National Aeronautics and Space Administration

Propulsion Technologies for Future Commercial Aircraft

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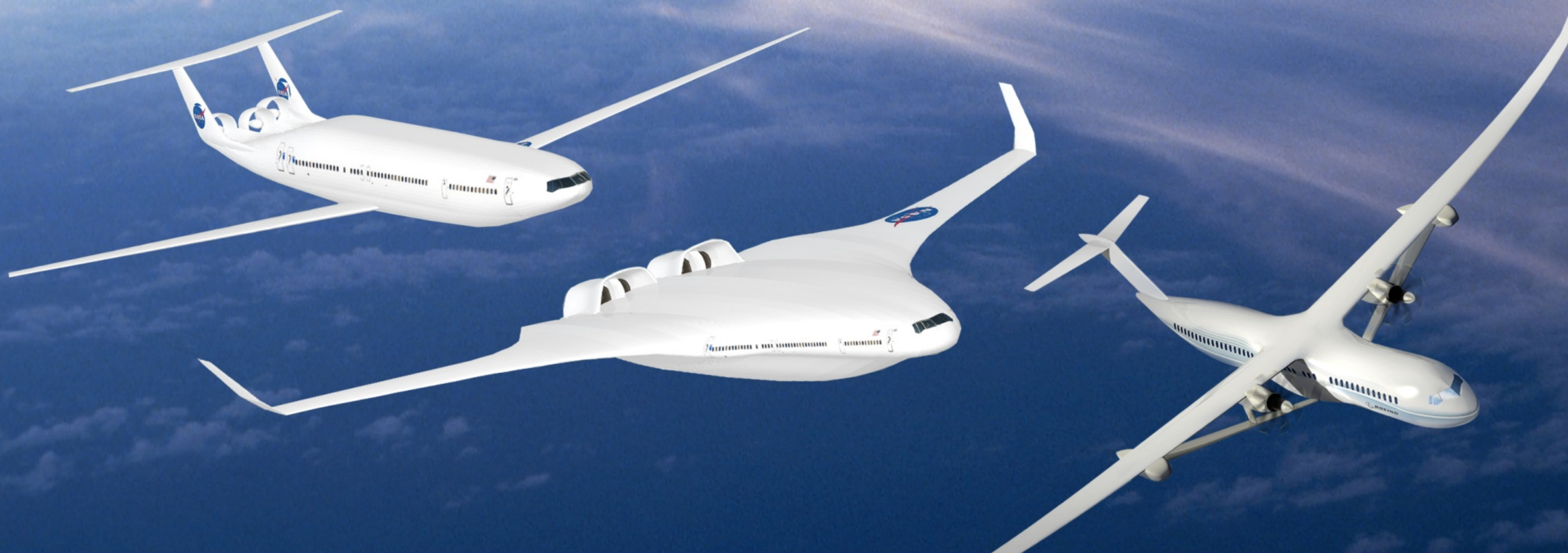
Subsonic Fixed Wing Project
NASA Fundamental Aeronautics Program



Panel Discussion on Challenges for Future Commercial Aircraft Propulsion
48th AIAA/ASME/SAE/ASEE Joint Propulsion Conference and Exhibit
Atlanta, GA
July 30- August 1, 2012

