National Aeronautics and
Space Administration

Concepts and technologies for Green Aviation

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www.nasa.gov

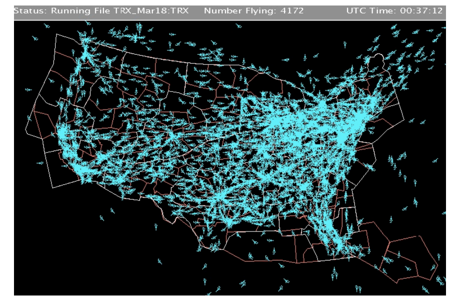
Outline

- Introduction
- N+1 Vehicle Themes and Progress
- N+2 Vehicle Themes and Progress
- N+3 Vehicle Themes and Progress
- Alternative Fuels Research
- Wrapup

Motivation

Economic Impact of Aviation

- **Manufacturing and services account for $436 billion in direct economic activity**
- **Provides $60.6B positive trade balance**
  - Reduces the total negative trade balance by 8%
- **25% of all companies' sales depend on air transportation**
- **655,500 jobs in the U.S. Aviation Industry**
  - 490,300 domestic manufacturing
  - 165,200 air transportation services
- **650 million travelers annually (~ 2 million travelers/day)**
  - 151 domestic airlines flying 8,100 aircraft
  - Airline annual operating revenue is $143B
- **51,000 controlled domestic flights/day**
  - 38,000 commercial or air taxi flights
  - FAA simultaneously controls over 4,000 flights for most of the day



Aviation has a huge impact on the nation's economy and touches most of the general public/taxpayers

Why Green Aviation? – National Challenges

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

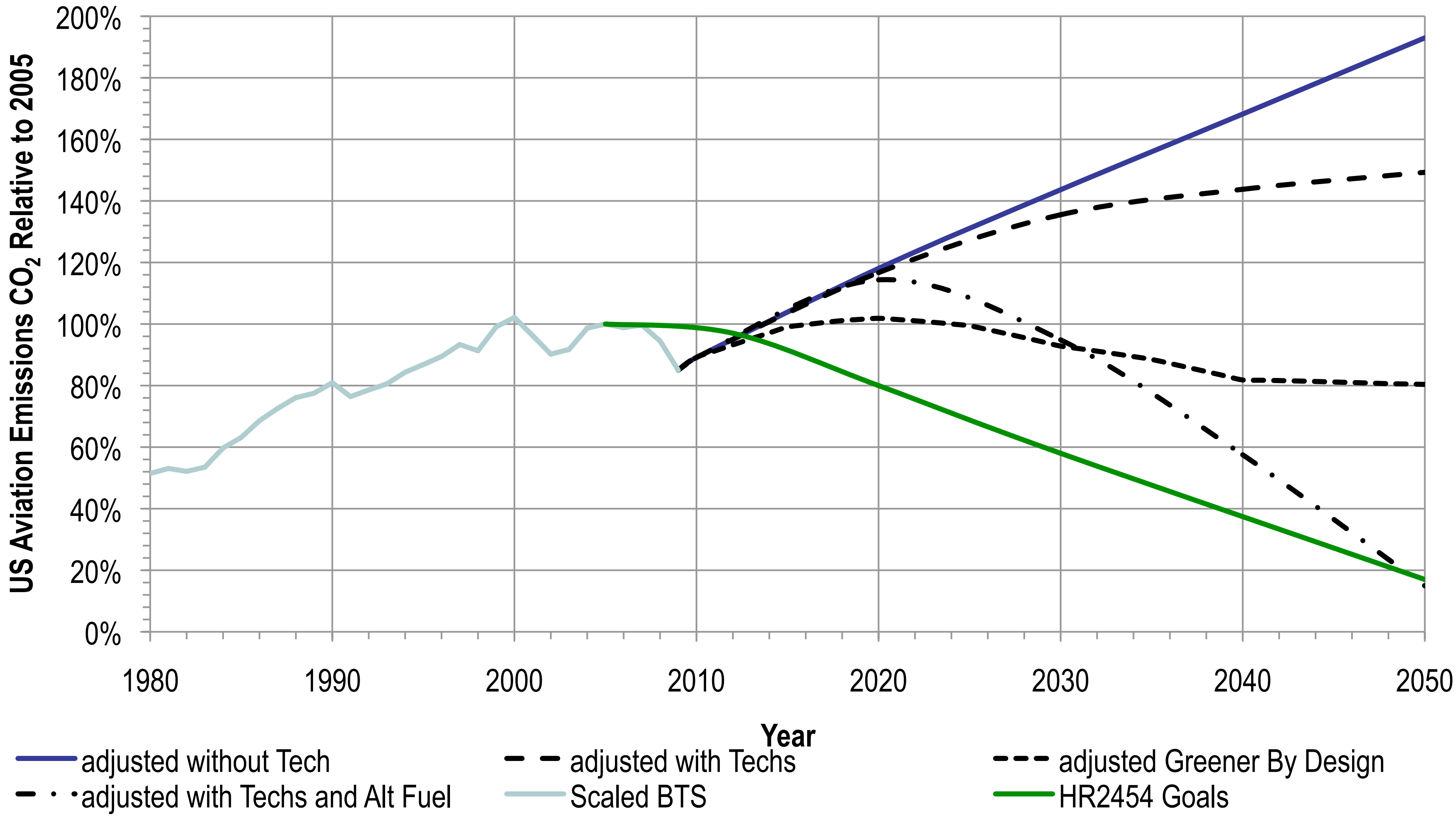
Noise

•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.

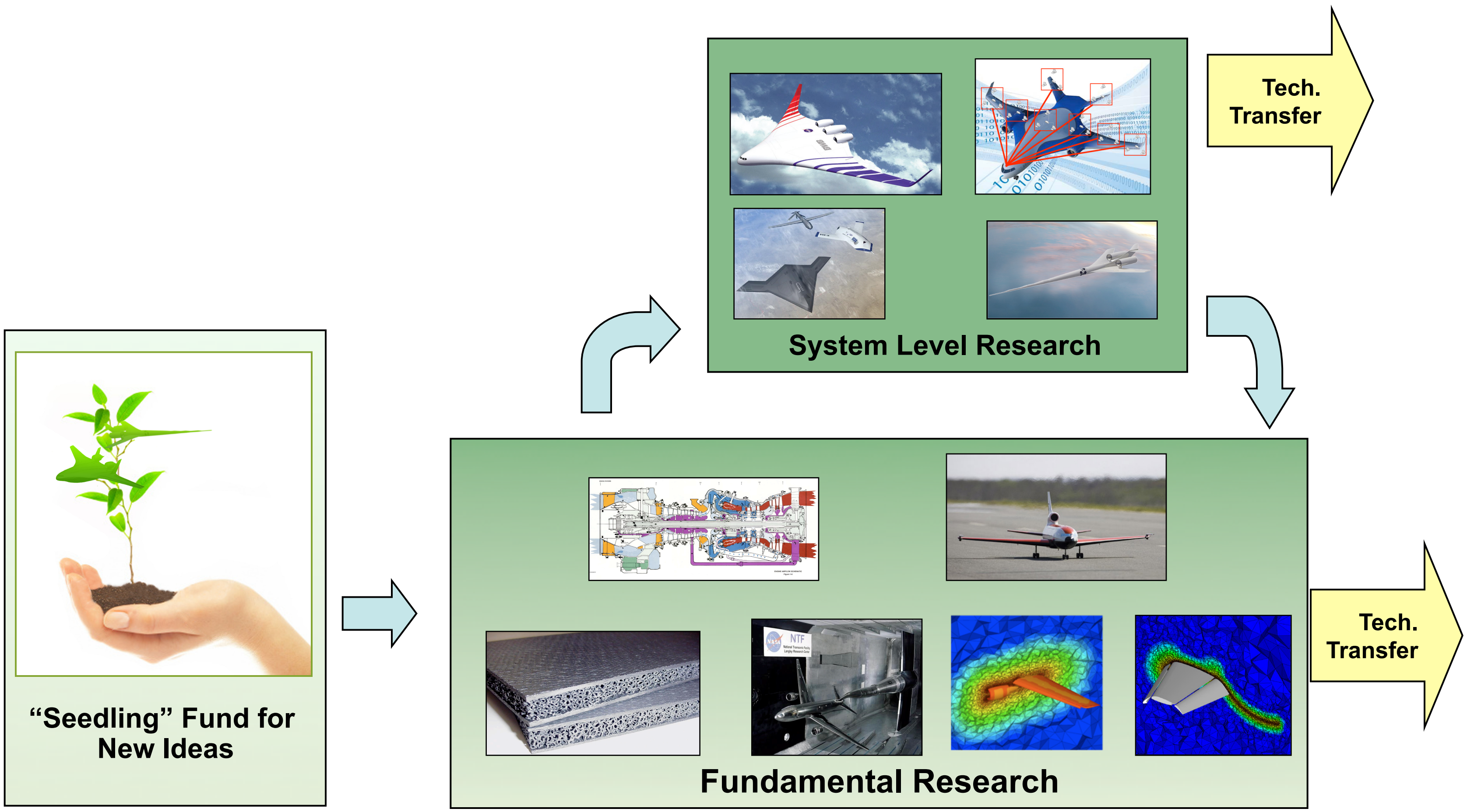
•Since 1980 FAA has invested over $5B in airport noise reduction programs

Projection of CO_2 Emissions



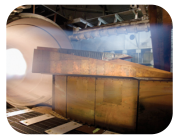
Magnitude of emissions growth and gap is dependent upon aviation traffic growth assumptions

NASA Aeronautics Investment Strategy



Enabling “Game Changing” concepts and technologies from advancing fundamental research ultimately to understand the feasibility of advanced systems

NASA Aeronautics Programs in FY2010

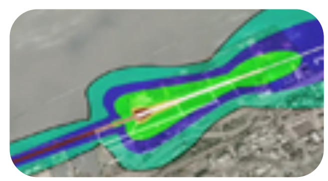



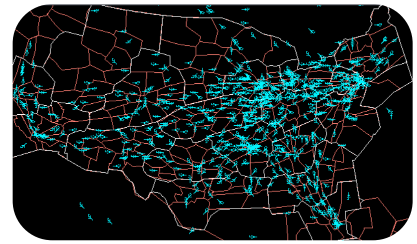

Fundamental Aeronautics Program

Conduct cutting-edge research that will produce innovative concepts, tools, and technologies to enable revolutionary changes for vehicles that fly in all speed regimes.

Integrated Systems Research Program

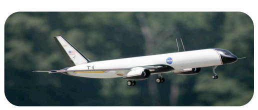
Conduct research at an integrated system-level on promising concepts and technologies and explore/assess/demonstrate the benefits in a relevant environment

Airspace Systems Program

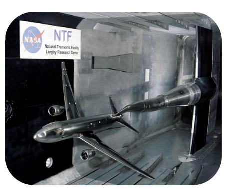
Directly address the fundamental ATM research needs for NextGen by developing revolutionary concepts, capabilities, and technologies that will enable significant increases in the capacity, efficiency and flexibility of the NAS.

