National Aeronautics and Space Administration

NASA's Current Plans for ERA Propulsion Technology

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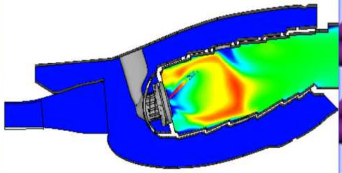

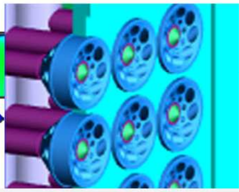

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www.nasa.gov

Outline

- Overview
  - Overall ERA Project
  - Propulsion Technology Element
- Technical Approach
  - Propulsion System-Level Benefits
  - Critical Technology Areas: Propulsor, Combustor, Core Turbomachinery
- Concluding Remarks

Research Focus Areas

1.0 Project Management

2.0 Airframe Technology — **ML/D, Empty Weight, Airframe Noise**

investigations where airframe system is 1st order effect

- 2.1 Lightweight Structures
- 2.2 Flight Dynamics and Control
- 2.3 Drag Reduction
- 2.4 Noise Reduction

3.0 Propulsion Technology — **SFC, Engine Noise, Emission Index**

investigations where propulsion system is 1st order effect

- 3.1 Combustor Technology
- 3.2 Propulsor Technology
- 3.3 Core Technology

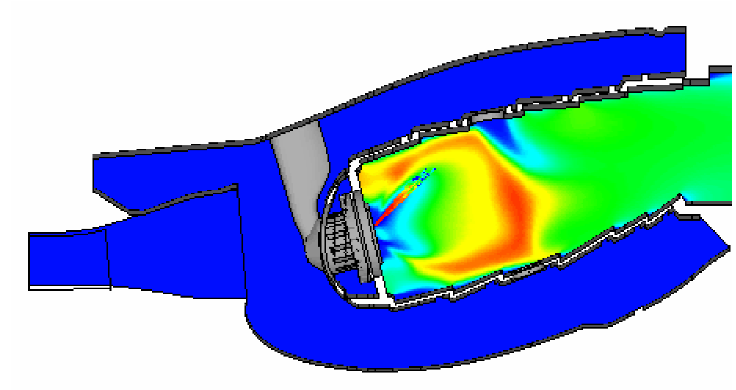
4.0 Vehicle Systems Integration — **ML/D, Weight, SFC, Emission Index, Noise**

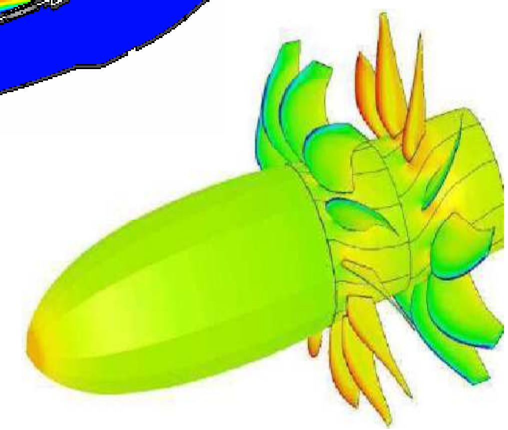
investigations where propulsion/airframe interaction is 1st order effect

- 4.1 Systems Analysis
- 4.2 Propulsion Airframe Integration
- 4.3 Propulsion Airframe Aeroacoustics
- 4.4 Advanced Vehicle Concepts

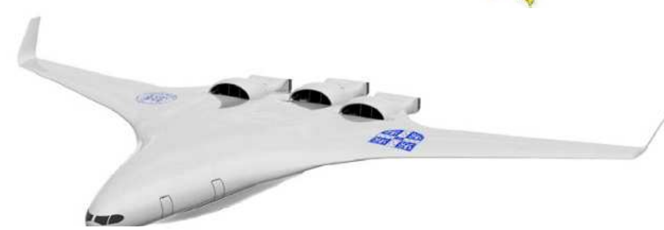
Propulsion Technology Focus Areas
System-Level Research