www.nasa.gov

Outline of Talk

Introduction

Future Challenges for Commercial Aviation

NASA Aeronautics Research and Subsonic Transport Metrics

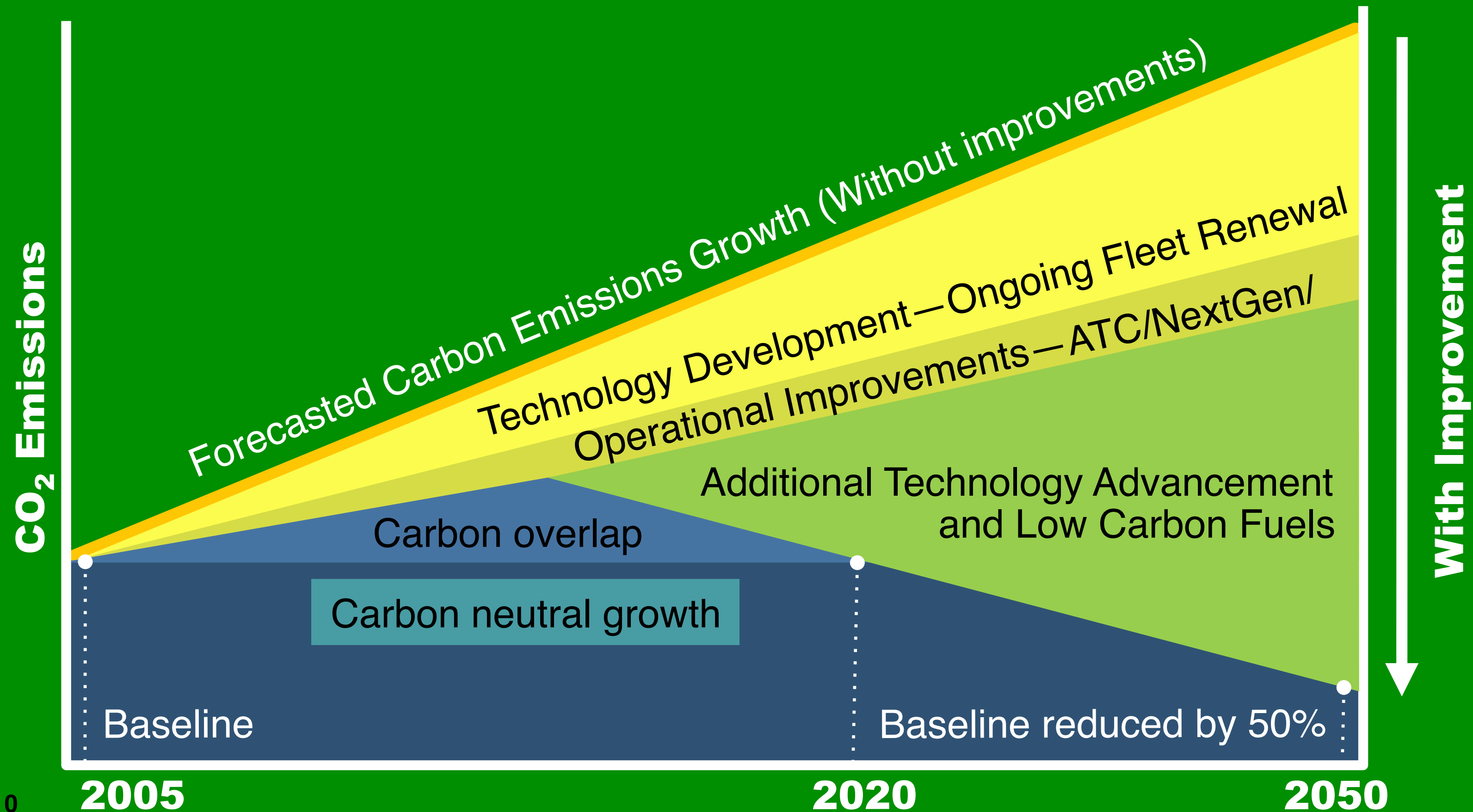
Future Propulsion Technologies

- NASA ERA Advance Vehicles Concepts (N+2)
- NASA Gen N+3 Advanced Vehicle Concept Studies
- Towards Electric Propulsion

Concluding Remarks

Major Challenges for Commercial Aviation

By 2050, substantially reduce emissions of carbon and oxides of nitrogen and contain objectionable noise within the airport boundary



Source: IATA, 2010

NASA Aeronautics Programs

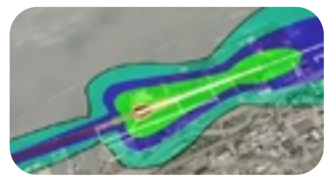


Fundamental Aeronautics Program

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

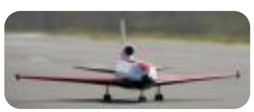
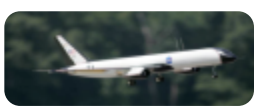
Conduct research at an integrated system-level on promising concepts and technologies and explore/assess/demonstrate the benefits in a relevant environment




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.




Fundamental Aeronautics Program
Subsonic Fixed Wing Project

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.

Traceability from National R&D Plan to ERA Project Technical Challenges

National R&D Plan

Energy and Environment	Enhance Mobility	National Security

Lead development of vehicle concepts that enable simultaneous reduction of fuel burn, noise and emissions

-75% LTO & -70% Cruise NOx Emissions below CAEP6	-42dB below Stage 4 Community Noise	-50% Aircraft Fuel/ Energy Consumption

Technical Focus Areas

Accelerate technology maturation through integrated system research

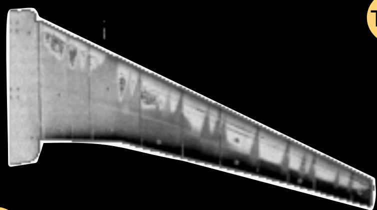
Innovative Flow Control Concepts for Drag Reduction	Advanced Composites for Weight Reduction	Advanced UHB Engines for SFC & Noise Reduction	Advanced Combustors for LTO Oxides of Ni reductions	Airframe & Engine Integration for Community Noise Reduction

