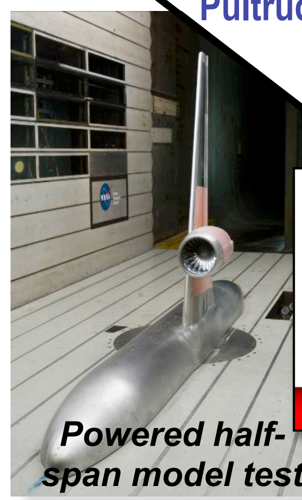


Pultruded Rod Stitched Efficient
Unitized Structure
PRSEUS

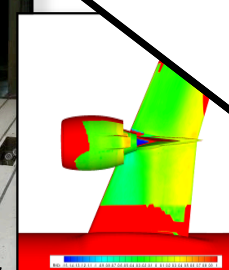




Open Rotor Propulsion Rig



Powered half-span model test

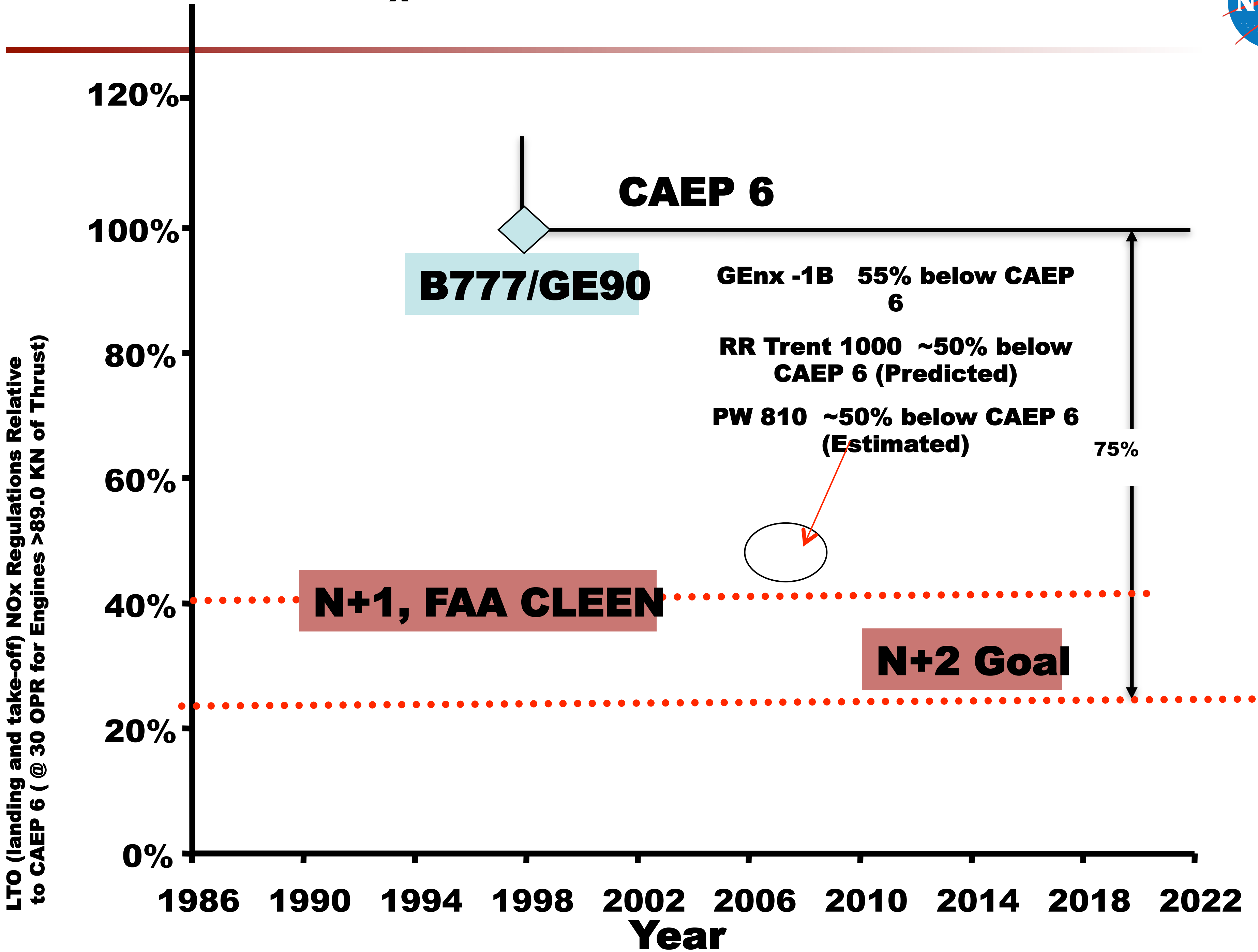


PSP Results

SFC REDUCTION via UHB

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

N+2 LTO NO_x Reduction Goal – More Insight

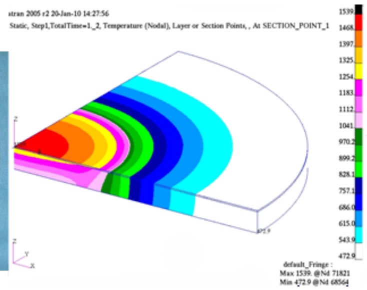


Addressing Reduced LTO NO_x Emissions

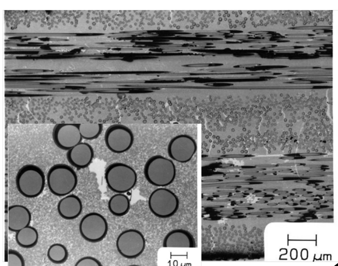
ERA CMC Combustor Liner

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

CMC combustor liner

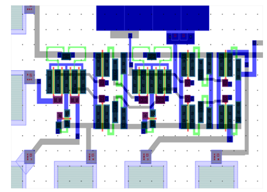


SIC CMC – enable higher temperature engine



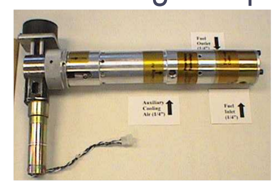
Active Combustion Instability Control

Demonstrating the capability to suppress combustor instabilities for low emission combustors

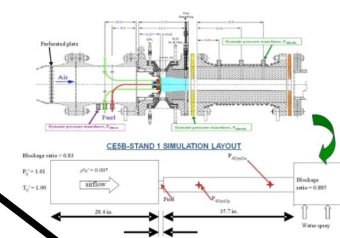


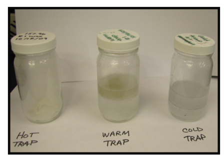
High Temperature SiC electronics circuits and dynamic pressure sensors

Fuel Modulation – high frequency fuel delivery systems

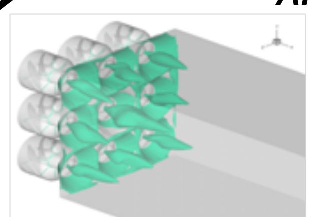


Instability Models and Control Methods





Alternative fuel



Innovative Injector Concept

ASCR Combustion Rig

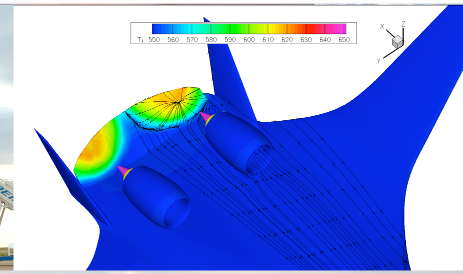
Low Nox, Fuel-Flexible Combustor

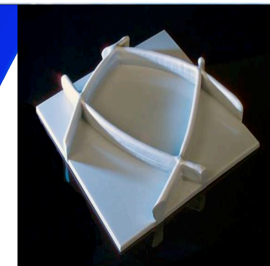
- **High Bypass Ratio/High Pressure Combustor**
- **Superior Alternative Fuel properties**
- **Enhance Fuel/Air Mixing**
- **Advanced Ignition**