Combustor Technology

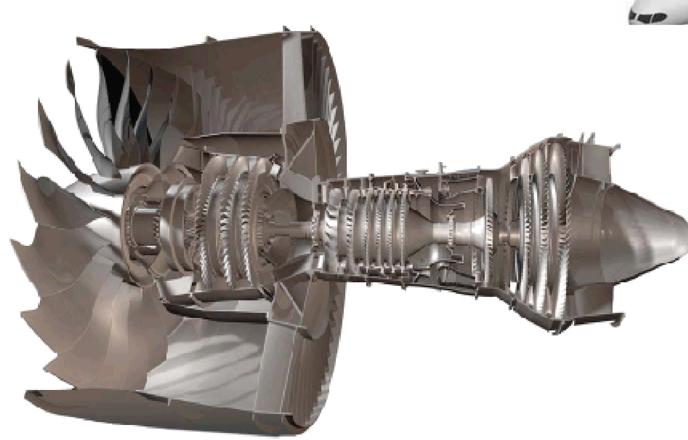




Propulsor Technology



Core Technology



Propulsion Technology Enablers

Noise

- increasing ducted BPR, potential embedding benefit

Emissions

- low NOx combustion, reduced SFC

Fuel Burn

- reduced SFC (increased BPR, OPR & turbine inlet temperature, potential embedding benefit)

$$\text{Aircraft Range} = \frac{\text{Velocity}}{\text{TSFC}} \left(\frac{\text{Lift}}{\text{Drag}} \right) \ln \left(1 + \frac{W_{fuel}}{W_{PL} + W_{O}} \right)$$

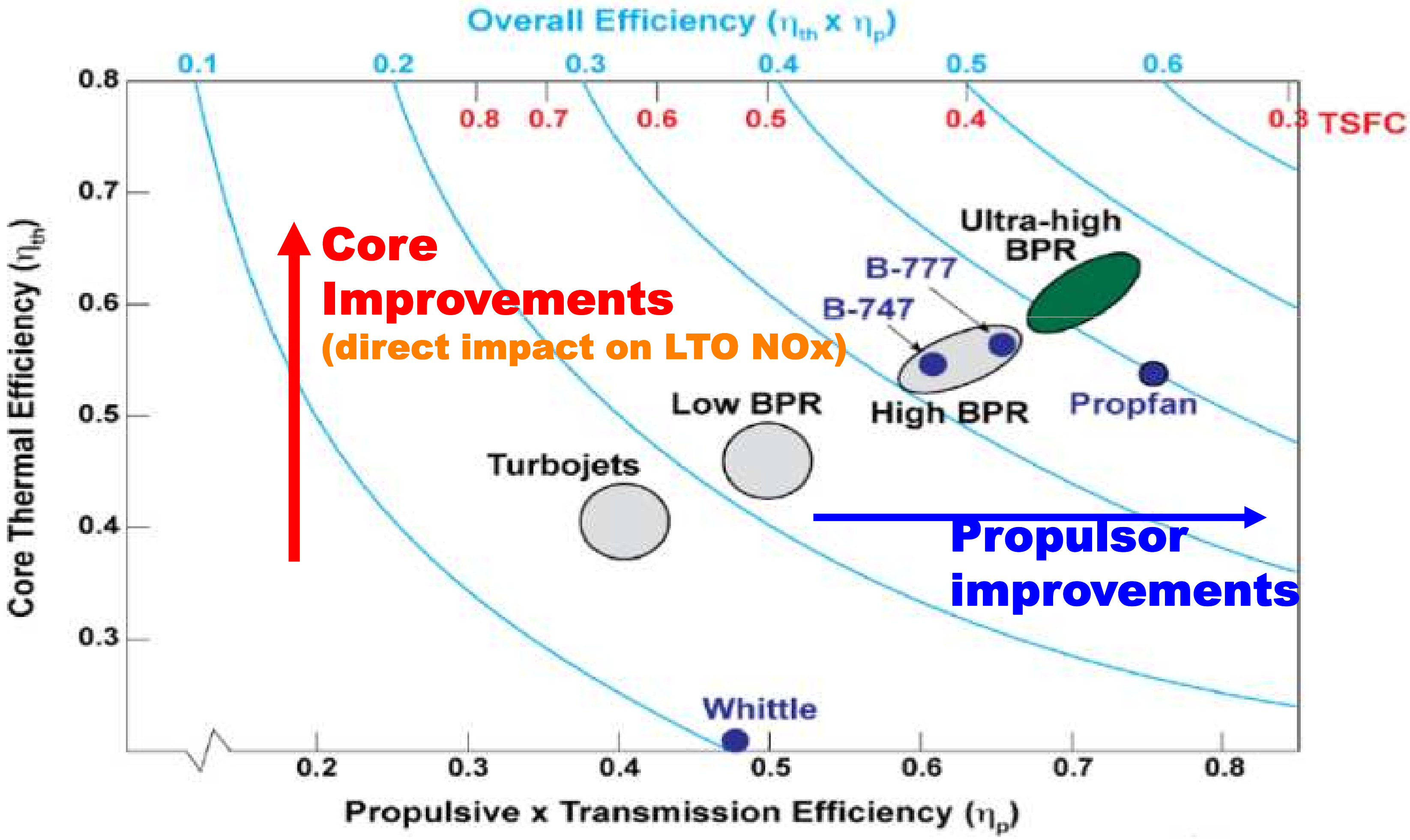
- Engine Fuel Consumption
- Aerodynamics
- Empty Weight