Aviation Safety Program

Conduct cutting-edge research that will produce innovative concepts, tools, and technologies to improve the intrinsic safety attributes of current and future aircraft.






Aeronautics Test Program

Preserve and promote the testing capabilities of one of the United States' largest, most versatile and comprehensive set of flight and ground-based research facilities.

Portfolio Relevance to NASA and Nation

- **The Next Generation Air Transportation System (NextGen)**
  - **Joint Planning and Development Office (JPDO): Vision 100 (2003)**
  - **Revolutionary transformation of the airspace, the vehicles that fly in it, and their operations, safety and environmental impact**
- **National Aeronautics R&D Policy (December 2006), Plan (December 2007) and Technical Appendix (December 2008)**
  - **"Mobility thru the air is vital . . . "**
  - **"Aviation is vital to national security and homeland defense."**
  - **"Assuring energy availability and efficiency . . . " and "The environment must be protected."**
- **NASA Strategic Plan (2006)**
  - **Strategic Goal 3: "Develop a balanced overall program of science, exploration and aeronautics consistent with the redirection of the human spaceflight program to focus on exploration."**
  - **Sub-goal 3E: "Advance knowledge in the fundamental disciplines of aeronautics and develop technologies for safer aircraft and higher capacity airspace systems."**

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Quantifiable System Level Metrics

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

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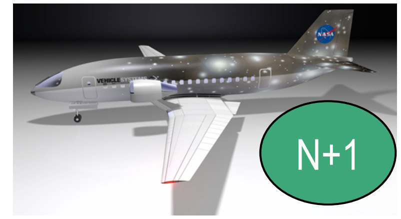
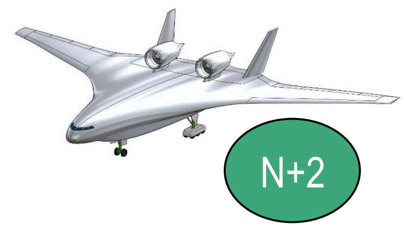
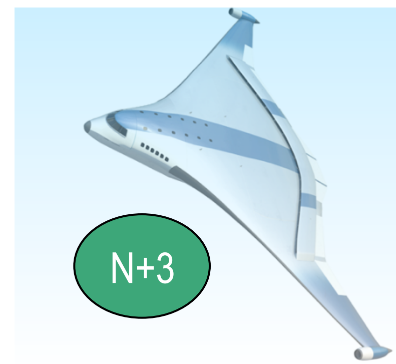
*** Technology readiness level for key technologies = 4-6

** Additional gains may be possible through operational improvements

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







Approach

- *Enable Major Changes in Engine Cycle/Airframe Configurations*
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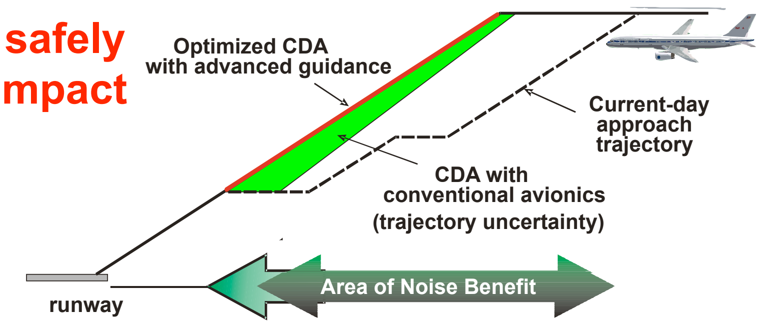
Impact of Green Operations

Develop & demonstrate novel operation concepts to safely increase throughput while reducing environmental impact



Today:
Continuous Descent Approaches (CDA's) only flown at off-peak hours or in low-congestion airspace

Tailored Arrivals & Enroute Descent Advisor (EDA)

- EDA combines scheduling with CDA to generate green solutions that maximize runway throughput and avoid conflicts
- Tailored Arrivals optimize CDA's to individual aircraft performance capability

San Francisco trials indicate fuel savings of up to 3000 pounds (10,000 lb CO_2 reduction) per flight for large aircraft during peak traffic conditions

Airborne Merging and Spacing

- Merging and spacing will be delegated to the flight deck instead of current ground-based process
- Will enhance EDA through closer spacing and eliminating missed slots

UPS claims Merging and Spacing operations with Continuous Descent Arrivals (CDAs) will enable savings of 1 million gallons of fuel per year

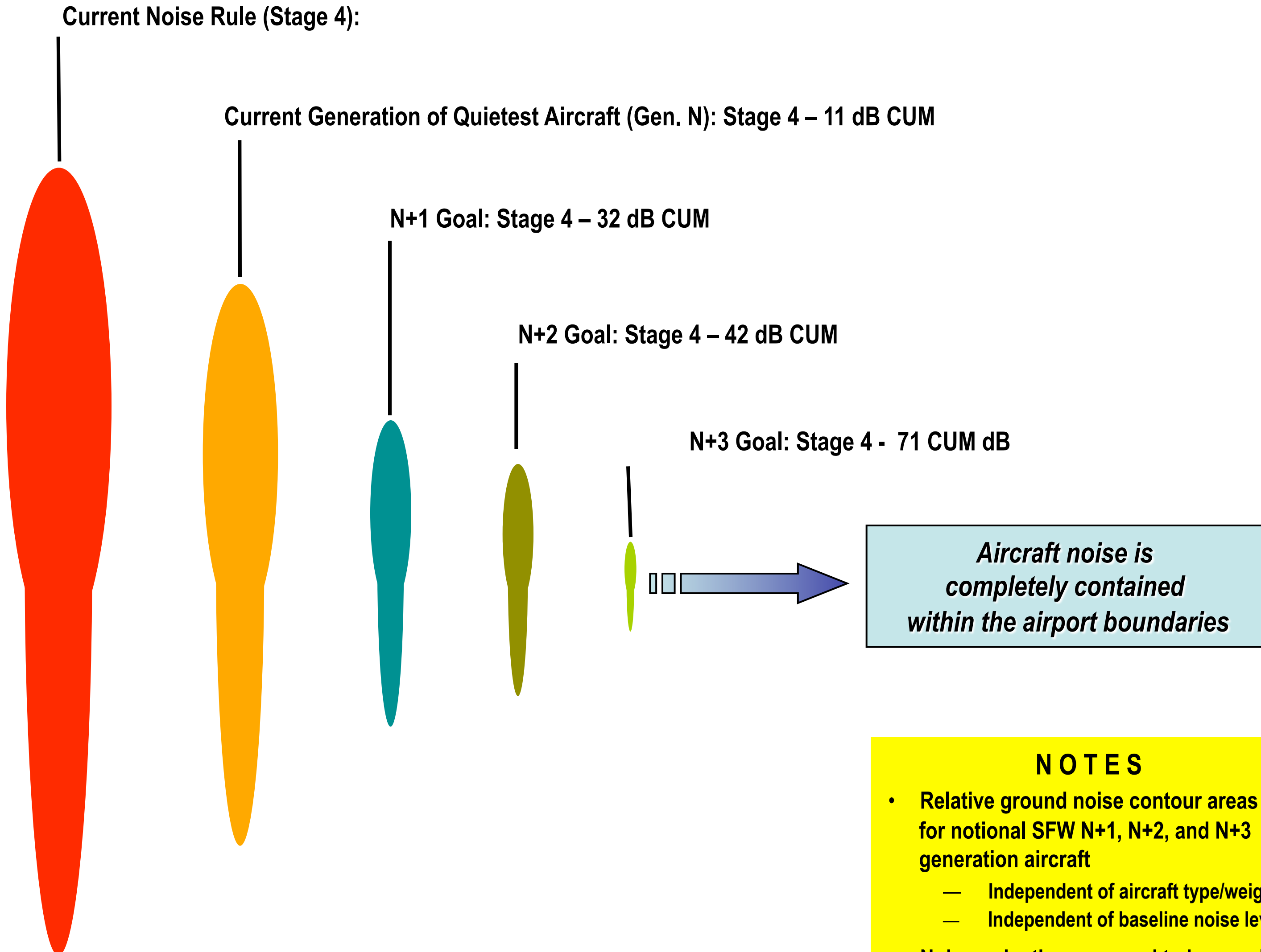
Energy navigation concept (eNAV)

- Optimized fuel burn, noise, and emissions reduction by commanding pilots when to deploy flaps, gear, engine power settings, etc.

Development Partners:
FAA, Boeing, United Airlines, US Air, UPS

Early Adapters of Tailored Arrivals:
United Airlines, Quantas, Air New Zealand, Japan Airlines

Goals for a single landing and takeoff



NOTES

- Relative ground noise contour areas for notional SFW N+1, N+2, and N+3 generation 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