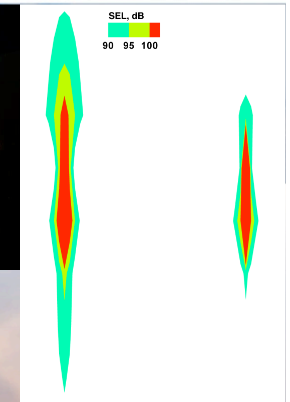
NASA Research Announcement – Broad Input Vehicle Concept/Preliminary Design Study

- NASA has released a BROAD solicitation this 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. Available funds = 36.6M

Progress Toward NASA's N+2 Noise Goal







Following slides contributed by Czech, Thomas, Elkoby, Burley, and Olson
AIAA Papers - AIAA 2010-3912, and 3913
Tuesday 9:00am, 9:30am, E32

NASA's efforts toward noise reduction

Propulsion
- Soft vane research
- Over the rotor treatment
- Variable area nozzle

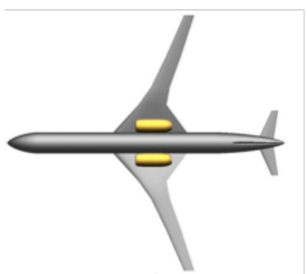
Airframe
- Low noise landing gear design
- Flap side edge treatments
- Compliant flap

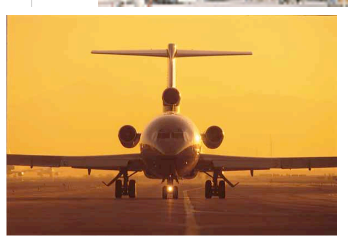
Integration and Configuration Effects
- Propulsion airframe aeroacoustics (LSAF)
    - UHB tube and wing AND HWB
        - Pylon effect noise reduction
        - Acoustic liner technology
        - Chevrons for shielding effectiveness
    - Open rotor tube and wing AND HWB
        - Pylon effects
        - Acoustic liner technology
- Propulsion airframe aeroacoustics (14x22)

Methods
- ANOPP to ANOPP 2
- Phased Array Development
- Processing

What can be achieved with configuration?

- **Propulsion Airframe Aeroacoustics (PAA) are the effects associated integration of the propulsion and airframe systems.**
- **Includes:**
  - Integration effects on inlet and exhaust systems
  - Flow interaction and acoustic propagation effects
- **Goal of PAA is to use configuration to reduce net radiated noise.**





NASA's N+2 Propulsion Airframe Aero Acoustics Roadmap

Pathfinding

2005 Pathfinding with Limited Data

Initial System Noise Assessment, sets Stage 4 –42dB Goal

Simple Shielding Experiment (2003)

Basic Concept Selection > Hybrid Wing Body (HWB) (2002)

Technology Development

2009 Preliminary with LSAF Data

2010 Critical Assessment with LSAF UHB/OR Data

HWB Aeroacoustic Experiments:

- Large-scale, high fidelity integrated HWB model
- LSAF in 2009
- 14 X 22 in 2012

Multi-Disciplinary HWB Aircraft Concept Design:

- NASA HWB system methods
- NRA with Boeing team

HWB Aircraft System Prediction Methods:

- ANOPP with PAA experimental inputs
- ANOPP2 for direct prediction

Maturation

2012 High-Fidelity Assessment

Broaden Technology Path, Refined Methods, Increasing Confidence

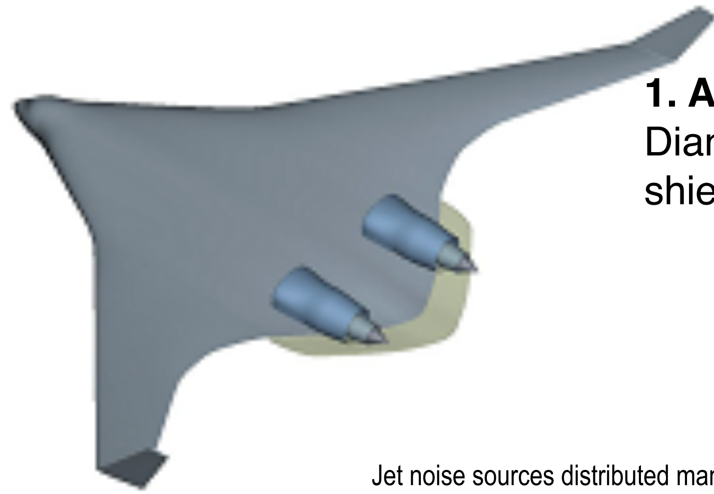
Industry Partnerships Key

Flight Demonstration

★ Noise assessments

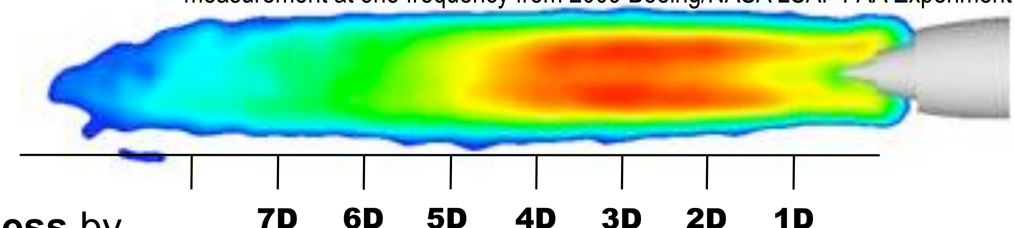
2010 Critical Assessment: Two Part Strategy to Develop Noise Reduction Potential of HWB

Baseline HWB Aircraft – NO aft shielding



1. Add Shield Area: Move Engines Two Diameters Upstream = more aft fan shielding, chance for jet shielding

Jet noise sources distributed many nozzle diameters downstream. Ref: phased array measurement at one frequency from 2009 Boeing/NASA LSAF PAA Experiment

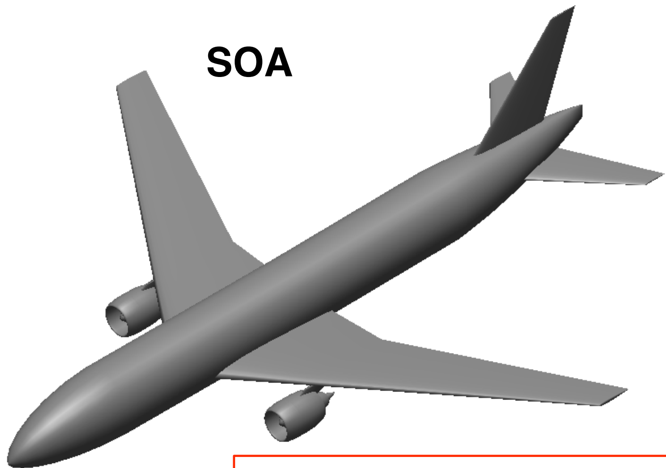


2. Increase Jet Shielding Effectiveness by developing nozzle/pylon technologies – elements from previous NASA/Boeing PAA research

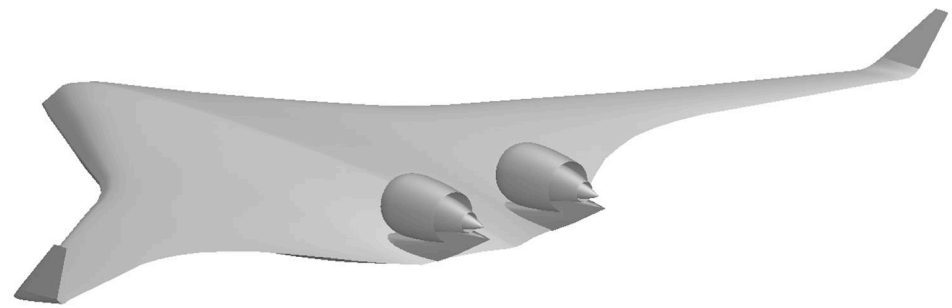
42 dB Goal set based on 2005 Pathfinding assessment assuming MAXIMUM success of this strategy – a stretch goal!