$$\text{TSFC} = \text{Velocity} / (\eta_{overall})(\text{fuel energy per unit mass})$$

$$\eta_{overall} = (\eta_{thermal})(\eta_{propulsive})(\eta_{transmission})(\eta_{combustion})$$

Propulsion Technology Opportunity

Propulsion system improvements require advances in propulsor and core/combustor technologies

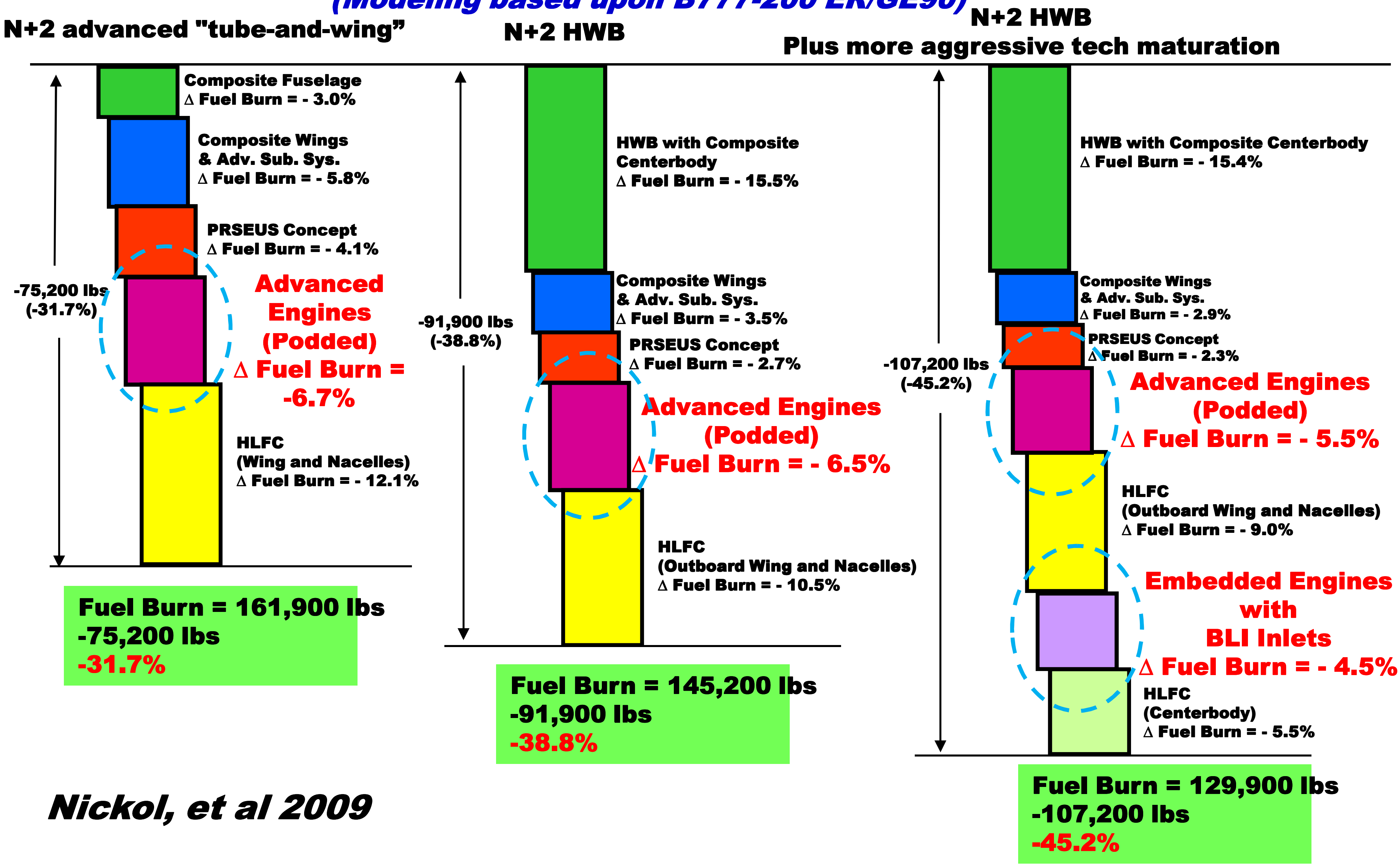


Alan Epstein
Pratt & Whitney Aircraft

Potential Reduction in Fuel Consumption

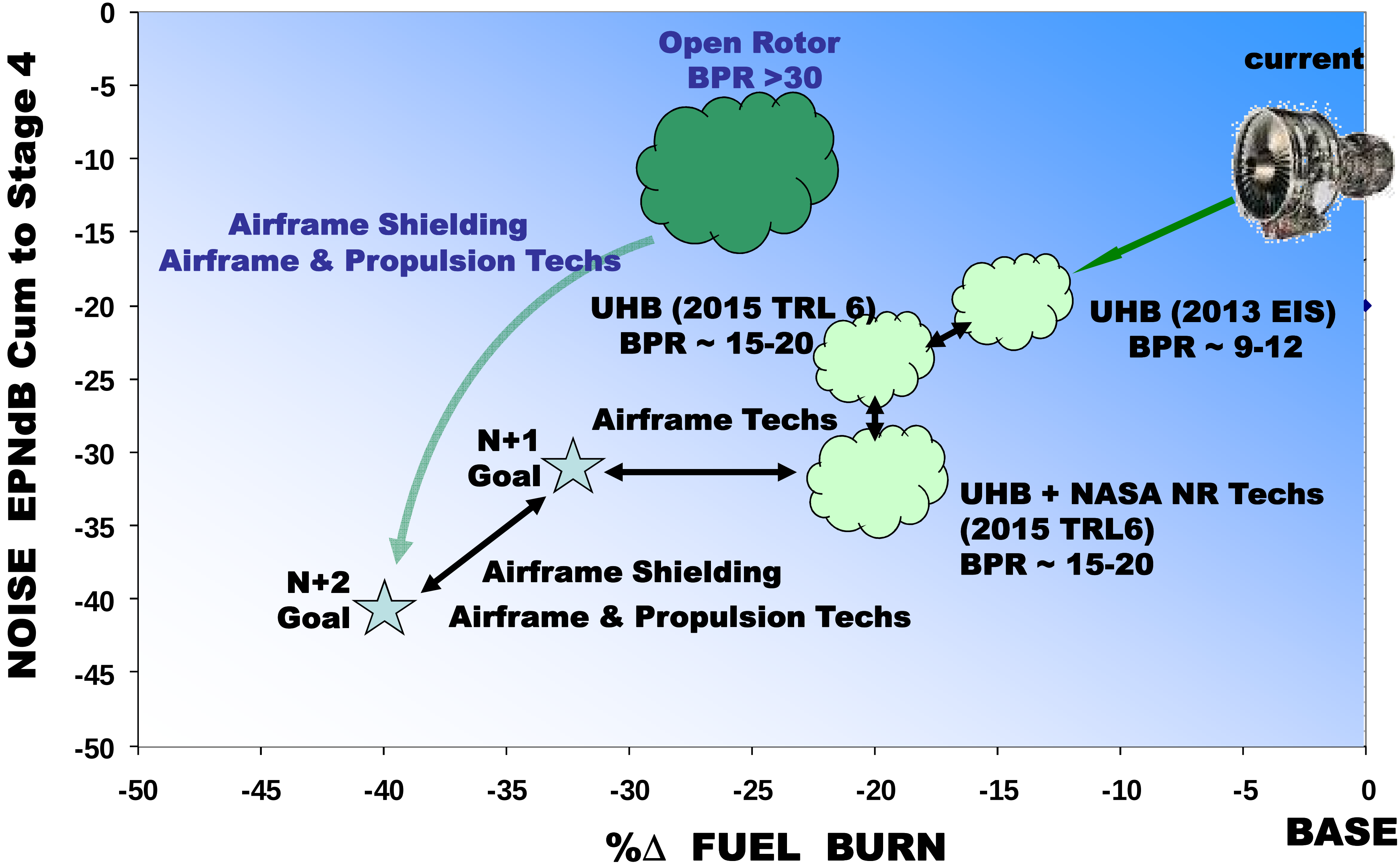
Key Propulsion Benefits