ERA Phase 1 Investigations

ERA Phase I Investigations

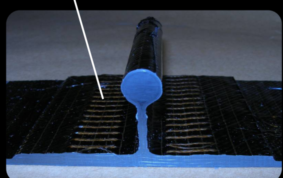
Reduce Mission Fuel Burn and Community Noise

TFA1 DRAG REDUCTION - Via Laminar Flow



TFA2 WEIGHT REDUCTION

PRSEUS – Pultruded Rod Stitched Efficient Unitized Structure



TFA3 SFC/NOISE REDUCTION

Advanced Cores and Development of Integration of Advanced UHB Engines

ERA Phase I Investigations

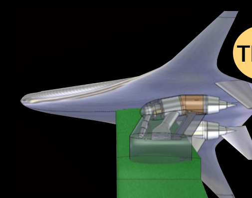
Reduce Mission Fuel Burn and Community Noise

TFA5 AIRFRAME NOISE

High-lift Systems and Landing Gear

TFA5 PROPULSION NOISE

Fan, Core and Jet Noise



TFA5 PROPULSION AIRFRAME AEROACOUSTICS

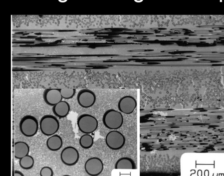
Airframe/Propulsion Interaction & Shielding

ERA Phase I Investigations

Reduce LTO and Cruise NOX

TFA4 CMC COMBUSTOR LINER

For higher engine temps

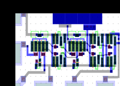


SIC CMC Concepts

CMC combustor liner

TFA4 INSTABILITY CONTROL

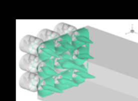
Suppress combustor instabilities



High Temperature SiC electronics circuits and dynamic pressure sensors

Fuel Modulation for high frequency fuel delivery systems

TFA4 LOW NOX, FUEL FLEXIBLE DESIGN/TEST



Innovative Injector Concept

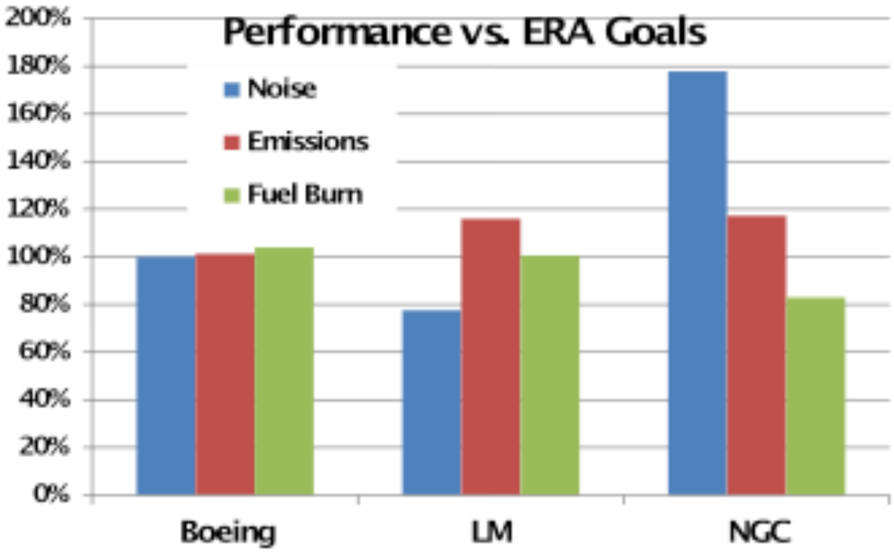
ASCR Combustion Rig

Environmentally Responsible Aviation
Advanced Vehicle Concepts

- Task 1 - Define / Development Future Scenario
- Task 2 - Develop a conceptual design of a 2025 EIS subsonic transport – passenger and/or cargo
- Task 3 - Develop associated tech maturation plans
- Task 4 - FY 2013 – 2015 Critical Technology Demonstrations
- Task 5 - Conceptual Design of a Subscale Testbed Vehicle

Advanced Vehicle Concept Study
Summary Results

Vehicle Performance



Key Technologies Identified

- Laminar flow control
- Advanced unitized composite structures
- Advanced UHB Engines

NASA Subsonic Transport System Level Metrics

Strategic Thrusts

1. Energy Efficiency

2. Environmental Compatibility

TECHNOLOGY BENEFITS*	TECHNOLOGY GENERATIONS (Technology Readiness Level = 4-6)		
	N+1 (2015)	N+2 (2020**)	N+3 (2025)
Noise (cum margin rel. to Stage 4)	-32 dB	-42 dB	-71 dB
LTO NOx Emissions (rel. to CAEP 6)	-60%	-75%	-80%
Cruise NOx Emissions (rel. to 2005 best in class)	-55%	-70%	-80%
Aircraft Fuel/Energy Consumption‡ (rel. to 2005 best in class)	-33%	-50%	-60%