2010 Critical Assessment: Aircraft Models and Study Framework

SOA



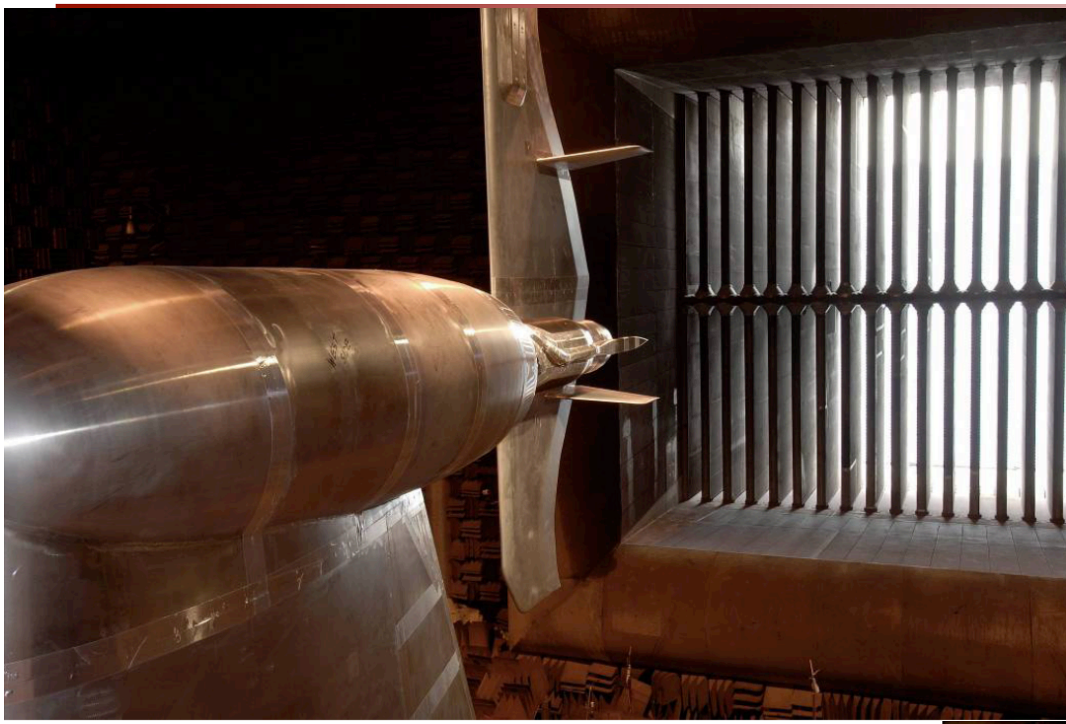
HWB



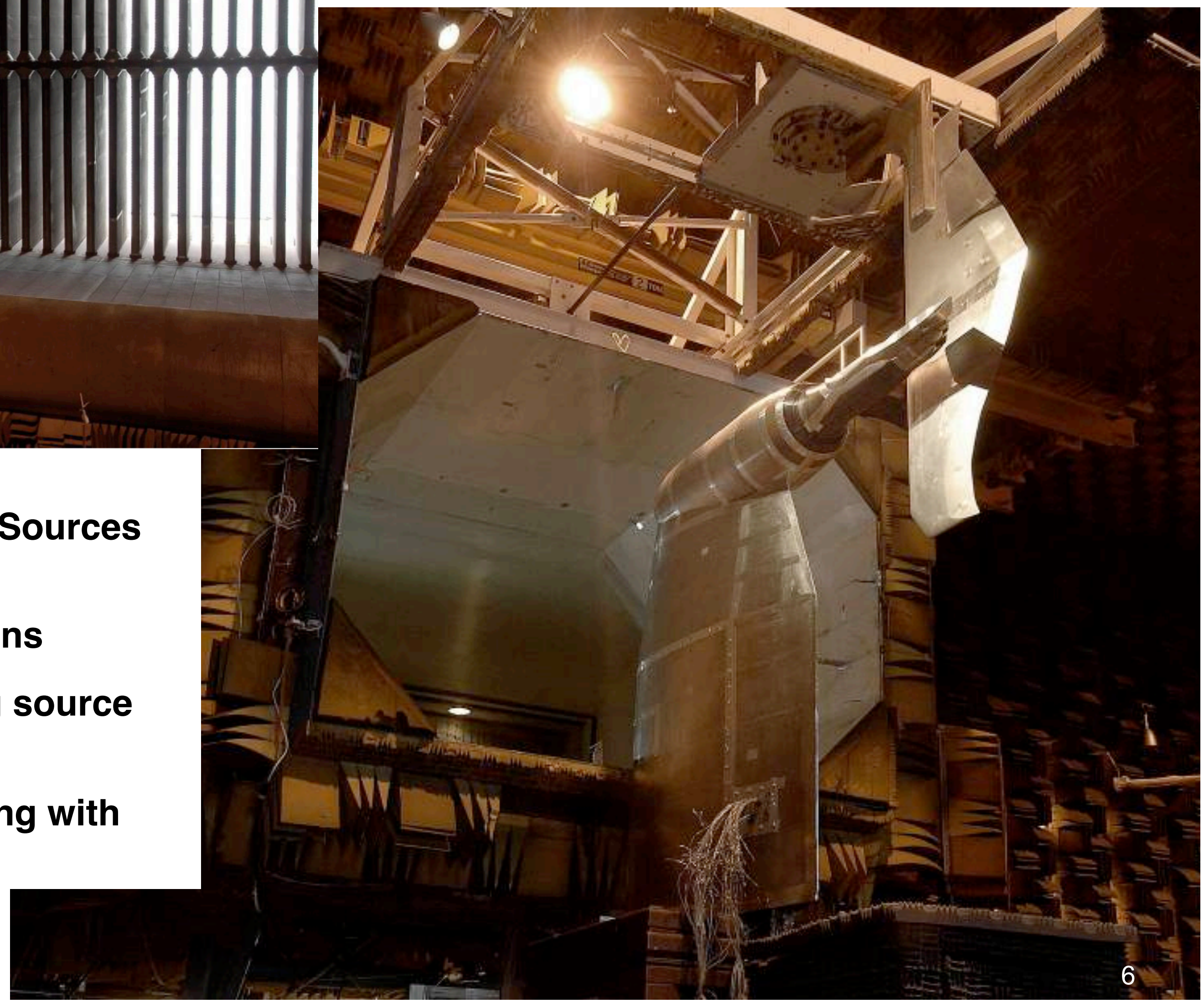
Both aircraft use equivalent technology levels and are sized for same payload, same 7500 NM mission, meet FAA airworthiness standards, and same GE-90-like engine used on both aircraft

	777-like SOA	HWB NASA Best
Weight-takeoff (lbs)	656,000	590,436
Weight-landing (lbs)	459,200	413,305
Max Fuel (lbs)	284,279	227,081
L/D (start of cruise)	19.5	23.0
Thrust per Engine (static sea level)	86,783	81,298
Takoff Field-Length (ft)	8648	8633

2010 Critical Assessment: Technology and Experimental Data for Key PAA Effects



Ref: Czech, Thomas, and Elkoby, "Propulsion Airframe Aeroacoustics Integration Effects for a Hybrid Wing Body Aircraft Configuration," AIAA 2010-3912



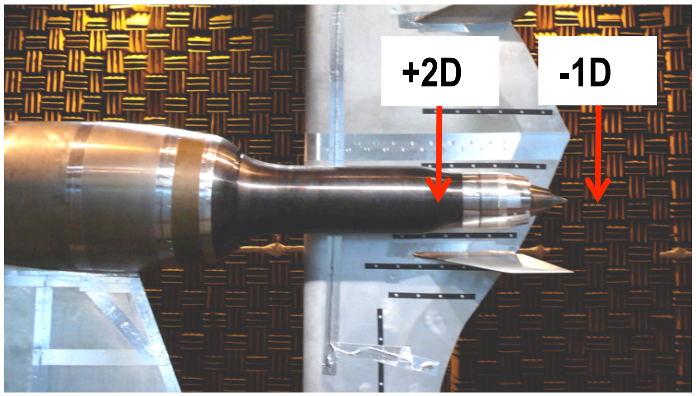
HWB Experiment Improves Basic Understanding of Aeroacoustic Sources and Parameters:

- Effects from Verticals and Elevons
- Jet-Airframe shielding including source modification
- Broadband point source shielding with flow effect

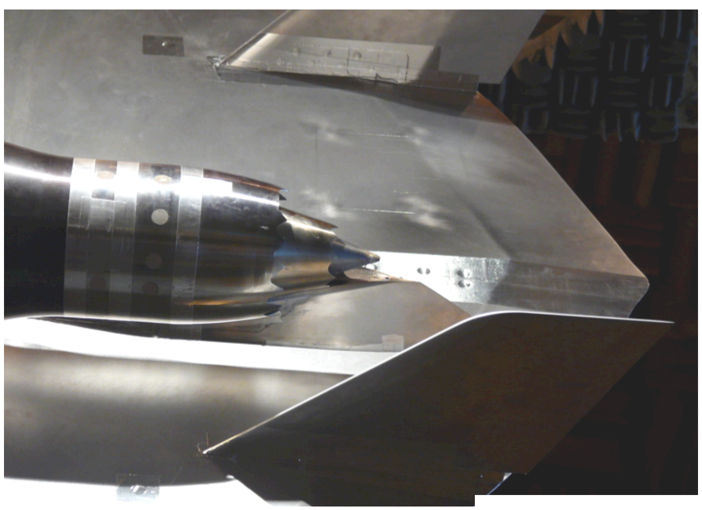
2010 Critical Assessment: Experimental Configurations

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

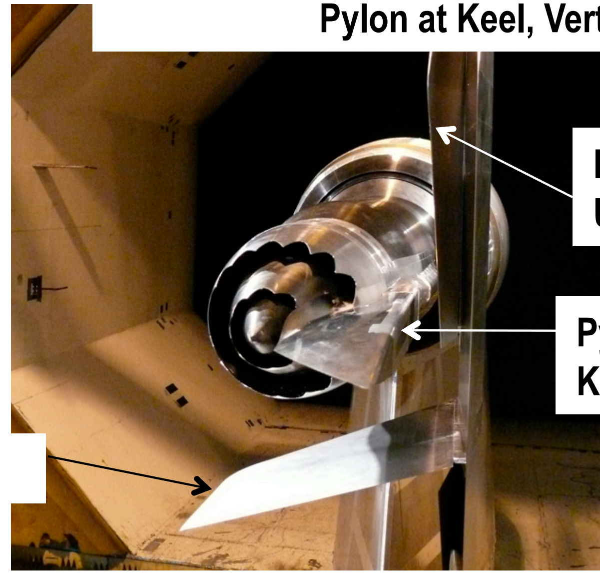
Config 2: Baseline Nozzle/Pylon at Keel, Aft Shielding +2D, Vert



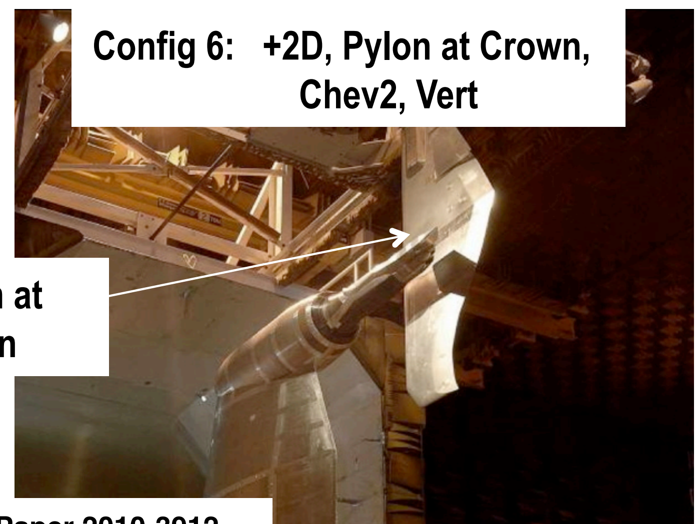
Config 3: +2D, Chev2, Pylon at Keel, Vert