Technology Benefits Relative to Large Twin Aisle (Modeling based upon B777-200 ER/GE90)



Nickol, et al 2009

Propulsor Technology Roadmap



Propulsor Technology

Technical Challenges

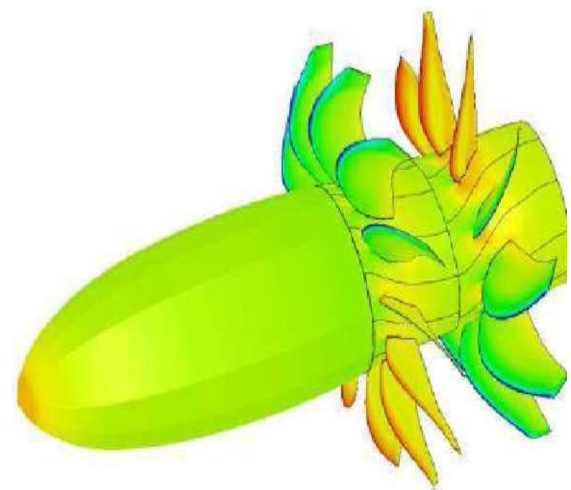
Noise Reduction | Energy Efficiency

Ultra high bypass ratio propulsor

Ducted vs. Unducted trade, noise vs. efficiency

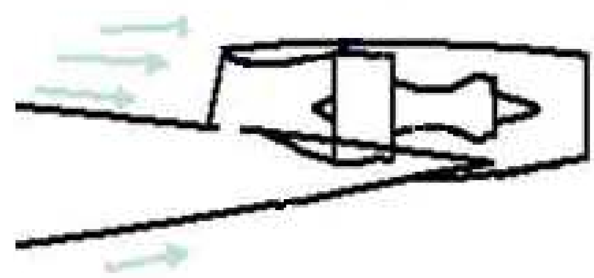
Concepts

- Ducted UHB
  - short inlets, laminar flow nacelles
  - SMA variable area nozzle
  - soft vane, over-the-rotor treatment
- Unducted UHB (Open Rotor)
  - increased rotor spacing, higher blade count, pylon spacing
- Embedded for boundary layer ingestion
  - inlet flow control, distortion tolerant fan



Challenges

- Open Rotor - reduced noise while maintaining high propulsive efficiency
- Ducted UHB - nacelle weight & drag with increasing diameter
- Embedded Propulsion – distortion control & effects on fan performance and noise
- All – propulsion / airframe integration