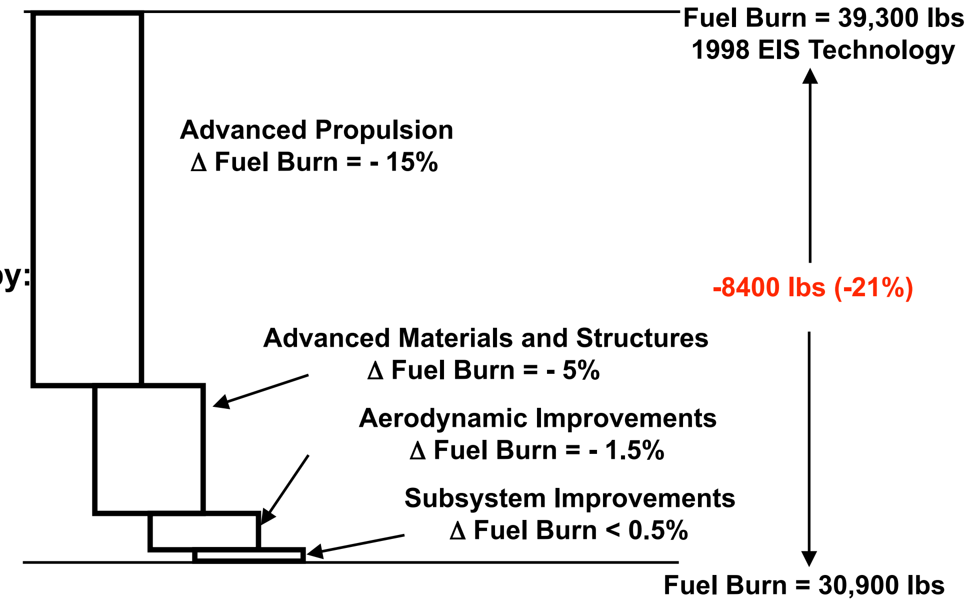
Thomas, Envia, et al

Performance - Fuel Burn - N+1

Detailed System Analysis

"N + 1" Advanced Small Twin

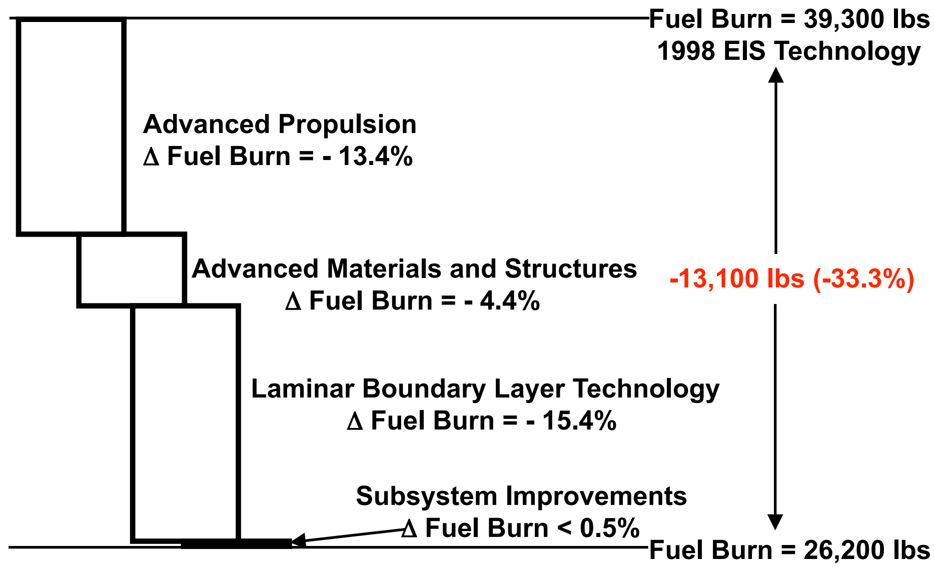
- 162 pax, 2940 nm mission baseline
- Ultra high bypass ratio engines, geared
- Key technology targets:
  - +1 point increase in turbomachinery efficiencies
  - 25% reduction in turbine cooling flow enabled by: improved cooling effectiveness and advanced materials
  - +50 deg. F compressor temperatures (T3)
  - +100 deg. F turbine rotor inlet temperatures
  - -15% airframe structure weight
  - -1% total vehicle drag
  - -15% hydraulic system weight



"N + 1" Advanced Small Twin - Plus

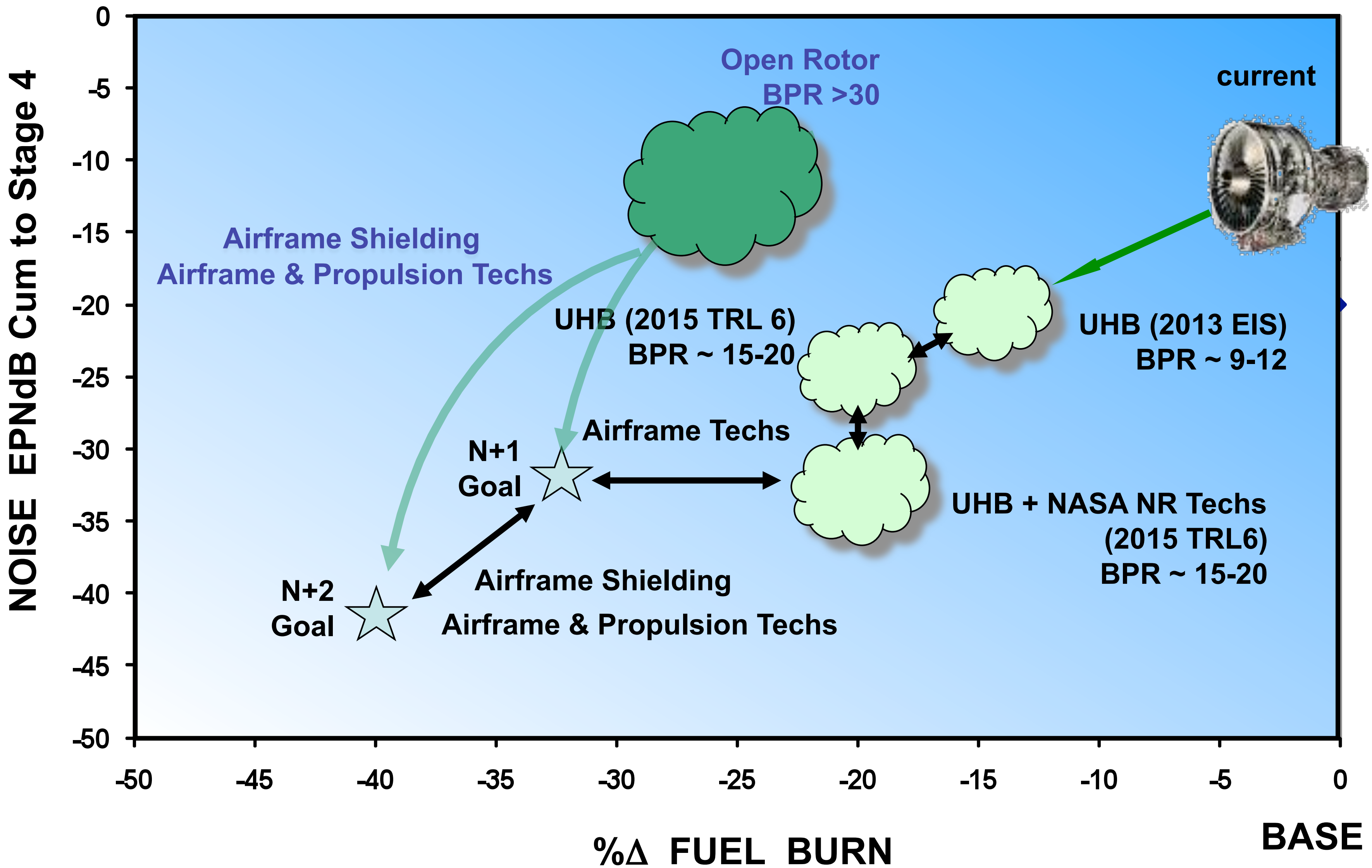
- All technologies listed above plus:
  Laminar Boundary Layer over
  - 67% upper wing,
  - 50% lower wing, tail, nacelles

  Result = -16.8% total vehicle drag
  - wing upper surface: 5.7%
  - wing lower surface: 3.8%
  - horizontal tail upper and lower surface: 2.2%
  - vertical tail both sides: 1.9%
  - nacelles: 3.2%



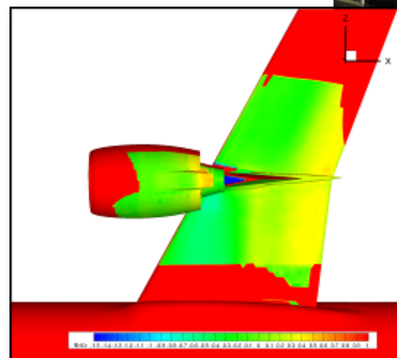
Guynn, Nickol, et al

UHB Propulsor Technology - Roadmap

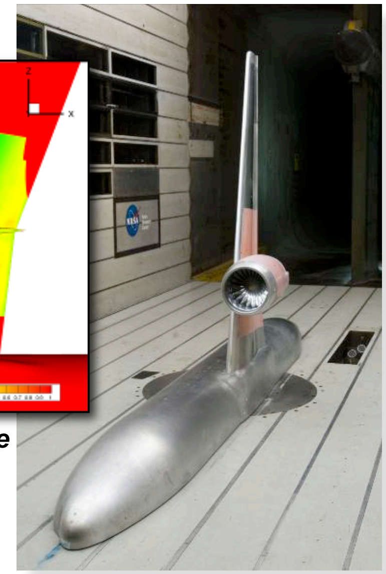


➢ *Pratt & Whitney Geared Turbofan*

- **Nacelle/Wing Interaction Test**
  - Highly successful collaboration between Industry Partner and three NASA centers
  - Test data provided design confidence for nacelle-wing integration at BPR = 12
- **Geared Turbofan Demonstrator Engine**
  - Successful ground demonstration of Geared Turbofan concept completed May 2008
    - Predicted fan performance verified
    - Acoustic characteristics within expectations
- **Future Collaboration**
  - Space Act Agreement negotiations initiated for continued research collaboration into next generation Geared Turbofan, starting with system analysis and design studies in 2009

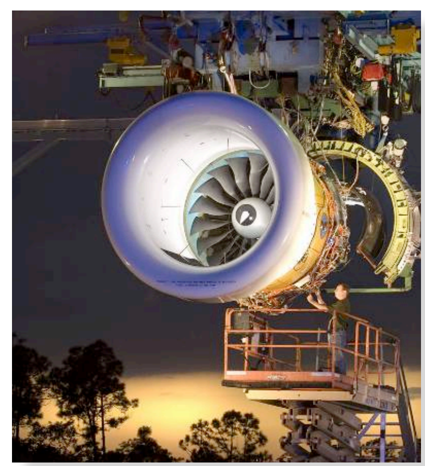


Pressure Sensitive Paint results



Powered half-span model test in Ames 11' wind tunnel

GTF Demonstrator Engine ground test



Flamm, Lord, Hughes, et al

➢ General Electric Open Rotor

- Space Act Agreement
  - Signed August 2008
  - Initiates collaborative research on Open Rotor propulsion concepts in NASA Glenn 9'x15' and 8'x6' wind tunnels in 2Q 2009

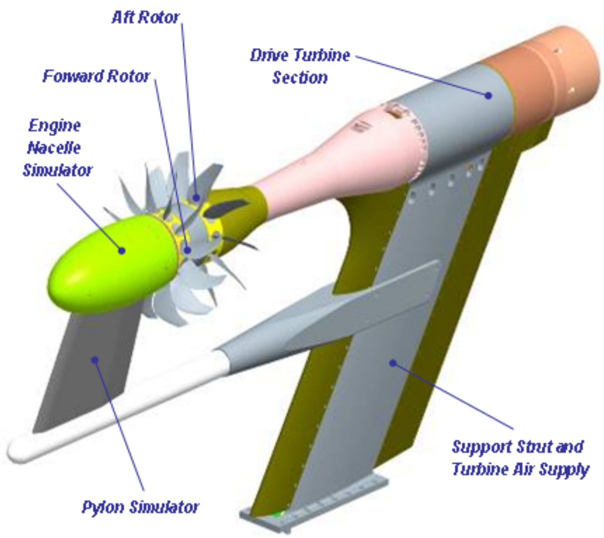
➢ Test Objectives

- Investigate performance and noise
- Produce shareable open rotor fan design
- Generate shareable database of test results

➢ Plan

- NASA refurbish 1980s counter-rotation propfan drive rig
- GE will design, fabricate and test 1980s technology based open rotor fan as Historical Baseline