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

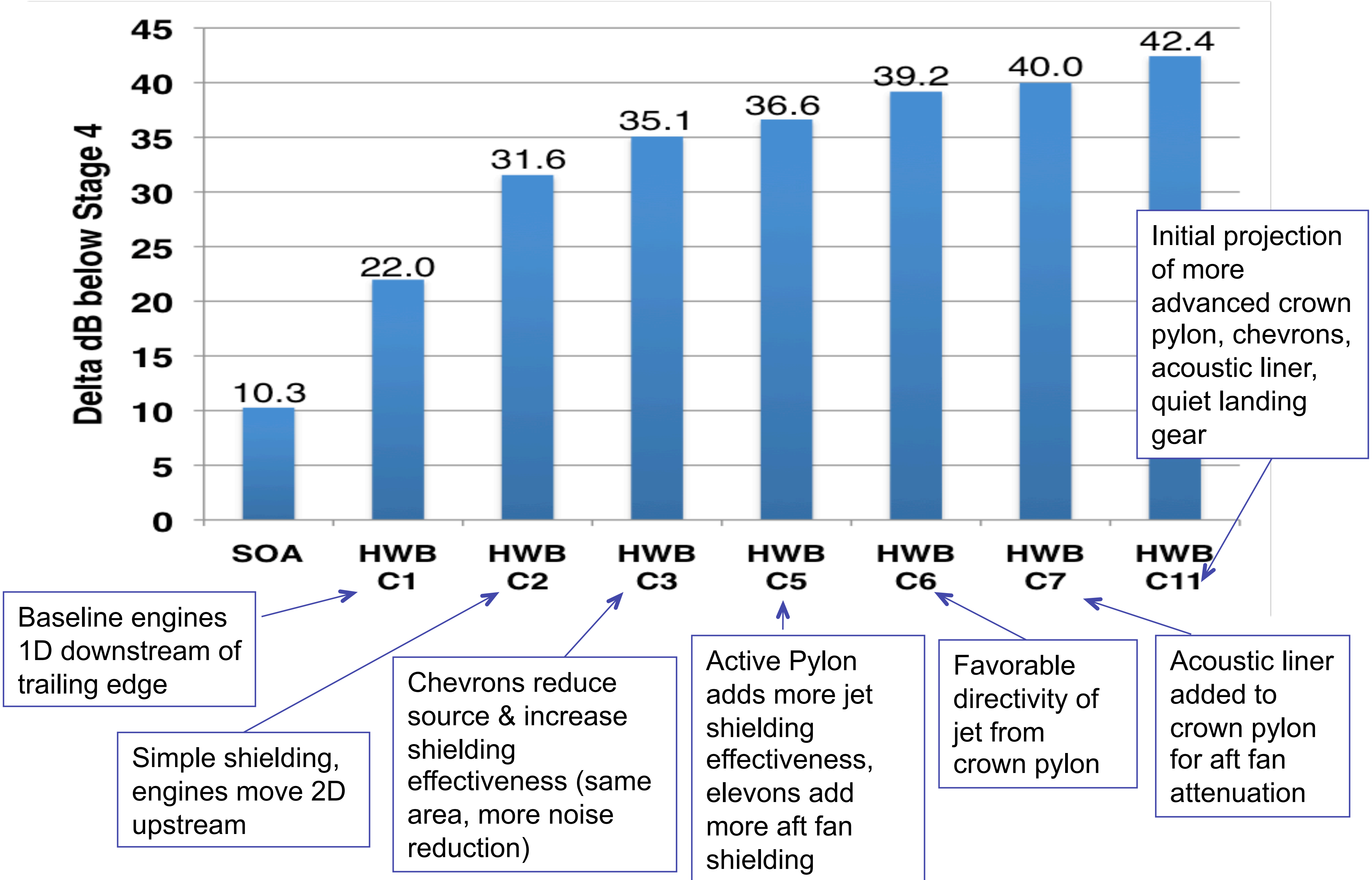


Config 6: +2D, Pylon at Crown, Chev2, Vert

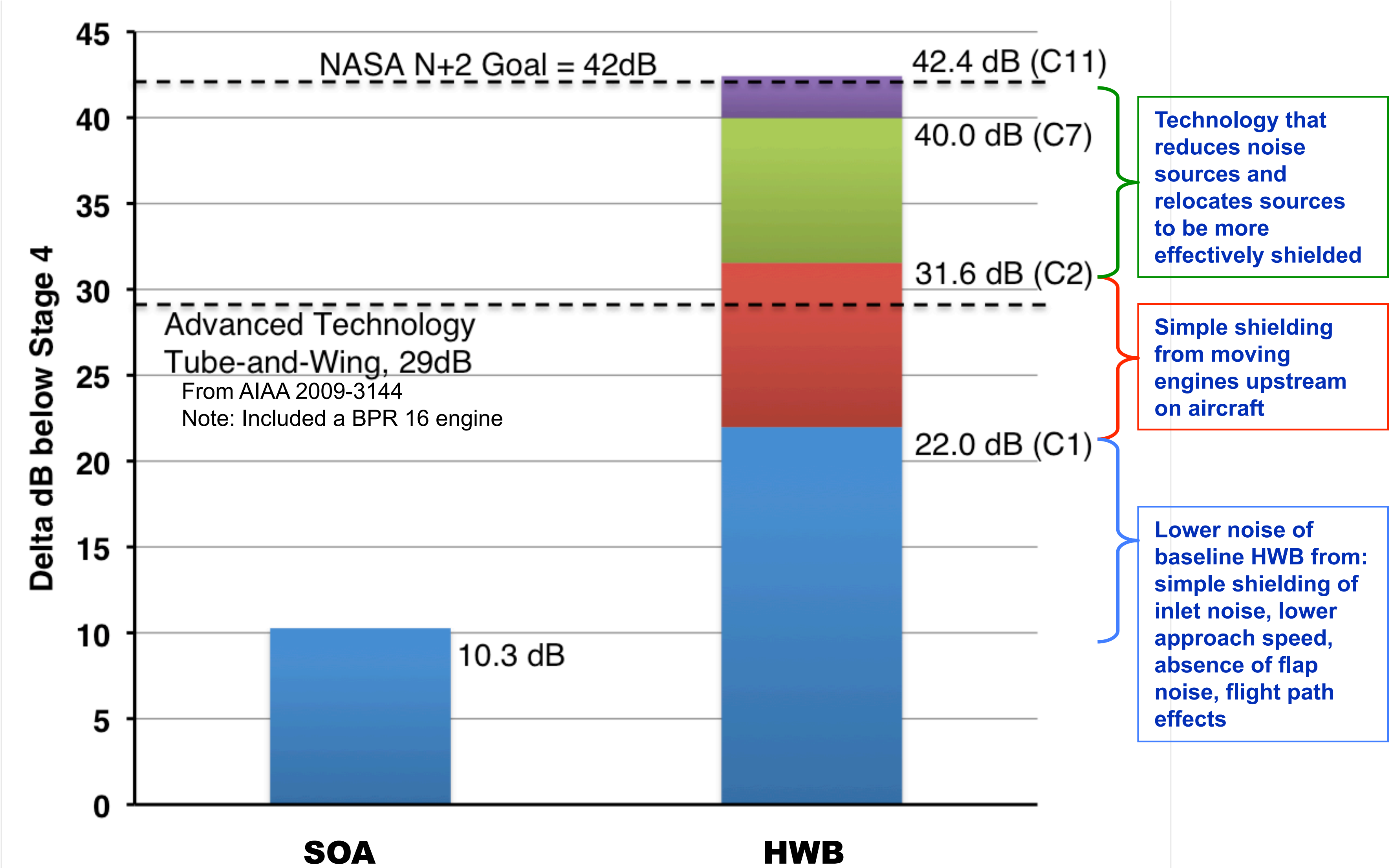


Ref: Czech, Thomas, and Elkoby AIAA Paper 2010-3912

2010 Critical Assessment: PAA Technology Effects on System Noise Levels



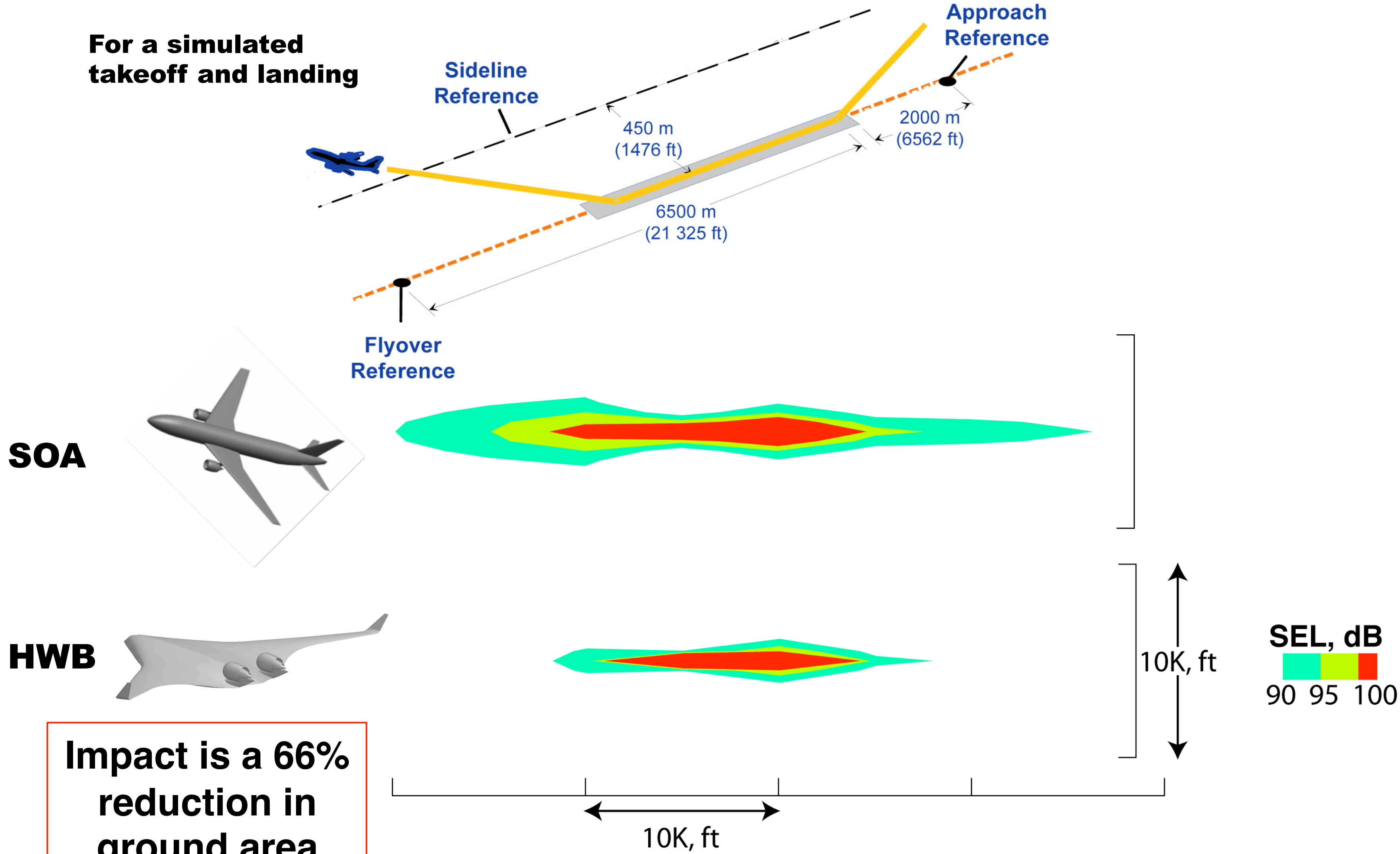
2010 Critical Assessment: Perspective on 42.4 dB Cumulative Level