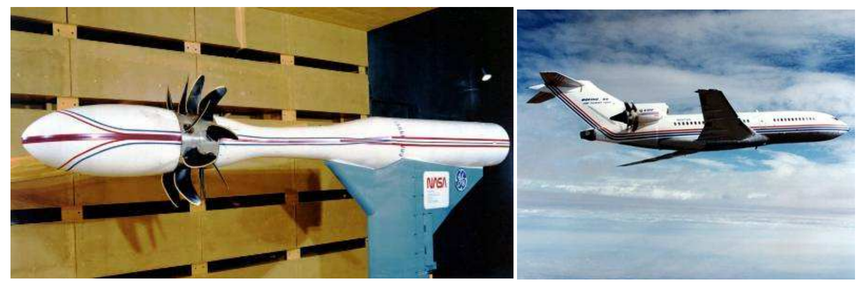
Propulsor Technology

Technical Overview

Noise Reduction | Energy Efficiency

- **Objective**
  - Explore propulsor (bypass flowpath) configurations for N+2 vehicle concepts to expand and better define the trade space between performance and noise reduction.
- **Approach**
  - Investigate feasibility of higher BPR propulsion systems: UHB Turbofans, Open Rotors and TBD Advanced Propulsor identified from NRA.
  - Evaluate UHB & Open Rotor for N+2; isolated and partially installed simulations in wind tunnel tests; Handoff to VSI for full installation experiments.
- **Benefit**
  - Propulsor concepts identified and validation data available for noise & performance trades.

UHB Turbofans



Open Rotor

FY10	FY11	FY12	FY13	FY14	FY15

- ▲ Select UHB & Open Rotor Concepts (FY10)
- ▲ Select Adv. Propulsor Concept For N+2 (FY11)
- ▲ Complete UHB Turbofan Tests (FY11/FY12)
- ▲ Complete Isolated Open Rotor Tests (FY12)

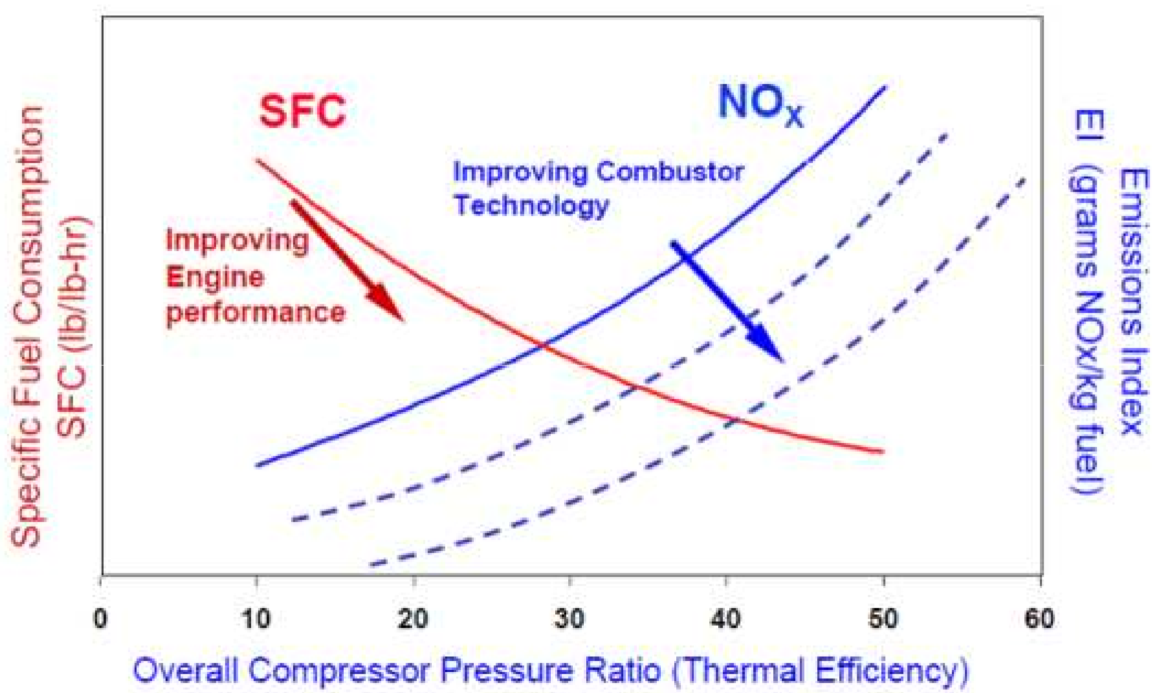
<u>possibilities</u>
- isolated and partially installed advanced propulsor ground tests similar to phase 1
- integrate with other techs (config, shielding)
- flight test propulsion concept
- incorporate in design of flight vehicle testbed