GE Open Rotor Concept



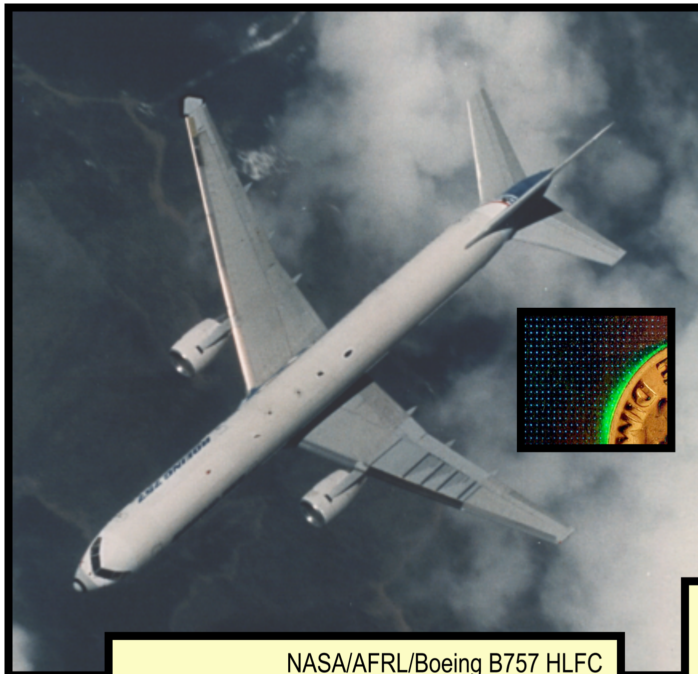
NASA Glenn Open Rotor Propulsion Rig

Hughes, GEAE, et al

Historical Collaboration in Laminar Flow

a few examples

NASA/Lockheed/Douglas JetStar HLFC
Simulated Airline Service - 1983-86



NASA/AFRL/Boeing B757 HLFC
Flight Experiment - 1990

NASA/Boeing HLFC Wing Model
8' TPT Wind Tunnel - 1995

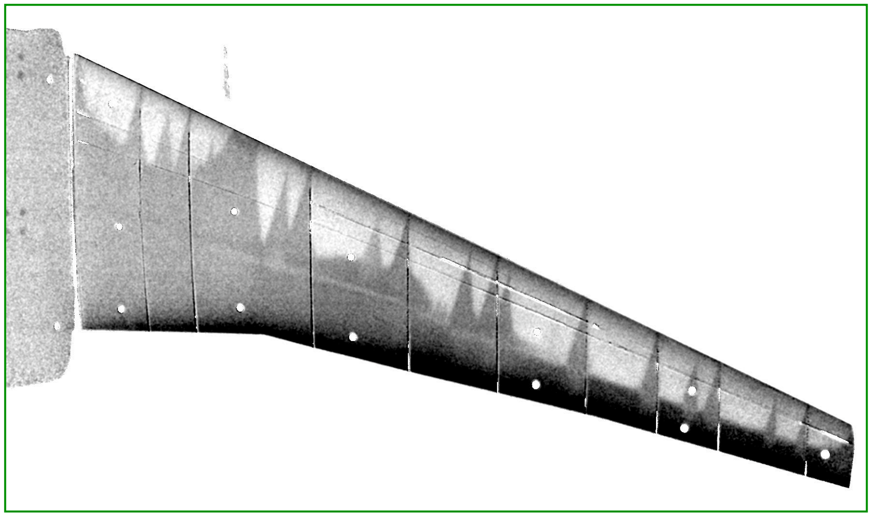
- History/experience/solutions on which to build
- Today, fuel cost share of DOC is significantly higher
- Global environmental concerns widely acknowledged

Laminar (Boundary Layer) Flow Research

Aero Objectives for NTF Tests

- Determine LF extent relative to predictions
- Determine effectiveness of TSP for transition detection
- Determine the suitability of the NTF for NLF testing
- Determine the effectiveness of small scale model manufacturing quality for NLF testing
- Determine drag (increments) for NLF relative to predictions

Preliminary Results



Rivers, Campbell, BCA (Om), et al

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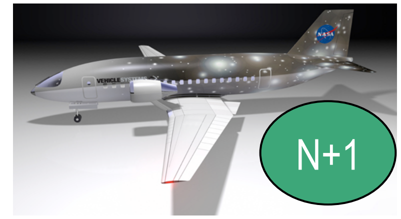

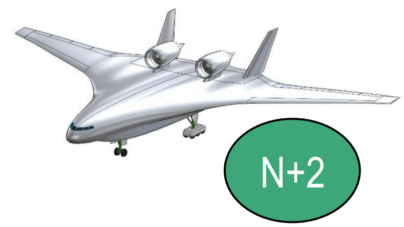

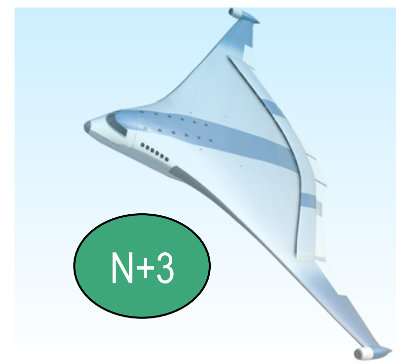

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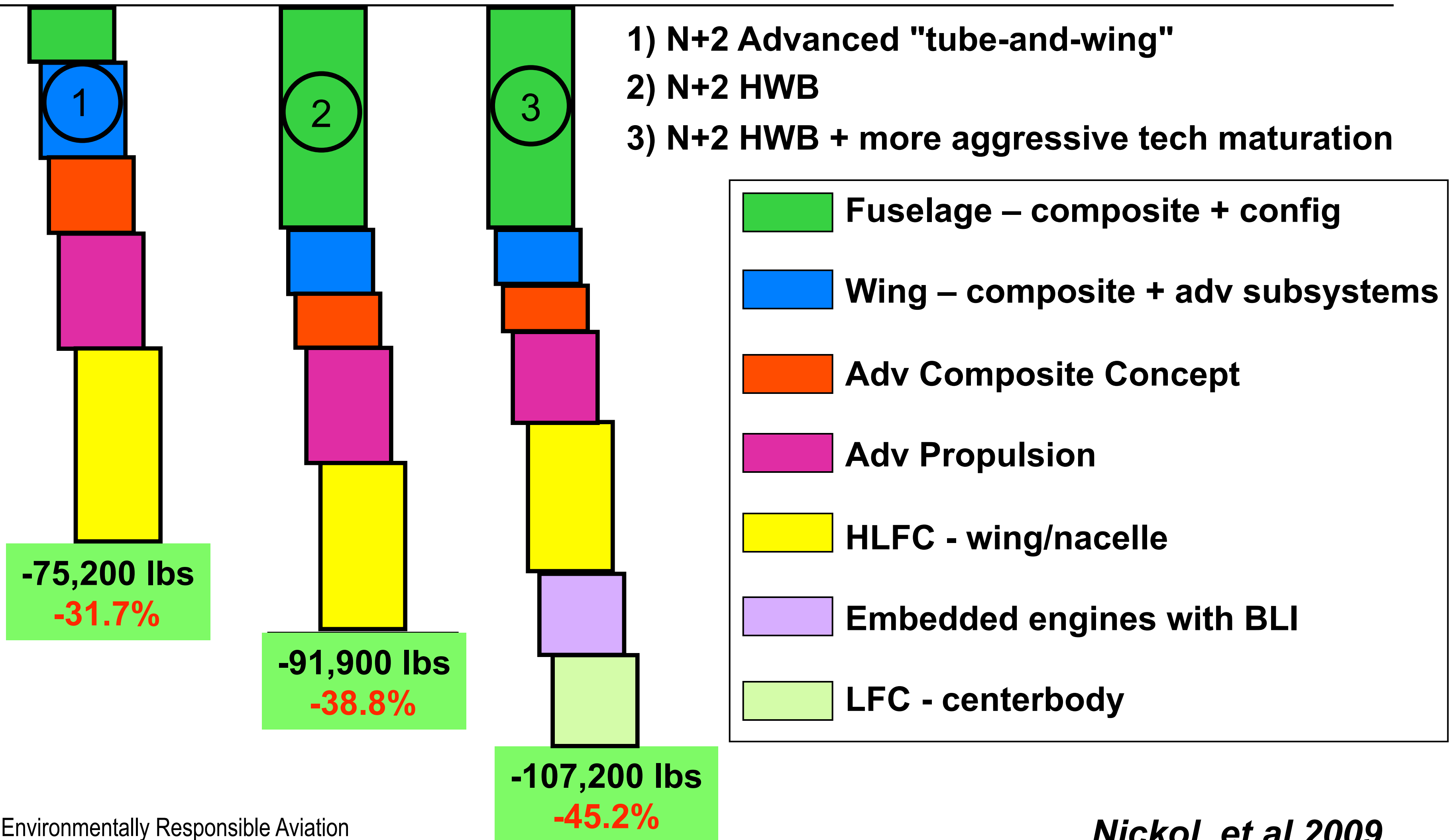
Potential Reduction in Fuel Consumption

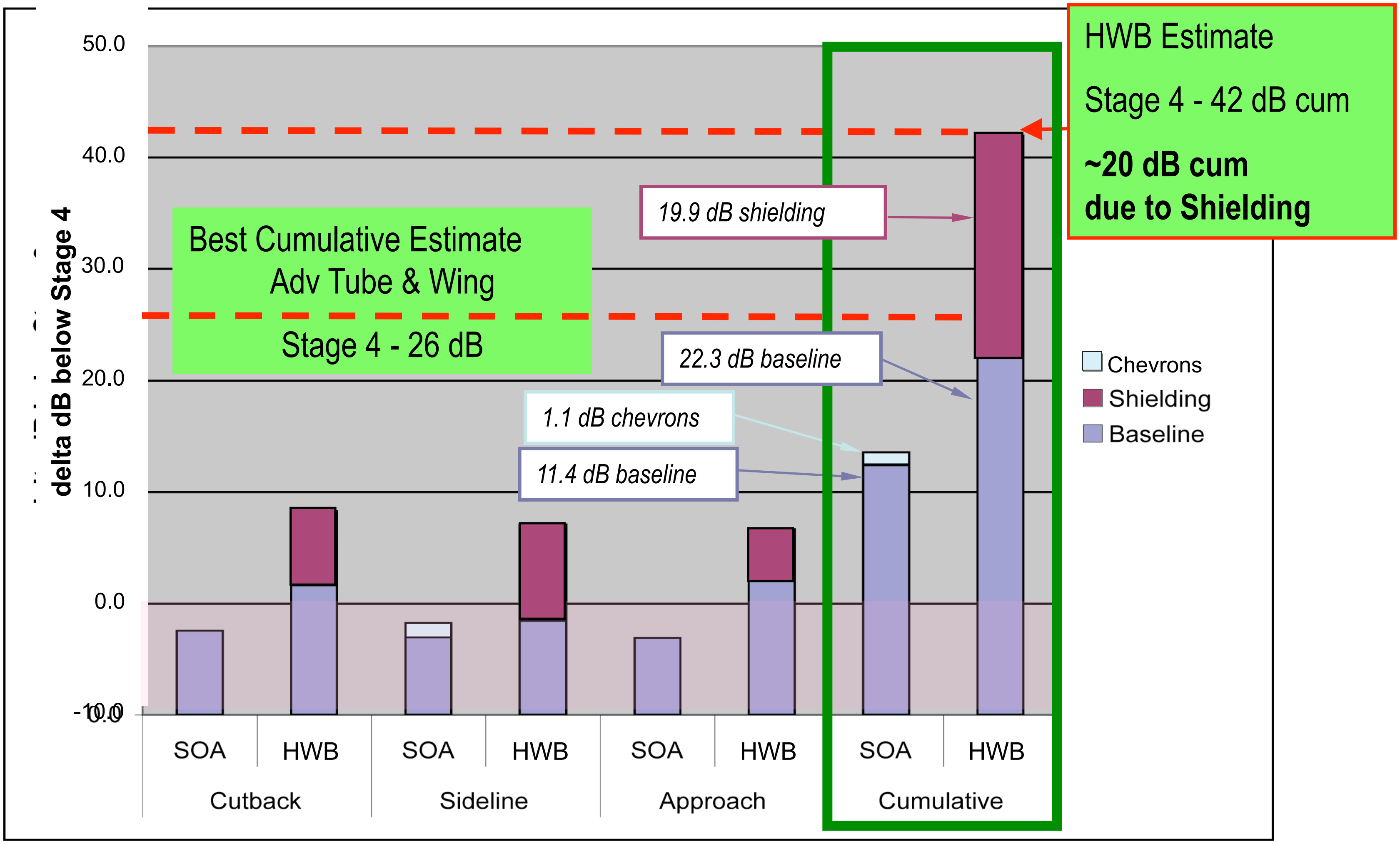
Reference Fuel Burn = 237,100 lbs
1997 Technology Large Twin Aisle Vehicle "777-200ER-like"