* Projected benefits once technologies are matured and implemented by industry. Benefits vary by vehicle size and mission. N+1 and N+3 values are referenced to a 737-800 with CFM56-7B engines, N+2 values are referenced to a 777-200 with GE90 engines

** ERA's time-phased approach includes advancing "long-pole" technologies to TRL 6 by 2015

‡ CO_2 emission benefits dependent on life-cycle CO_{2e} per MJ for fuel and/or energy source used

Research addressing revolutionary future goals with opportunities for near term impact

The NASA Subsonic Fixed Wing Project

Explore and Develop Tools, Technologies, and Concepts for Improved Energy Efficiency and Environmental Compatibility for Sustained Growth of Commercial Aviation

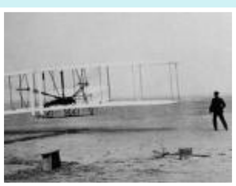
Objectives

- Prediction and analysis tools for reduced uncertainty
- Concepts and technologies for dramatic improvements in noise, emissions and performance

Relevance

- Address daunting energy and environmental challenges for aviation
- Enable growth in mobility/aviation/transportation
- Subsonic air transportation vital to our economy and quality of life

Evolution of Subsonic Transports



1903 — 1930s — 1950s — 2000s

NASA Gen N+3 Advanced Vehicle Concept Studies
Summary

Advanced concept studies for commercial subsonic transport aircraft for 2030-35 EIS

Boeing, GE, GA Tech

NG, RR, Tufts, Sensis, Spirit

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GE, Cessna, GA Tech

MIT, Aurora, P&W, Aerodyne

Trends:

- Tailored/Multifunctional Structures
- High AR/Active Structural Control
- **Highly Integrated Propulsion Systems**
- **Ultra-high BPR (20+ w/ small cores)**
- ***Alternative fuels and emerging hybrid electric concepts***
- Noise reduction by component, configuration, and operations improvements

NASA, VA Tech, GT

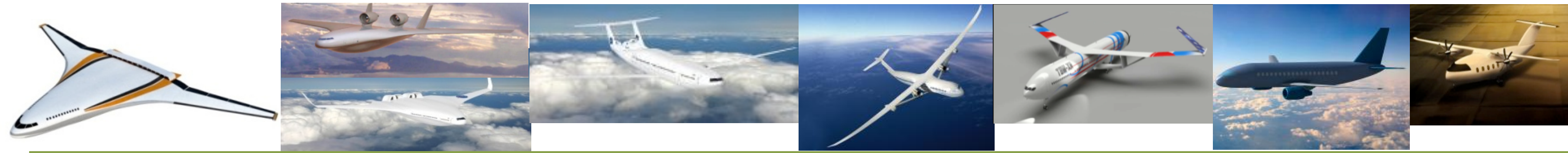
NASA

Advances required on multiple fronts…

Diversified Portfolio Addressing N+3 Goals

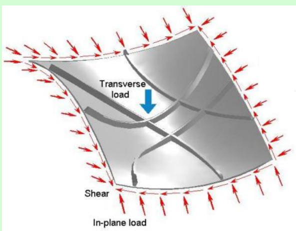
Broadly applicable subsystems technical challenges