Combustor/Core Technology

Technical Challenges

Low NOx combustor concepts for high OPR environment

Increase thermal efficiency without increasing NOx emissions



Injector Concepts

- Partial Pre-Mixed
- Lean Direct Multi-Injection

Enabling Technology

- lightweight CMC liners
- advanced instability controls

Challenges

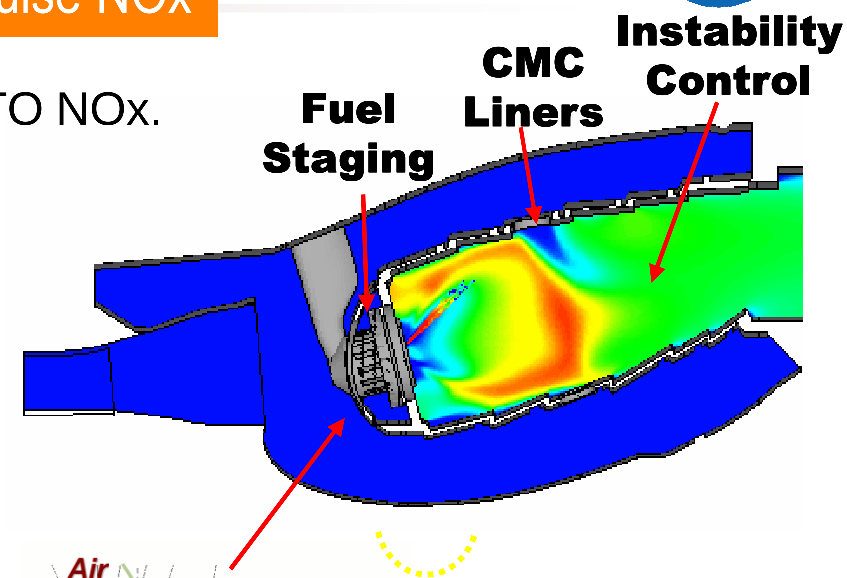
- Improved fuel-air mixing to minimize hot spots that create additional NOx
- Lightweight liners to handle higher temperatures associated with higher OPR
- Fuel Flexibility

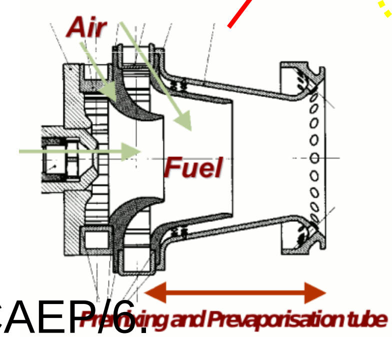
Combustor Technology

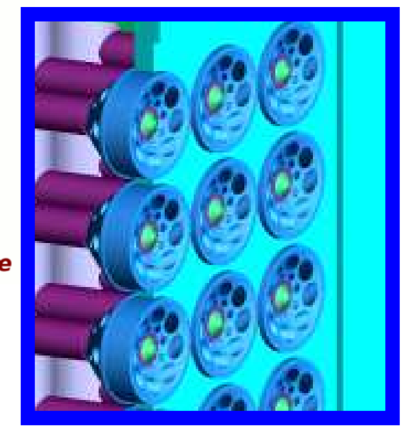
Technical Overview

LTO and Cruise NOx

- Objective
  - Extend maturation of technologies for reducing LTO NOx. Concepts must ensure fuel flexibility.
- Approach
  - Pursue 4 concepts:
    - Lean Partial-Mixed Combustor
    - Lean Direct Multi-Injection
    - 2 TBD from NRA
  - Flametube, sector, and annular combustor tests.
  - Select single concept for future engine tests.
  - Assume 50% cost share with industry.
  - Parallel effort to assess CMC durability and ability to manufacture liners
- Benefit
  - Technologies to reduce LTO NOx by 75% below CAEP/6.