- **Simple Shielding NOT enough to REACH GOALS**
- **Technology still key to maximizing total noise reduction**

2010 Critical Assessment: Sound Exposure Level Contour Results

For a simulated takeoff and landing



Impact is a 66% reduction in ground area

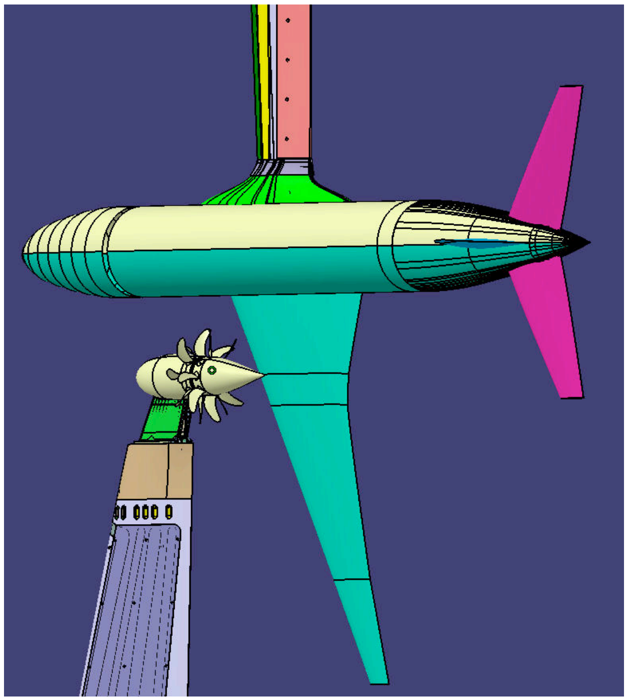
2010 Critical Assessment: Summary

- Significantly updated HWB system noise assessment with key elements:
  - NASA ANOPP system noise method
  - NASA updated HWB aircraft model and flight path
  - Boeing/NASA PAA LSAF experimental results
- 42.4 dB cumulative with relatively near term technology:
  - existing GE90-like engine
  - PAA chevron nozzle and crown pylon technology
  - acoustic liner applied on the crown pylon
  - quiet landing gear technology
  - Reduced approach flight speed

Results in higher confidence assessment compared to earlier pathfinding assessment

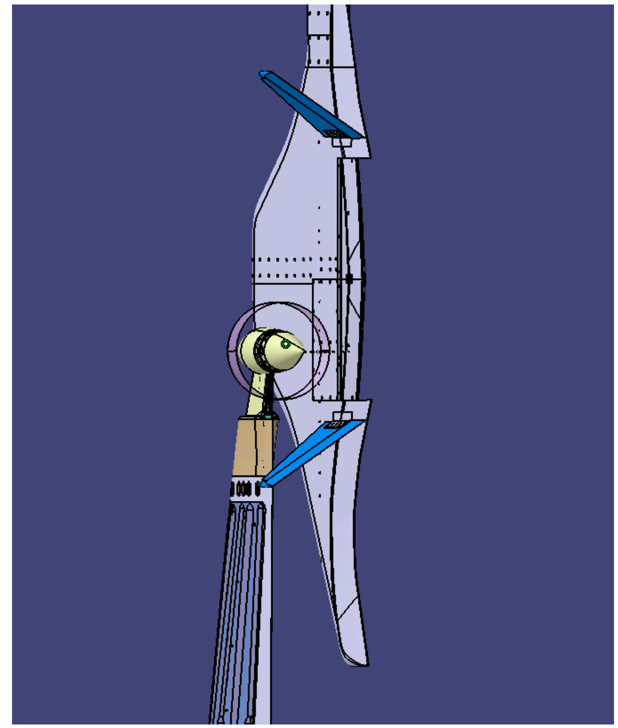
2010 Critical Assessment (Augmentation): Open Rotor PAA Experiment in the LSAF

Objective: Study PAA effects of counter-rotating open rotor for both HWB and Tube-and-Wing aircraft types



Parameters/Effects:
- **Airframe/Rotor Spacing**
- **R1/R2 Speed Variation**
- **Angle-of-attack**

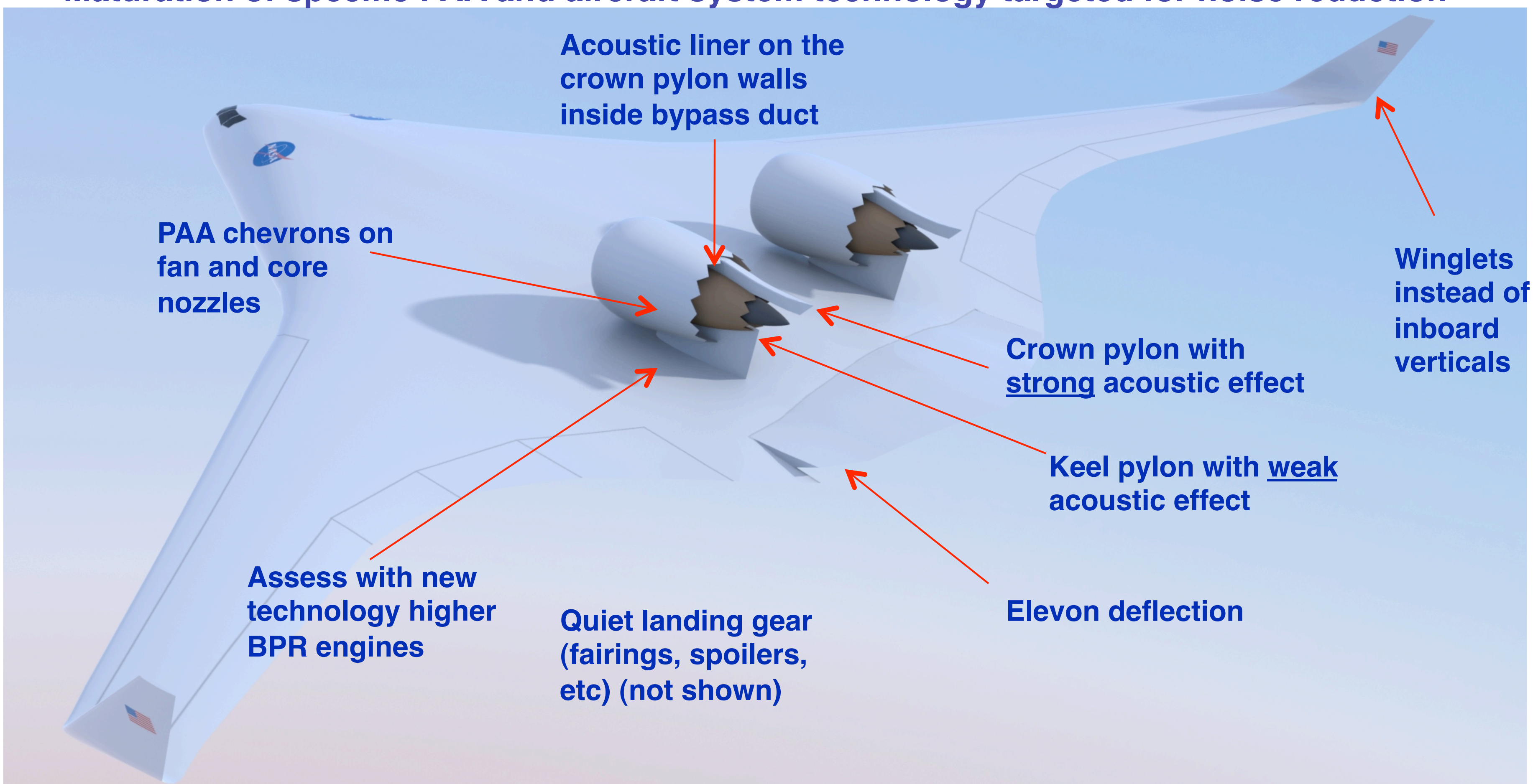
Instrumentation:
- **Far Field Mic**
- **Near Field Mic Traverse**
- **Flow Field Survey**
- **Phased Array Traverse**
- **Surface Unsteady Pressure**