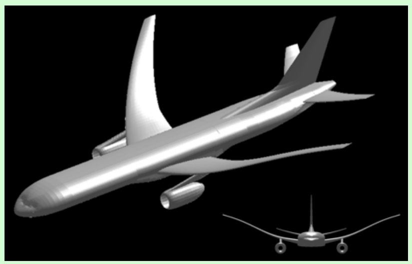
N+3 Vehicle Concepts

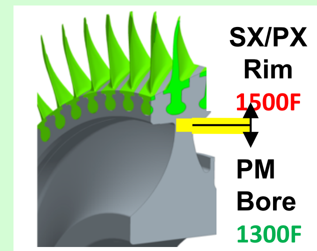


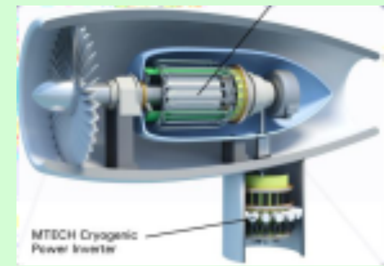
Research Themes

Reduce Drag, Weight, TSEC, Emissions and Noise









Tailored Fuselage

High AR Elastic Wing

Quiet, Simplified High-Lift

High Eff. Gas Generator

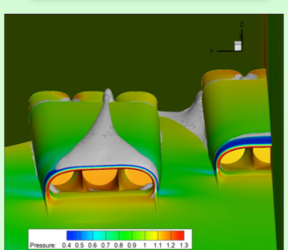
Lightweight Hybrid Electric Propulsion

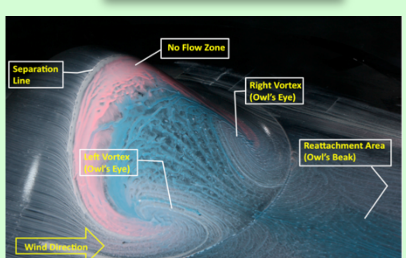
Propulsion Airframe Integration

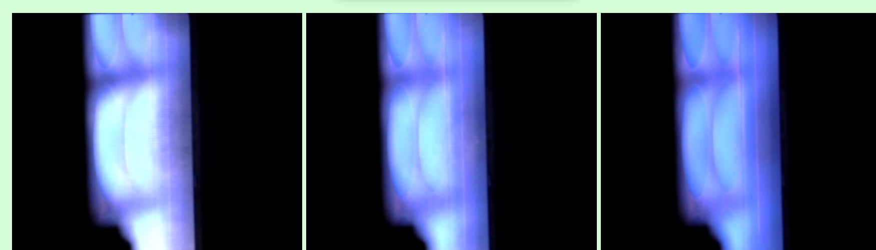
Tools

Alternative Fuels

Technical Challenges







Gen N+3 Propulsion Technologies

Northrop Grumman/Rolls Royce SELECT

Three-Shaft Turbofan
- High BPR (~18) = propulsive efficiency
- High OPR (~50) = thermal efficiency
- Low noise
- Low weight

Technology Suite
Three-shaft Turbofan Engine
Ultra-High Bypass Ratio of ~18
CMC Turbine Blades
Lean-Burn CMC Combustor
Intercooled Compressor Stages
Swept Fan Outlet Guide Vanes
Fan Blade Sweep Design
Lightweight Fan/Fan Cowl
Compressor Flow Control
Active Compressor Clearance Control
Variable Geometry Nozzles

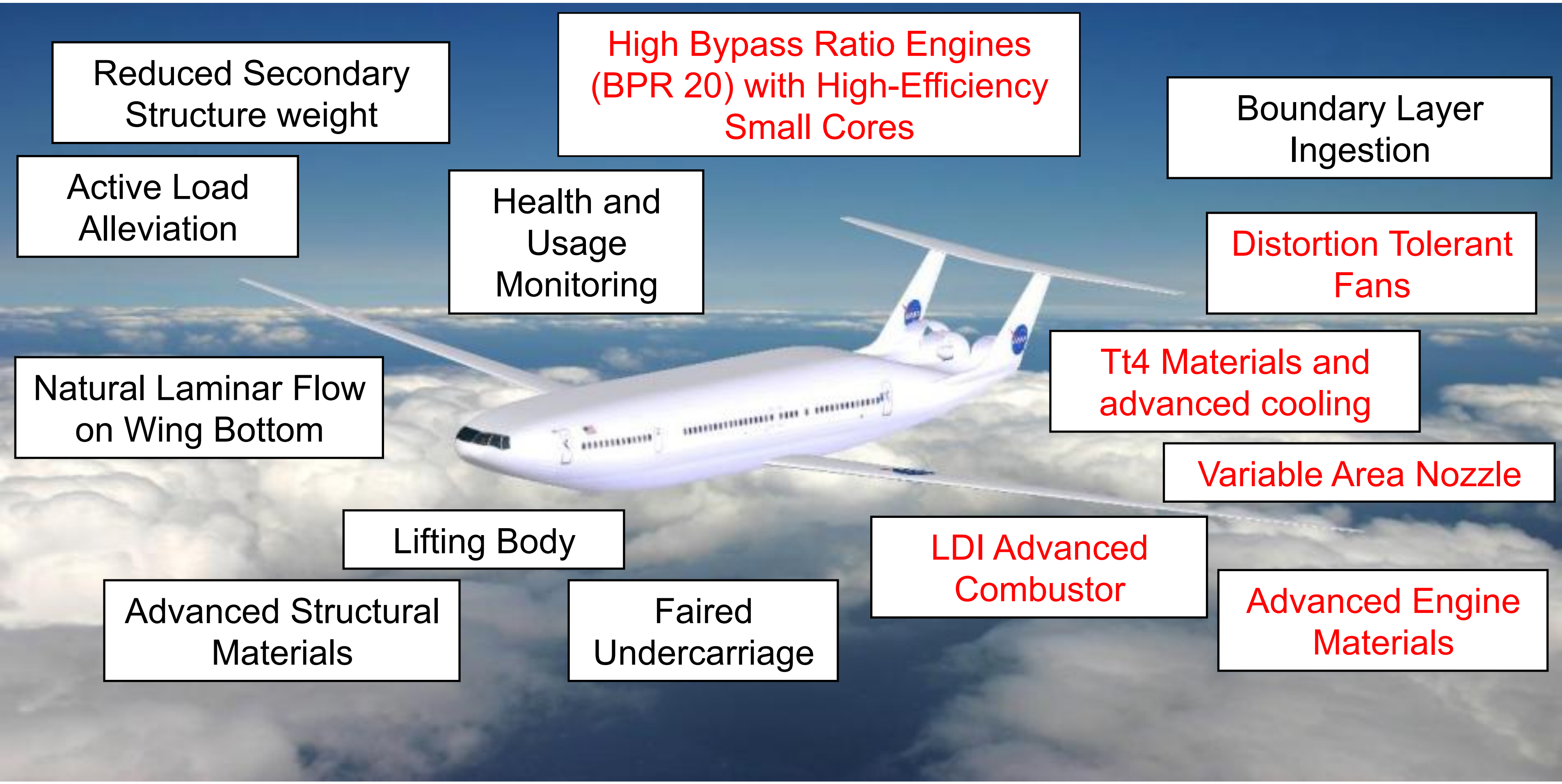
- Open rotor had best sea level static fuel consumption
- Open rotor potential noise not quantified in time to be included