Nickol, et al 2009

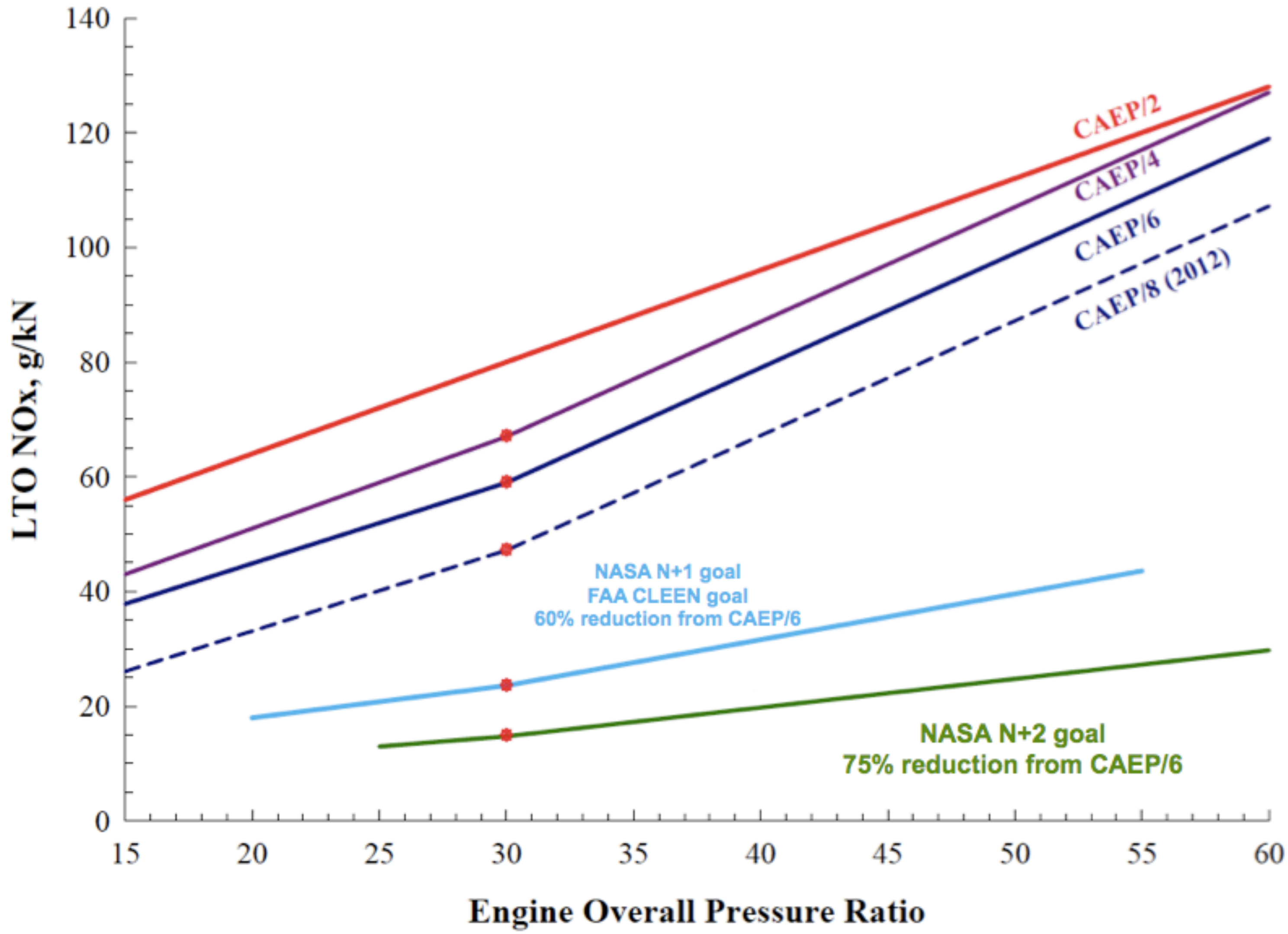
N+2 Potential Noise Reduction

Includes estimate of maximum propulsion noise shielding



Thomas, Berton, et al

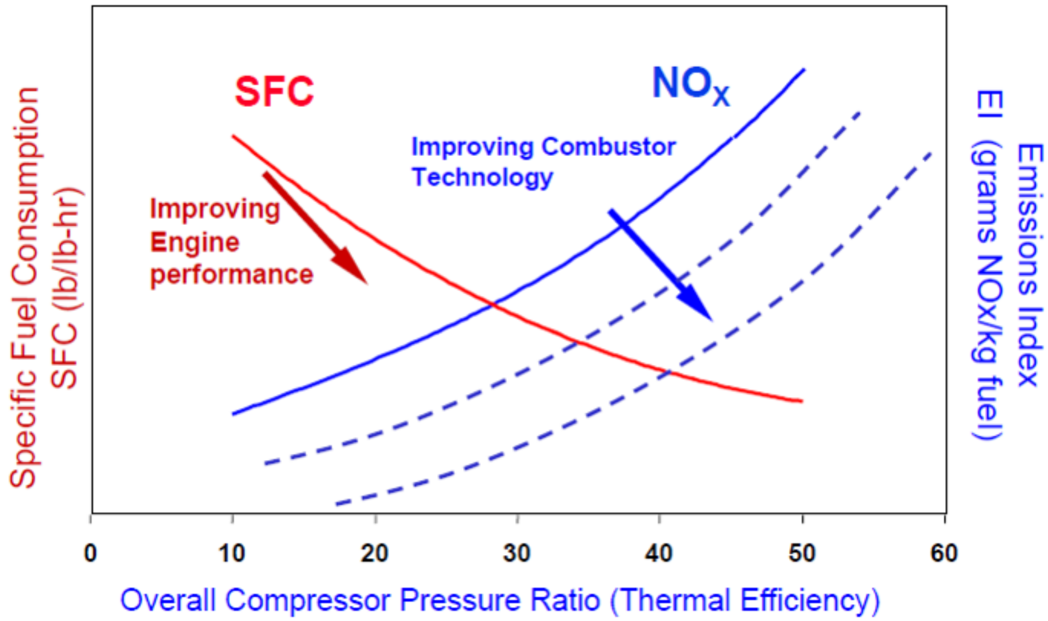
Potential N+2 LTO NO_x Reduction



Reduced LTO NO_x Emissions

Low NOx combustor concepts for high OPR environment

Increase thermal efficiency without increasing NOx emissions



<u>NASA Injector Concepts</u>

- Partial Pre-Mixed
- Lean Direct Multi-Injection

<u>Enabling Technology</u>

- lightweight CMC liners
- advanced instability controls

- Improved fuel-air mixing to <u>minimize</u> hot spots that create additional NOx
- Lightweight liners to handle higher temperatures associated with higher OPR
- Fuel flexibility to accommodate emerging alternative fuels
- Coordinating with DoD Programs

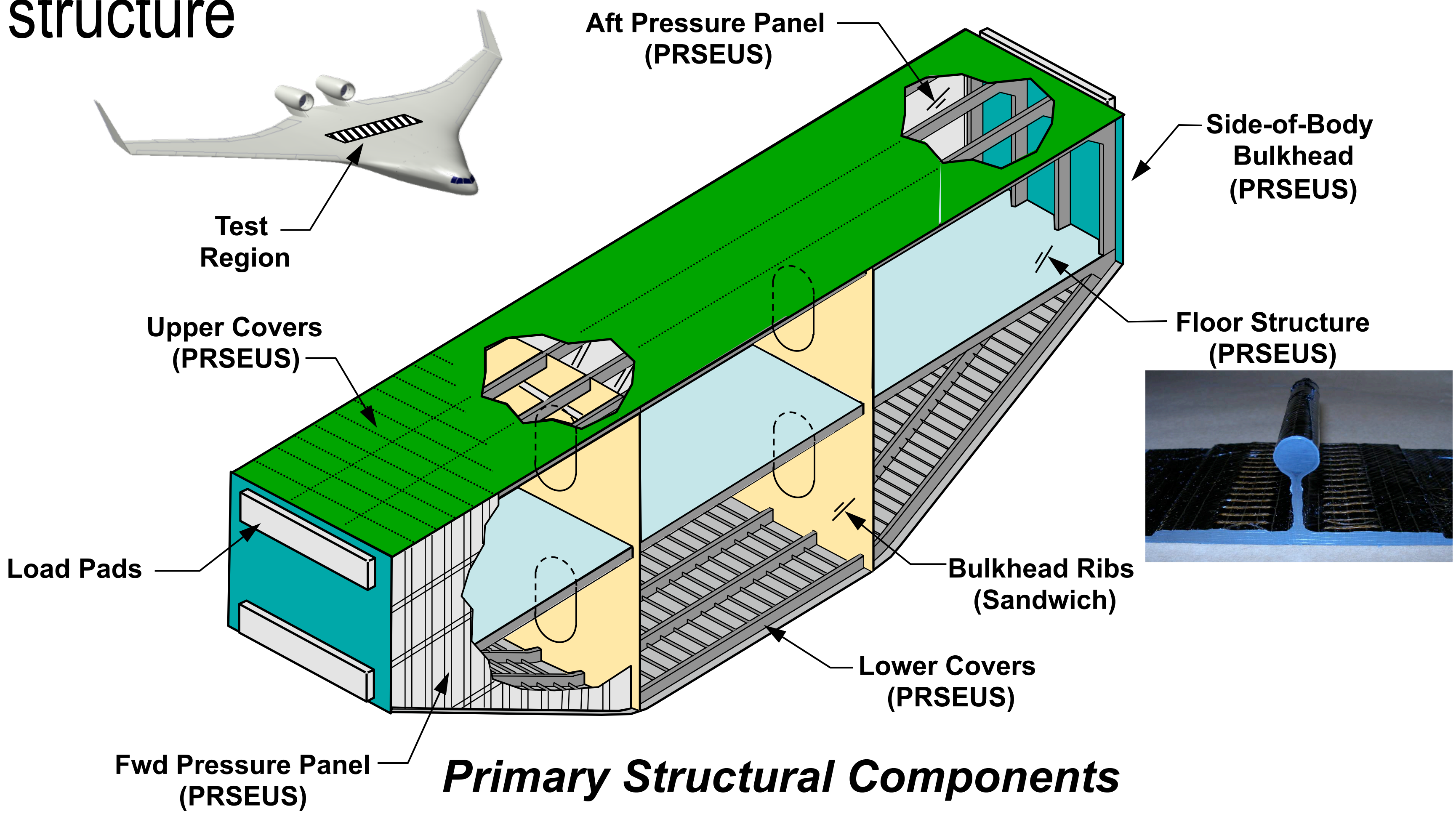
Progress (1)