- To be used in prediction method validation for ANOPP2
- Will lead to a NASA assessment of the potential noise reduction of open rotors with PAA effects

2012 High Fidelity Experiment: Future Directions for a Lower Noise HWB

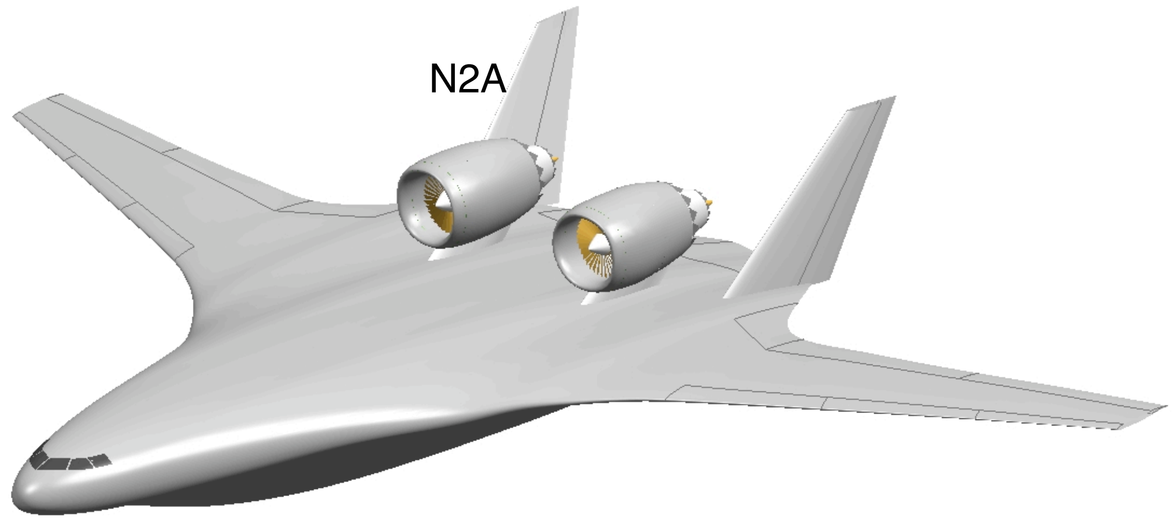
- Better suppression map of more realistic fan noise simulation
- Flight path and aircraft model
- Maturation of specific PAA and aircraft system technology targeted for noise reduction



Critical step toward higher fidelity HWB aeroacoustic capabilities

2012 High Fidelity Experiment:
High Fidelity HWB Capabilities

Collaborative Effort:
NASA, Boeing Research and Technology, MIT, UCI, UTRC



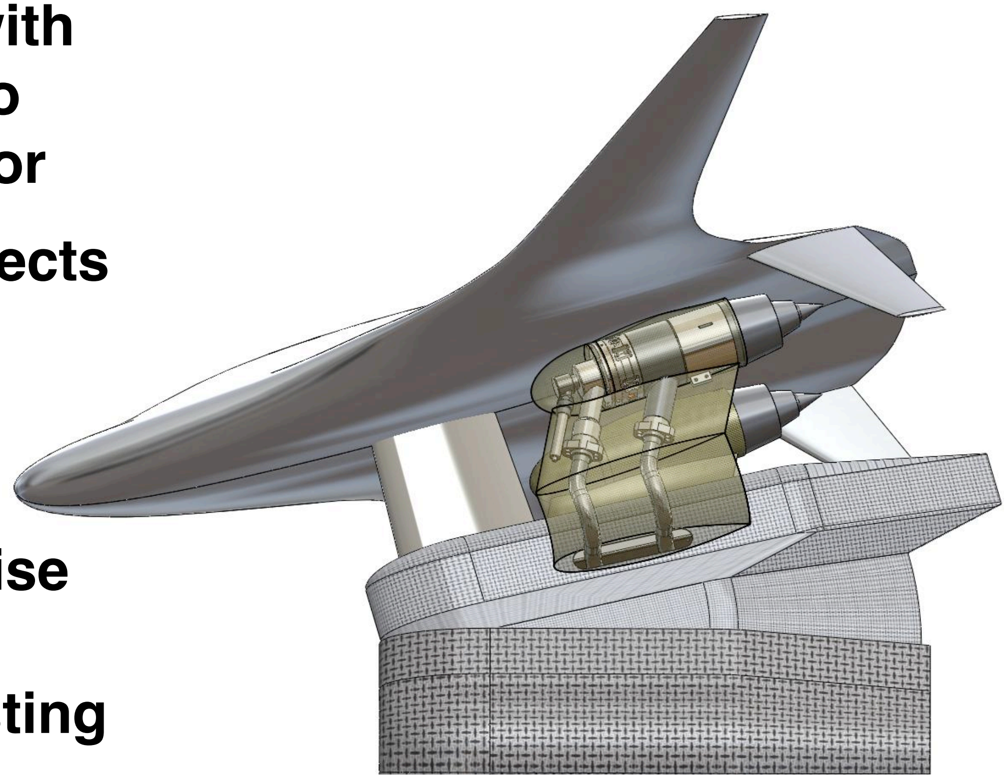
<u>Objectives</u>:

- **Develop HWB subsonic transport configuration and subsystems to meet the N+2 noise goal of -42 dB while achieving a reduction in fuel burn**
- **Develop improved noise prediction methods**
- **Design, fabricate HWB model and subsystems that will be tested for the understanding of noise, aerodynamics and validation of prediction methods**

2012 High Fidelity Experiment:
Acoustic Testing Approach

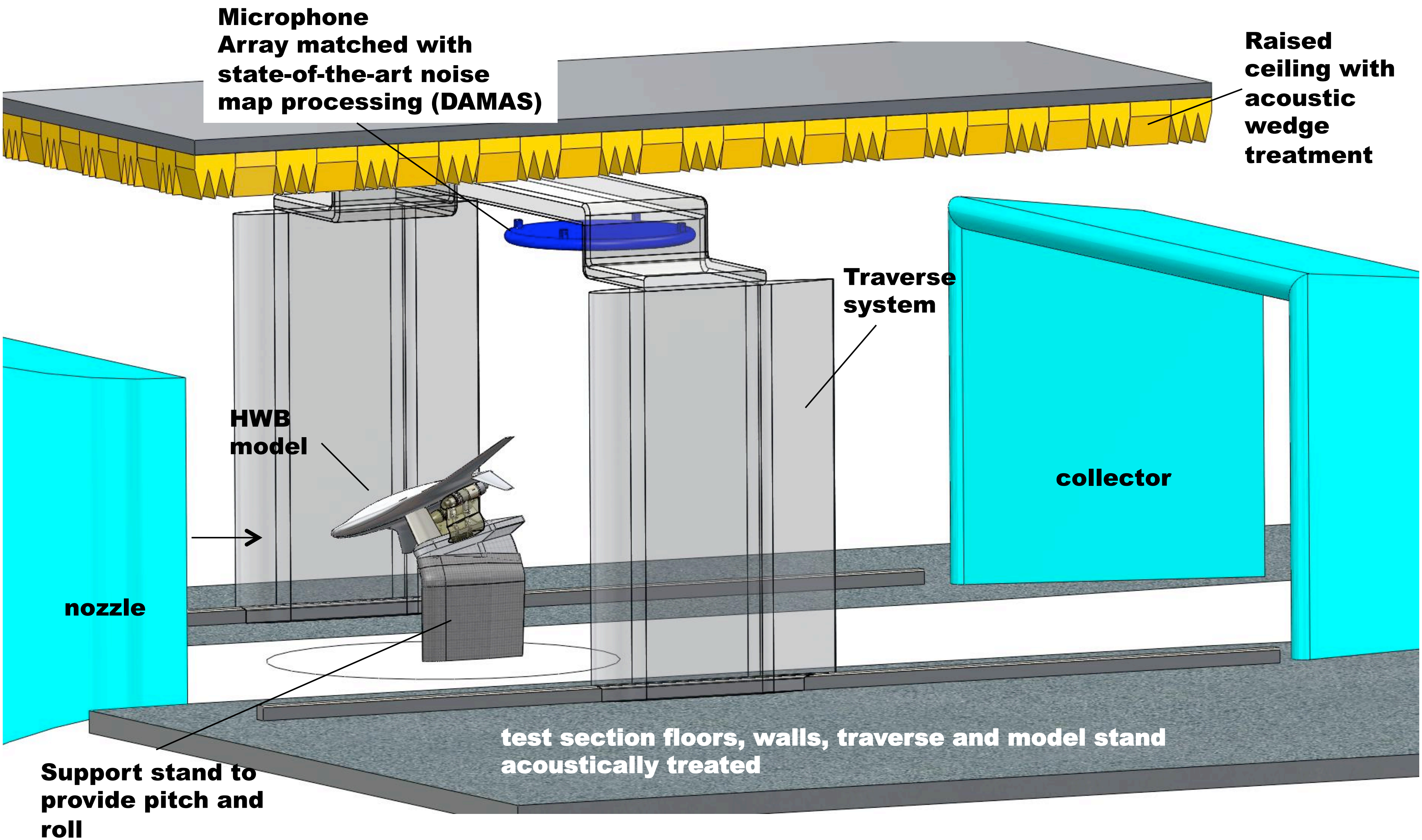
• **High-fidelity scaled HWB model with accurate engine noise simulation to produce a benchmark data bases for**