NASA-CR-2010-216798

NORTHROP GRUMMAN Rolls-Royce Sensis Tufts University SPIRIT AEROSYSTEMS

MIT/Pratt & Whitney D Series

Novel configuration plus suite of airframe and propulsion technologies, and operations modifications

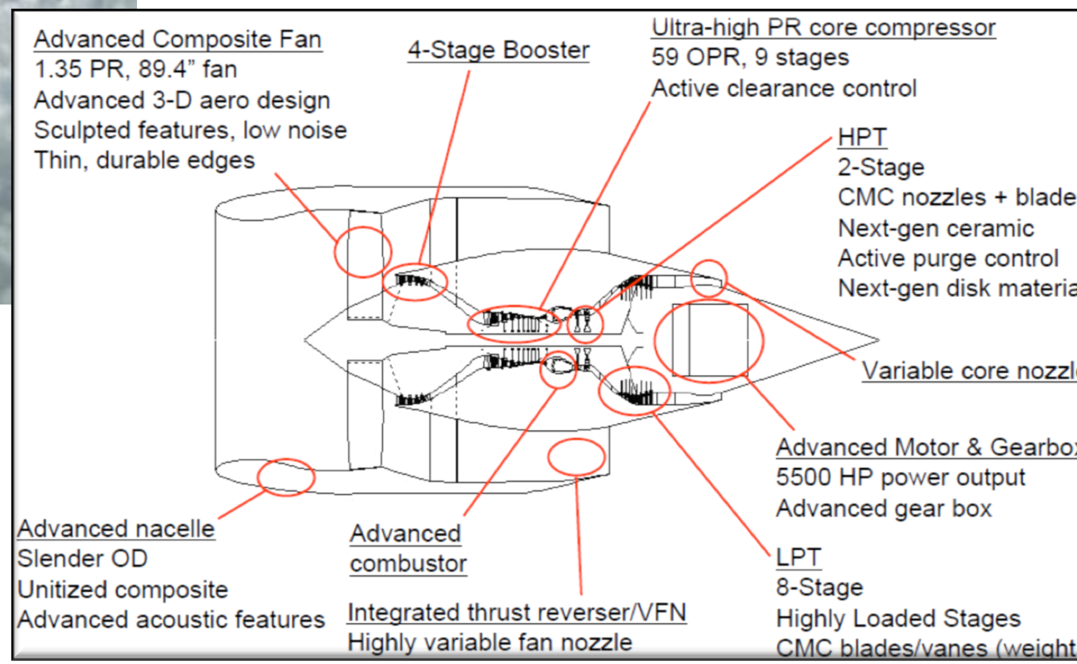


NASA-CR-2010-216794 Vol. 1 & 2

Massachusetts Institute of Technology Aurora Flight Sciences Pratt & Whitney A United Technologies Company

Boeing/General Electric SUGAR "Volt"

High Aspect Ratio Truss Braced Wing
Hybrid Electric (Batteries) Propulsion Systems