Working Long Poles - Low speed flight controls

Risch, Vicroy, Princeon, et al

Progress (2)

Working long poles - Non-circular pressurized fuselage structure



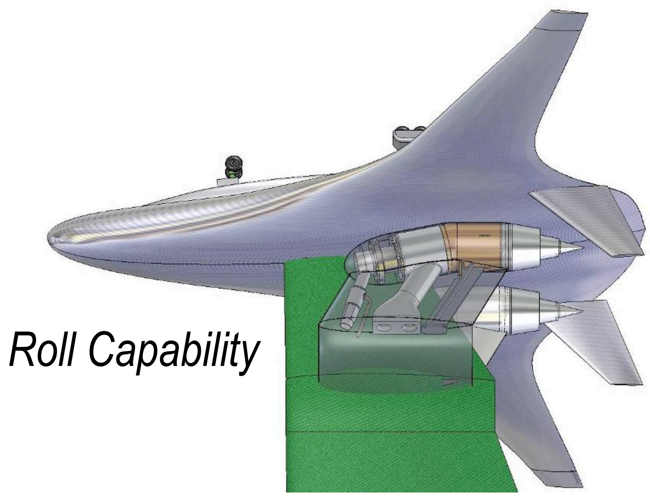
Primary Structural Components

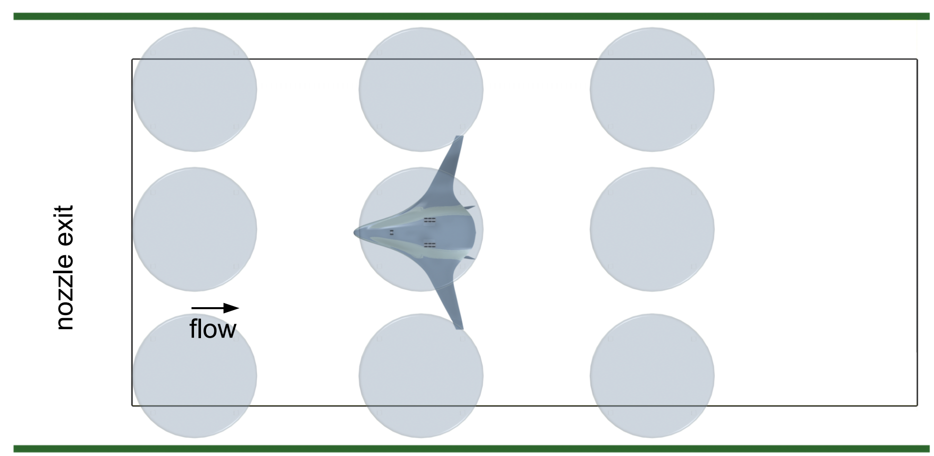
Jegley, Velicki, Vivek, Zoran, et al

Progress (3)

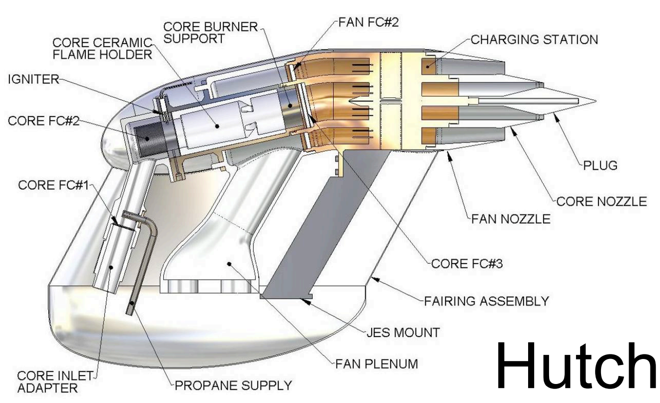
Working long poles - noise characteristics

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





Top view with some array positions



Phased Array (DAMAS type) processing to measure low noise levels in 14 x 22

Hutchinson, Gatlin, Kawai, et al

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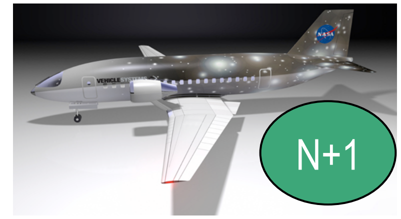

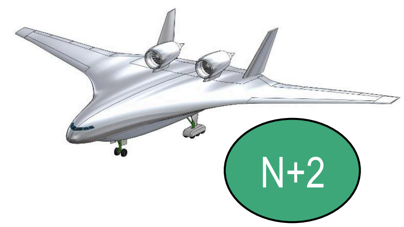

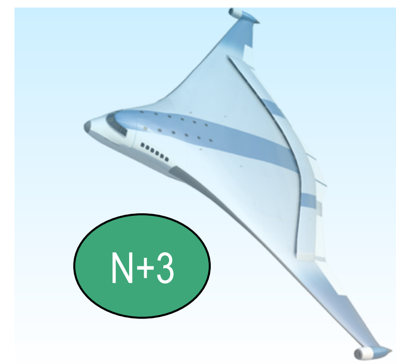

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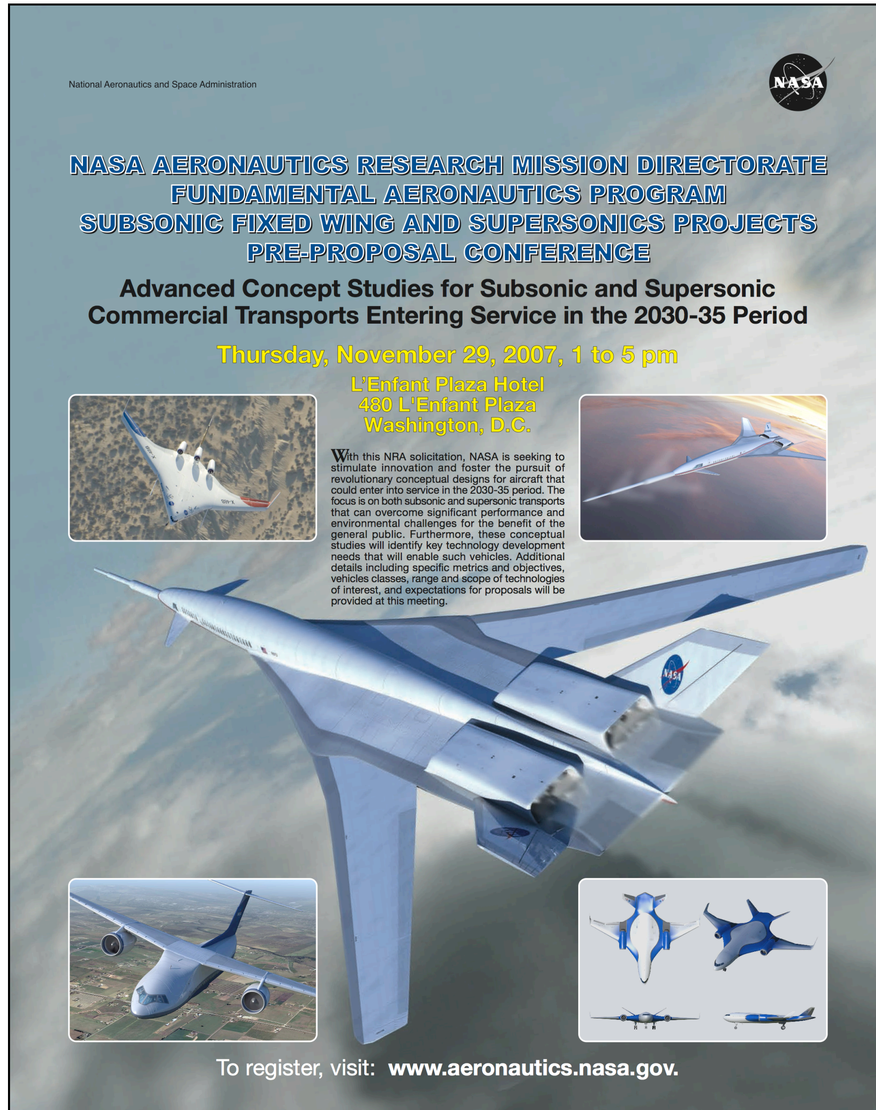
N+3 NRA Objectives

- Identify advanced airframe and propulsion concepts, as well as corresponding enabling technologies for commercial aircraft anticipated for entry into service in the 2030-35 timeframe, market permitting
  - Advanced Vehicle Concept Study
  - Commercial Aircraft include both passenger and cargo vehicles
  - Anticipate changes in environmental sensitivity, demand, & energy
- Results to aid planning of follow-on technology programs