Multipoint Injection

Bidders Conference

Select Low-NOx Combustor Concepts

FY09	FY10	FY11	FY12	FY13	FY14	FY15

Initiate Low-NOx Combustor Concept Studies

Complete Flametube Experiments

Complete Sector Tests

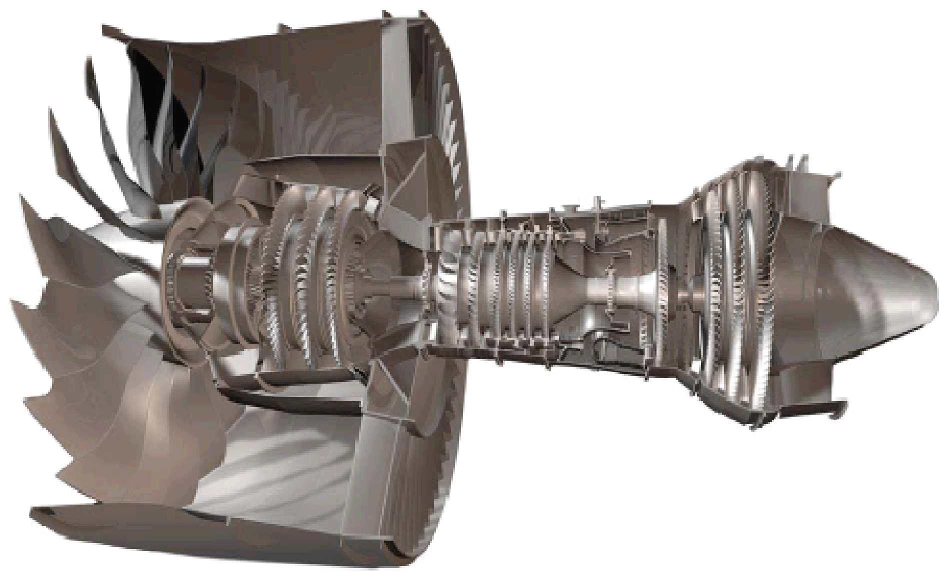
Complete Annular Combustor Tests

Core Technology

Technical Overview

LTO NOx | Energy Efficiency

- **Objective**
  - Explore core architectures and develop key technologies needed for N+2 propulsion
- **Approach**
  - Explore high OPR and high T4 core engine concepts; leverage existing work on high OPR compressors from VAATE, turbine cooling work in Subsonic Fixed Wing.
  - Pursue Ceramic Matrix Composite (CMC) turbine components; assess fabrication methods for cooled vanes and nozzles
- **Benefit**
  - Technologies to increase thermal efficiency that enable higher BPR propulsion (turbofans, open rotors & embedded engines)



Advanced Core for UHB Turbofan (P&W GTF)

FY10 | FY11 | FY12 | FY13 | FY14 | FY15

- Assess CMC Fab Methods, Durability & Heat Transfer
- Identify Core N+2 Concepts
- • high OPR compressor
- • increase T4
- **Increasing integration/complexity**
- Complete Test of Advanced Core Components

High OPR Core Compressor Testing

- Objective: Validate innovative engineering concepts and models for higher Overall Pressure Ratio (OPR) in an Advanced Technology Development Compressor (ATDC) testbed to achieve NASA fuel burn and LTO NOx emissions goals.

- Approach: Collaborate and cost share with industry, government and academia to create and operate an ATDC testbed in the GRC W7 Facility.

- W7 Multi-Stage Compressor Test Facility Progress:
  - Refurbished straddle mounted driveline 90% complete
  - 640 lbs 5-Stage checkout rotor in final balancing
  - Start final phase "A" test article assembly 1QFY10
  - New high temperature throttle valve installed
  - Meetings with aircraft engine companies to discuss collaboration and cost share for W7 ATDC Testbed
  - W7 basic compressor rig envelope and Phase "A" driveline/flow test drawings sent to P&W, GEAE, & Rolls-Royce
  - Test cell prep and checkout testing FY10/11, W7 ATDC design and fabrication FY10/11, research/development testing FY12/13

- **640lbs 5-Stage Checkout Rotor in GRC Dynamic Balancing Machine**

Research Team: Scott Thorp, GRC (Aero Mech. Lead); John Fabian, GRC (Aero. Lead)

Concluding Remarks

- System studies identify propulsion technology as key to meeting ERA fuel burn, noise, and emissions goals
- Technical approaches include development of reduced NOx combustors, increased bypass ratio propulsors, increased pressure ratio compressors, increased temperature turbines, and embedded engines
- Partnerships with industry will be key to meeting the goals