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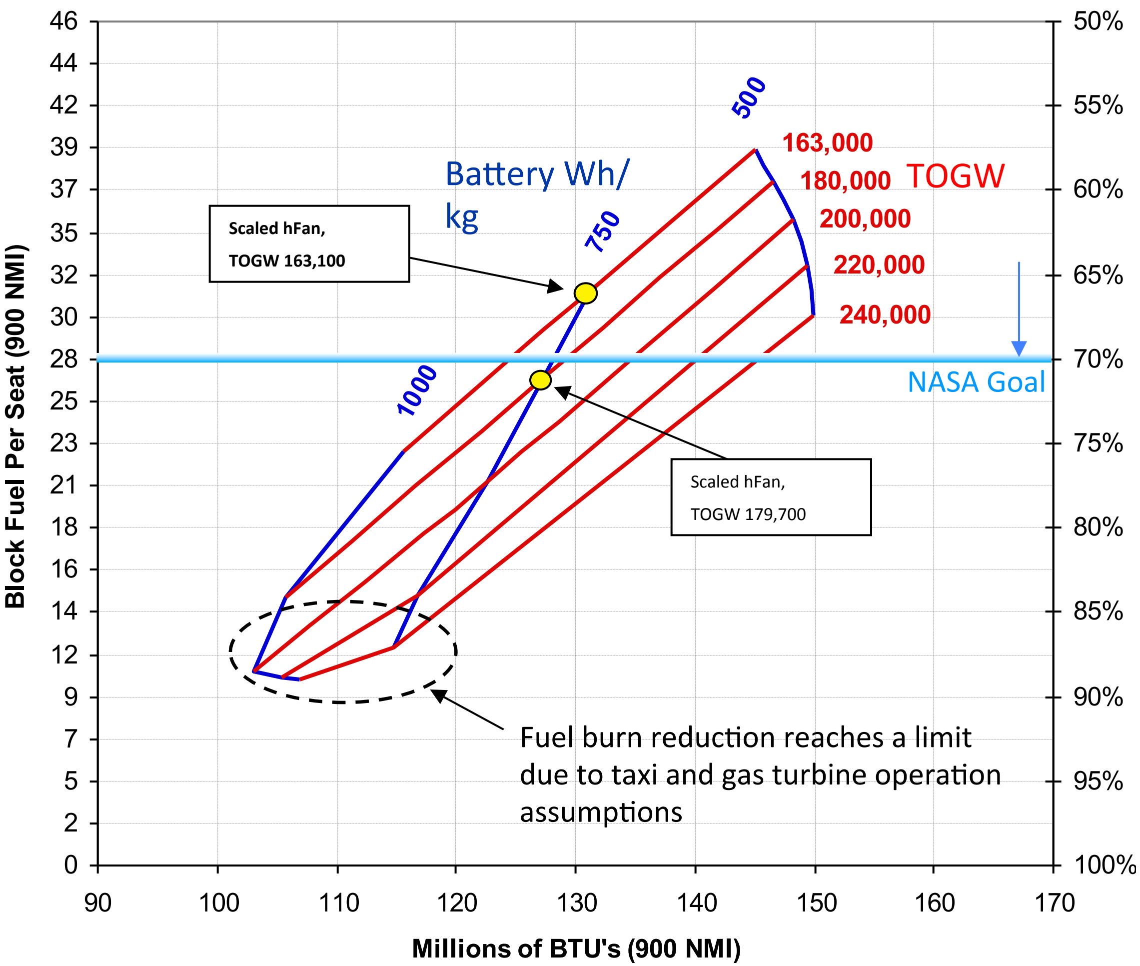
SUGAR Volt – Opportunities