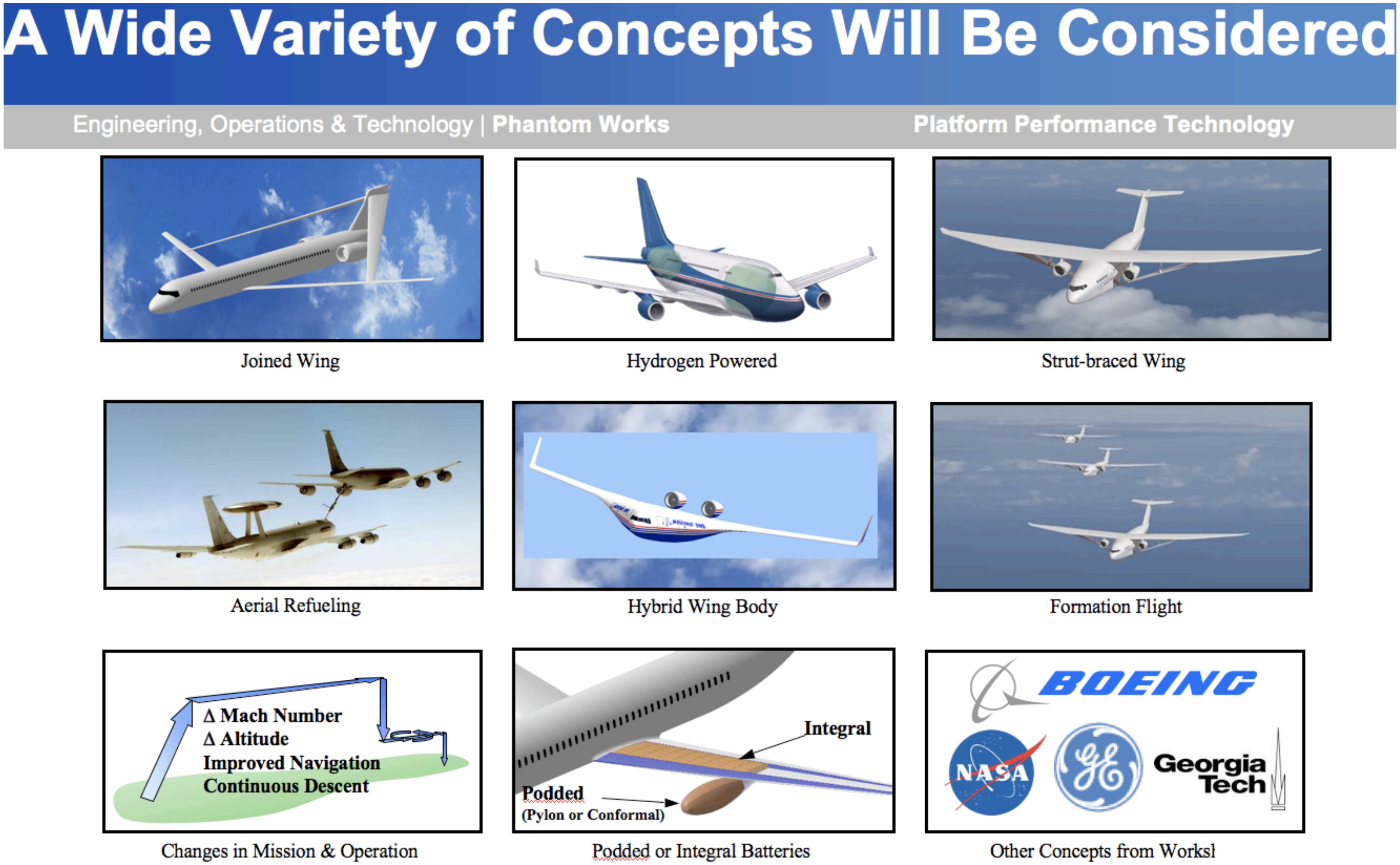
N+3 Advanced Concept Study NRA

- 29 Nov 07 bidders conference
- 15 Apr 08 solicitation
- 29 May 08 proposals due
- 2 July 08 selections made
- 1 Oct 08 contract start
- Phase I: 18 Months
  - NASA Independent Assessment @ 15 months
- Phase II: 18-24 Months with significant technology demonstration

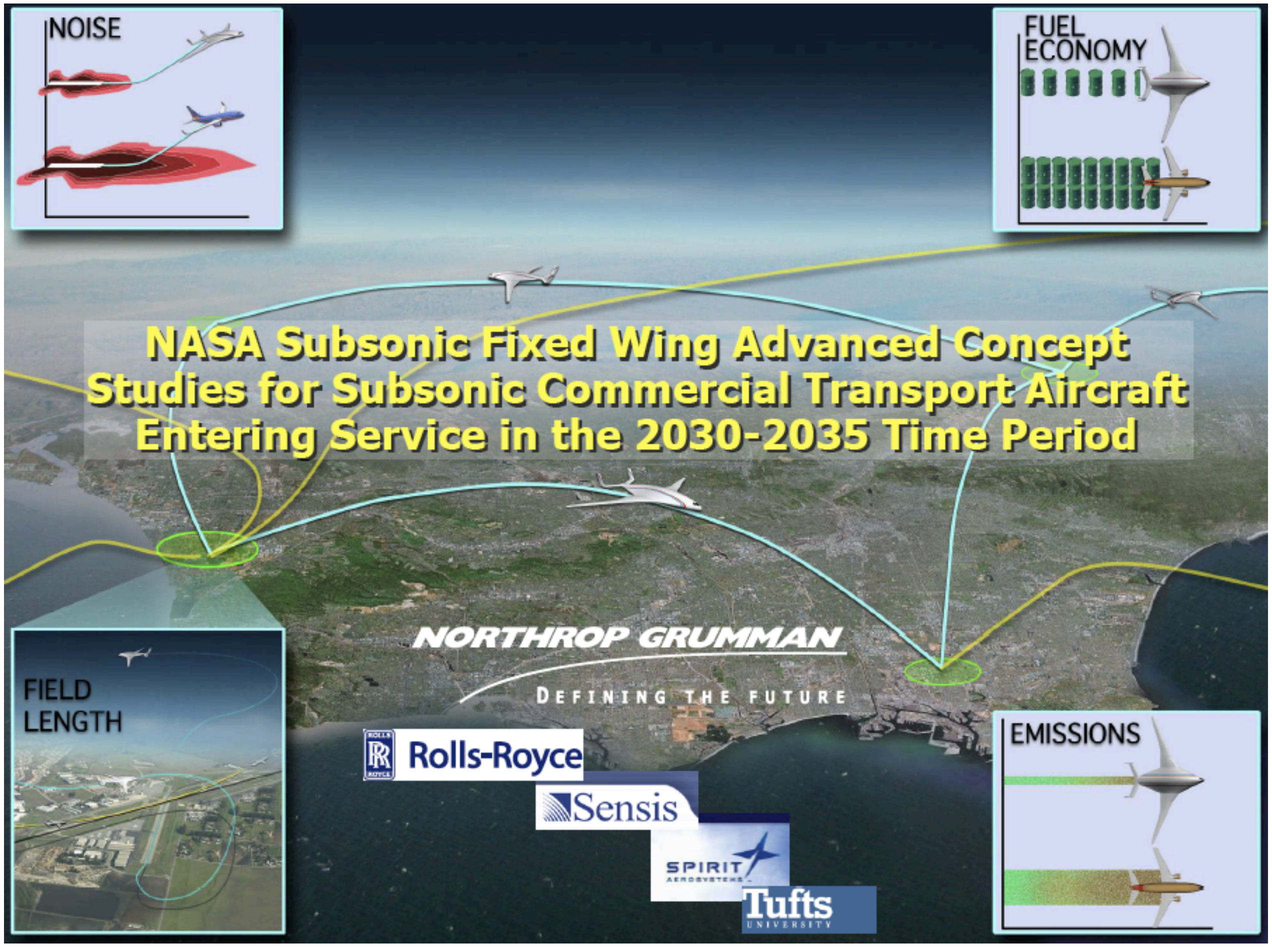


N+3 NRA Requirements

- Develop a Future Scenario for commercial aircraft operators in the 2030-35 timeframe
  - provide a context within which the proposer's advanced vehicle concept(s) may meet a market need and enter into service.
- Develop an Advanced Vehicle Concept to fill a broad, primary need within the future scenario.
- Assess Technology Risk - establish suite of enabling technologies and corresponding technology development roadmaps; a risk analysis must be provided to characterize the relative importance of each technology toward enabling the N+3 vehicle concept, and the relative difficulty anticipated in overcoming development challenges.
- Establish Credibility and Traceability of the proposed advanced vehicle concept(s) benefits. Detailed System Study must include:
  - A current technology reference vehicle and mission
    - to be used to calibrate capabilities and establish the credibility of the results.
  - A 2030-35 technology conventional configuration vehicle and mission
    - to quantify improvements toward the goals in the proposer's future scenario due to the use of advanced technologies, and improvements due to the advanced vehicle configuration.
  - A 2030-35 technology advanced configuration vehicle and mission


A Wide Variety of Concepts Will Be Considered
Engineering, Operations & Technology | Phantom Works
Platform Performance Technology
Joined Wing
Hydrogen Powered
Strut-braced Wing
Aerial Refueling
Hybrid Wing Body
Formation Flight
Δ Mach Number
Δ Altitude
Improved Navigation
Continuous Descent
Integral
Podded
(Pylon or Conformal)
BOEING
NASA
Georgia Tech
Changes in Mission & Operation
Podded or Integral Batteries
Other Concepts from Worksl

Northrop Grumman



Massachusetts Institute of Technology

Aircraft & Technology Concepts for an N+3 Subsonic Transport

- MIT
- Aurora
- Aerodyne
- Pratt & Whitney
- Boeing PW

General Electric

Outline

- Introduction and Effects of “Technology on the ATS”
- N+1 Vehicle Themes and Progress
- N+2 Vehicle Themes and Progress
- N+3 Vehicle Themes and Progress
- Alternative Fuels Research
- Wrapup

Alternative Fuels

- Goals:
  - Characterization of FT and biomass fuels against ASTM standards
  - Fuel - flexible combustor design

Alternative Fuels

A new standard for blends of JP-8 and synthetic fuel was just approved by ASTM. A standard for biofuel blends is coming.

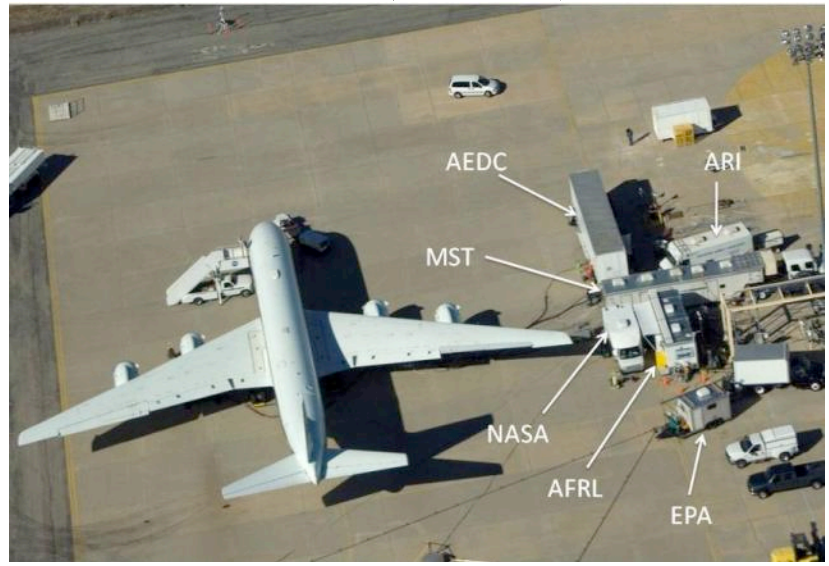
There are no standardized methods to measure volatile and particulate matter in engine exhausts

NASA is leading efforts to develop measurement methods and to document local air quality characteristics of alternative synthetic fuels (Fischer-Tropsch (F-T) fuels)

First ever test of 100% F-T fuel in Feb, 2009
- Particulate matter reduced by 90% at engine idle, 30-40% at higher power settings
- No sulfur dioxide emissions (no sulfur in F-T fuel)
- Results to be disseminated in NASA Workshop, Fall 2009