- **HWB Twin jet noise and PAA effects**
- **HWB Fan noise PAA effects**
- **HWB Airframe noise**
- **Scalable to full-vehicle HWB noise**



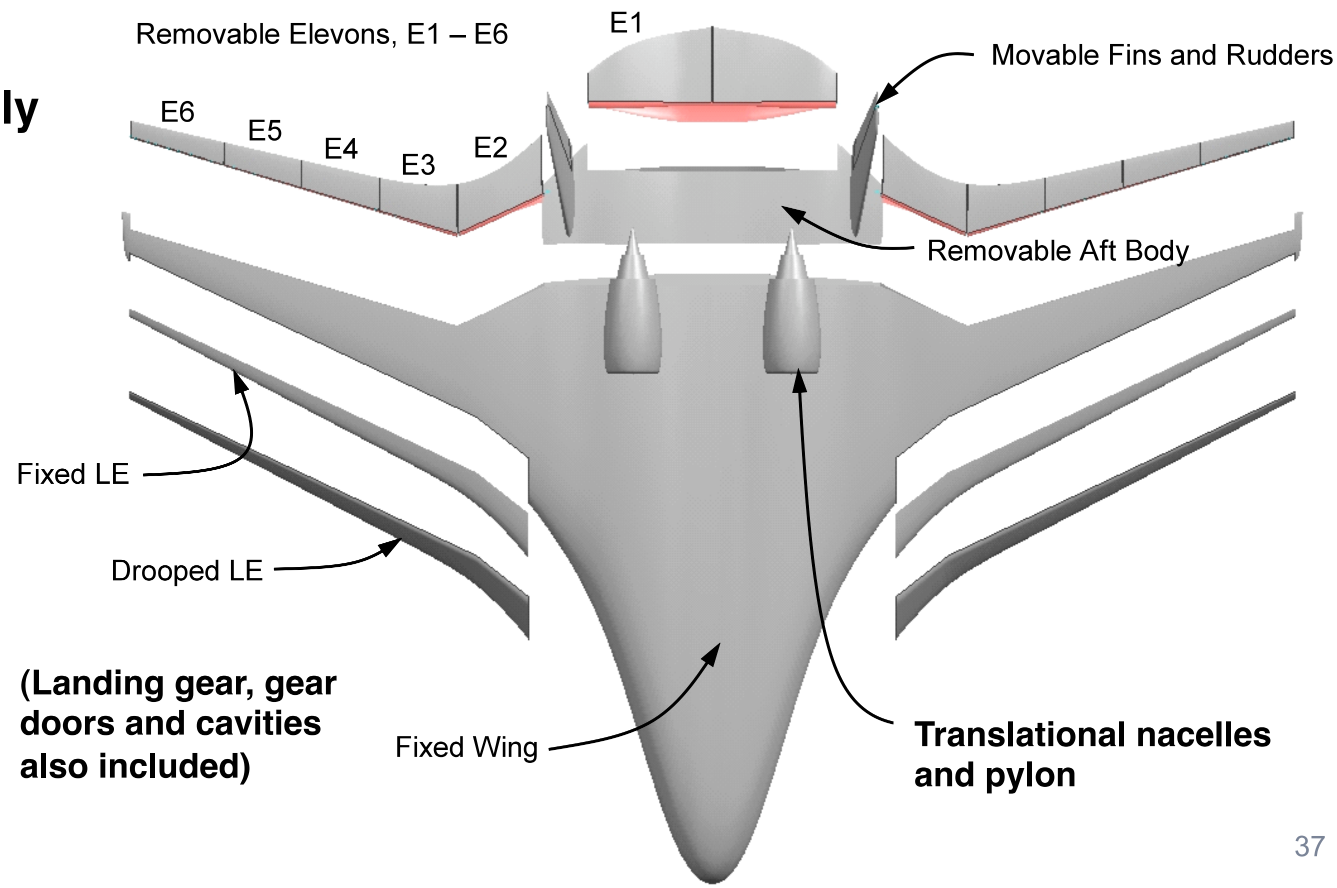
• **Installation of new twin hot-jet testing capability for the 14x22 tunnel – variable position and dual stream**

2012 High Fidelity Experiment:
Acoustic Test Set Up Overview in the LaRC 14x22



2012 High Fidelity Experiment:
HWB Scale Wind Tunnel Model

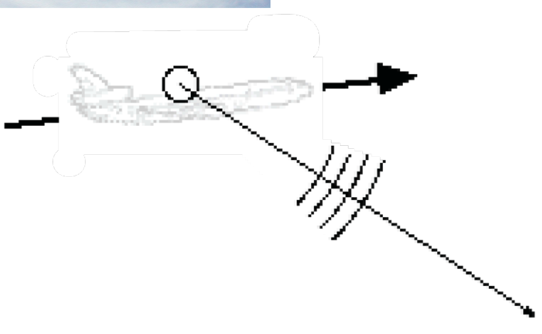
- **5.8% of full scale (12.35 ft span). Allows measurements over the full scale equivalent range of 230 Hz to 4.1 kHz (4 to 70 kHz model scale).**
- **Modular with control surfaces deflected to match specific flight conditions.**
- **Mountable upright (aero testing) and inverted (acoustic testing).**
- **Fuselage details accurately scaled for airframe noise studies.**
- **Nacelle configurations (multiple positioning):**
  - **- Flow-through,**
  - **- Fan noise simulator,**
  - **- Jet engine simulator.**



2012 High Fidelity Experiment: Aircraft System Noise Paradigm Shift

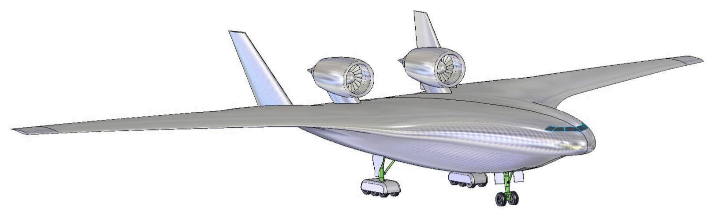
ANOPP 1 (Current Generation)

- Aircraft noise sources are placed at a single point
- Effects of engine installation are added based on past experience (barrier model for acoustic shielding)
- Cannot venture too far outside experience base



ANOPP 2 (Next Generation)

Must venture outside experience base



Outcome after High Fidelity HWB:

- Benchmark datasets
- New ANOPP2 Variable Fidelity Methods
- Validation of ANOPP2 with:
  - Aircraft noise sources at true locations.
  - All interaction effects: engine installation, airframe configuration, **scattering**

Questions and Discussion

NASA