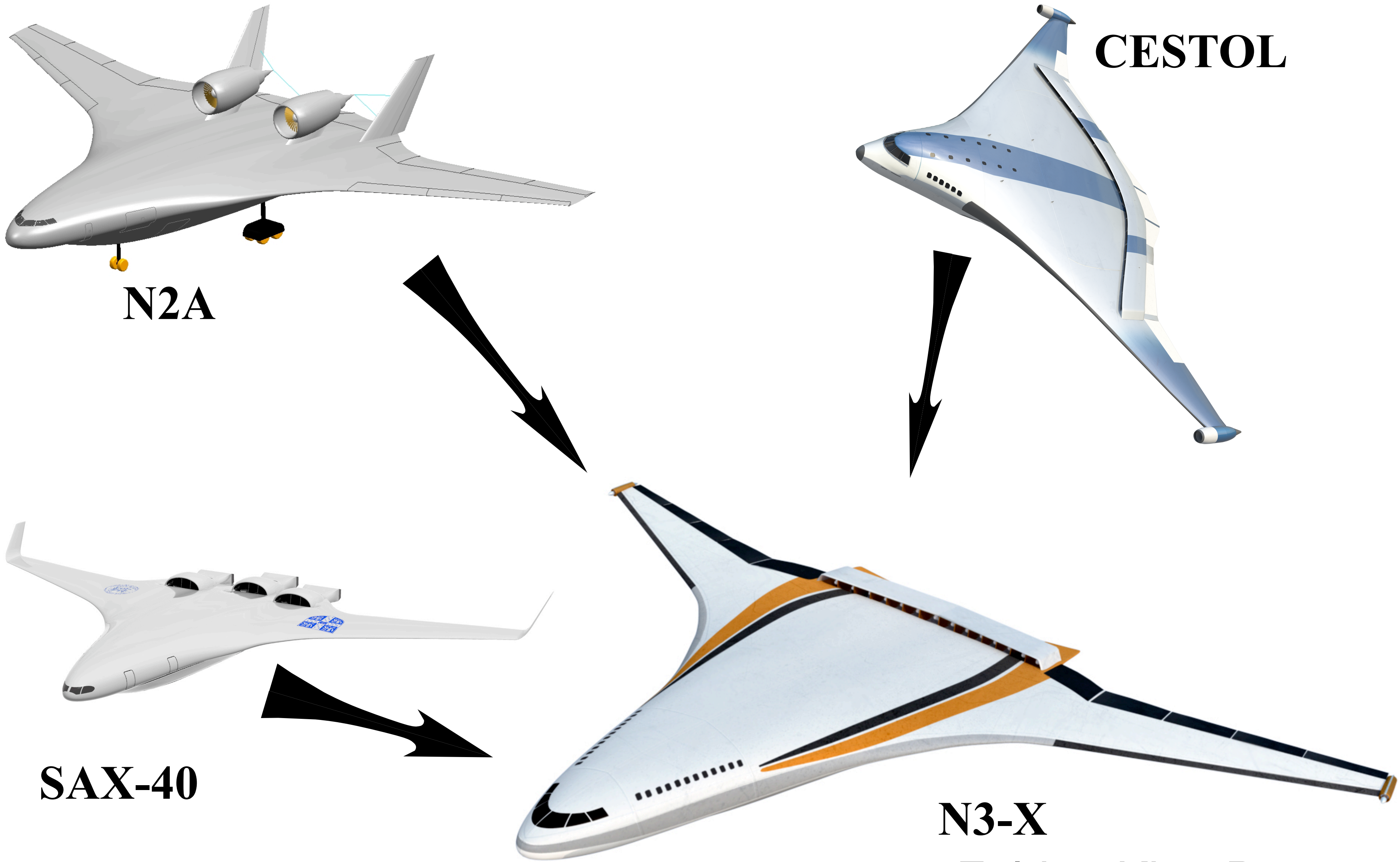
Partners:
Air Force – AFRL and AEDC
Aerodyne Research Inc (ARI)
Montana State University (MSU)
EPA
Pratt & Whitney
General Electric

NASA DC-8 with CFM56 engines
Palmdale, CA Feb, 2009



PWA Geared Turbofan Demonstrator Engine January, 2008

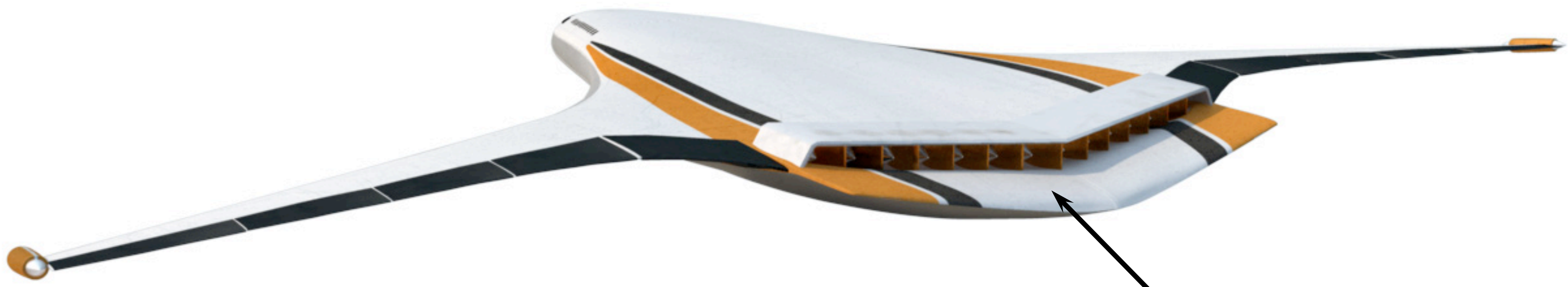
Alternative Fuels - What about hydrogen you say?



Felder, Kim, Brown

Alternative Fuels - What about hydrogen you say?

N3-X Distributed Turboelectric Propulsion System



Superconducting motor driven fans in a continuous nacelle

Wing-tip mounted superconducting turbogenerators

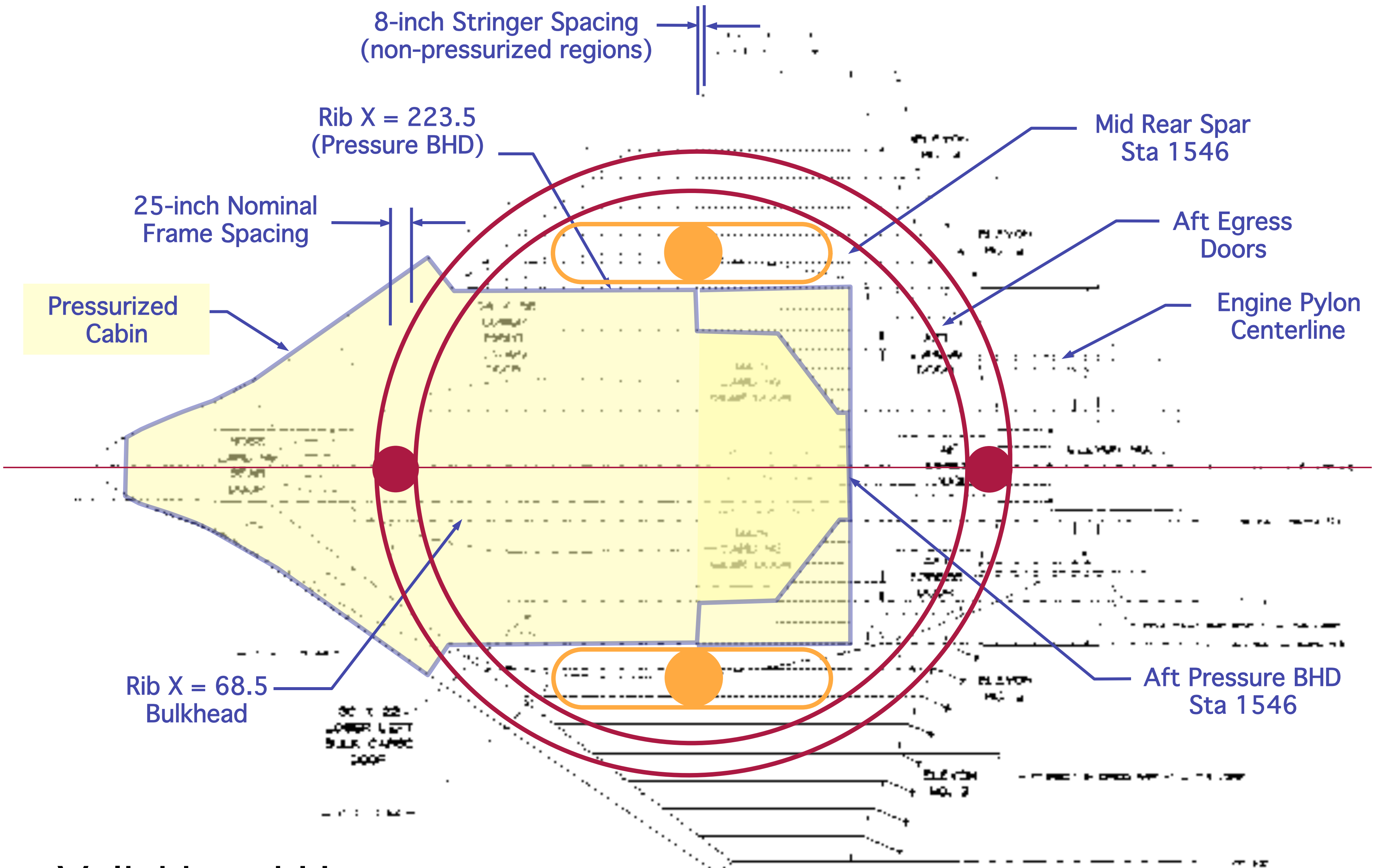
Felder, Kim, Brown

Alternative Fuels - Cryogenic Cooling Options

- Jet fuel with Refrigeration
  - Jet-A fuel weight is baseline for comparison
- Liquid Hydrogen cooled and fueled
  - No refrigeration required
  - 4 times the volume & 1/3 the weight of the jet fuel baseline
- Liquid Methane cooled and fueled
  - 5% of the baseline refrigeration
  - 64% larger volume & 14% less weight the jet fuel baseline
- Liquid Hydrogen cooled and Hydrogen/Jet-A fueled
  - No refrigeration required
  - 32% larger volume & 6% less weight than the jet fuel baseline
- Liquid Methane/Refrigeration cooled and Methane/Jet-A fueled
  - 5% of the baseline refrigeration
  - 17% larger volume & 2% less weight than the jet fuel baseline

Felder, Kim, Brown

Structural Concepts for Storing the LH2



Velicki and Hansen

Outline

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Comments or Questions?

The stakeholders say they want it all - ultra low emissions and "nearly silent"

N3-X Distributed Turboelectric Propulsion System

Wing-tip mounted superconducting turbogenerators

Superconducting motor driven fans in a continuous nacelle