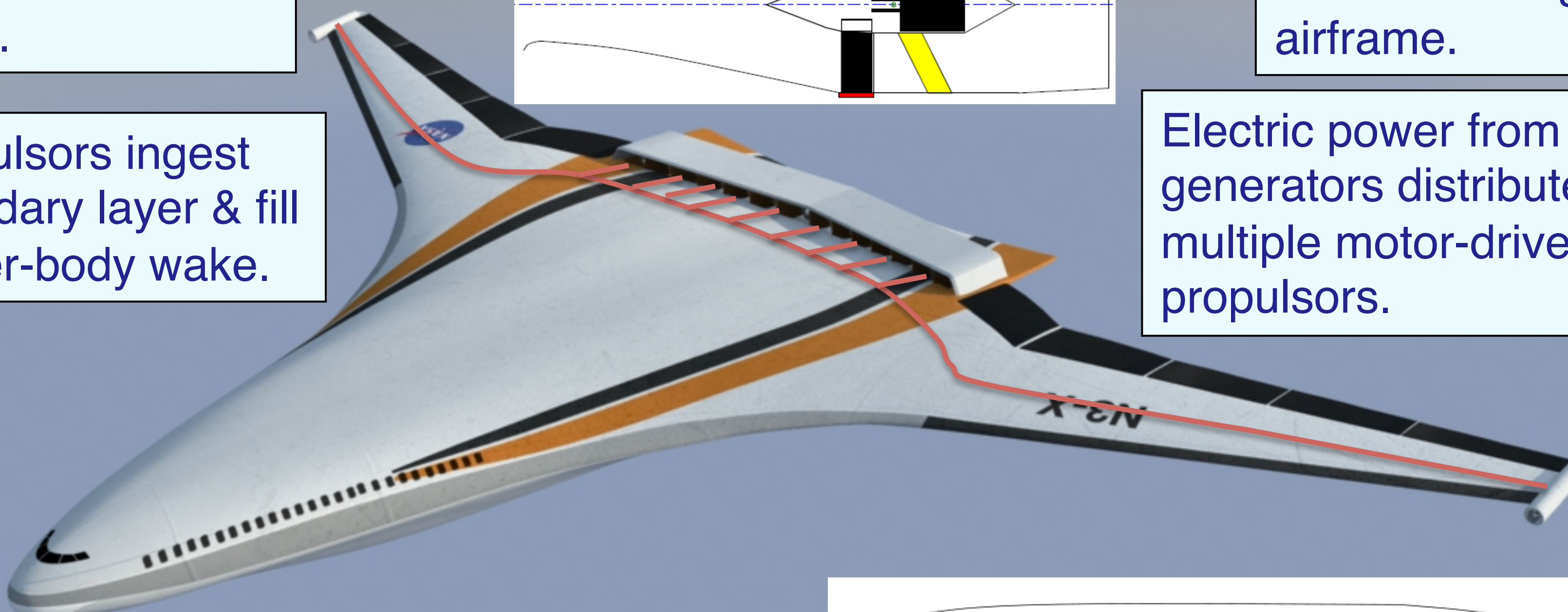


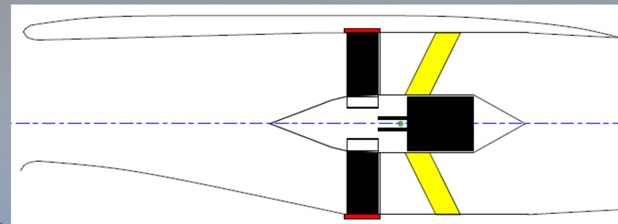
- With a 750 Wh/kg battery, increasing aircraft weight to accommodate higher battery capacity reduces fuel burn and total energy
- >500 WH/kg battery technology needed to meet NASA fuel burn goal
- 85-90% fuel burn reduction is max. achievable for SUGAR hybrid architecture and assumptions

NASA Turboelectric Distributed Propulsion

Low velocity core exhaust reduces noise.

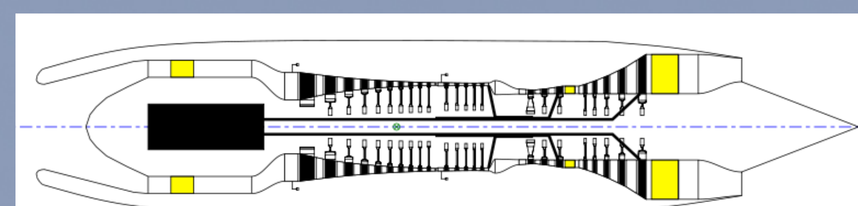
Propulsors ingest boundary layer & fill center-body wake.





Forward and aft fan noise shielding by airframe.

Electric power from generators distributed to multiple motor-driven propulsors.



Many small fans give a large total fan area and very high effective bypass ratio

Large efficient engines with freestream inlets drive superconducting generators.

Toward Large Electric Aircraft Propulsion

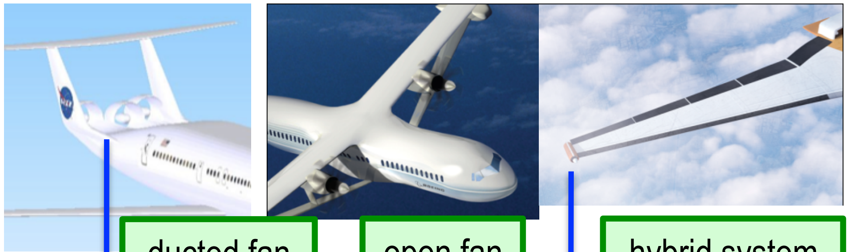
- Hybrid-electric and turboelectric aircraft offer cleaner skies and fuel savings
- Hybrid electrics use battery power for short-range cruise, fuel and turbine engine for long-range
- Battery-powered cruise emits little or no CO_2 and water vapor on short flights (Boeing SUGAR Volt study)
- Turboelectric distributed propulsion offers up to 20% fuel savings on Blended Wing Body aircraft
- Distributed and/or more-electric propulsion critical to meeting NASA N+3 fuel burn, noise, and emissions metrics

Hybrid Electric Gas turbine – battery hybrid (e.g. SUGAR Volt)

Superconducting turboelectric distributed propulsion

Propulsion Related Research Elements

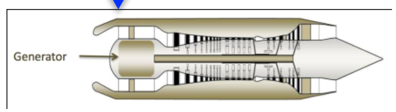
versatile core applicable to variety of propulsion systems/installations

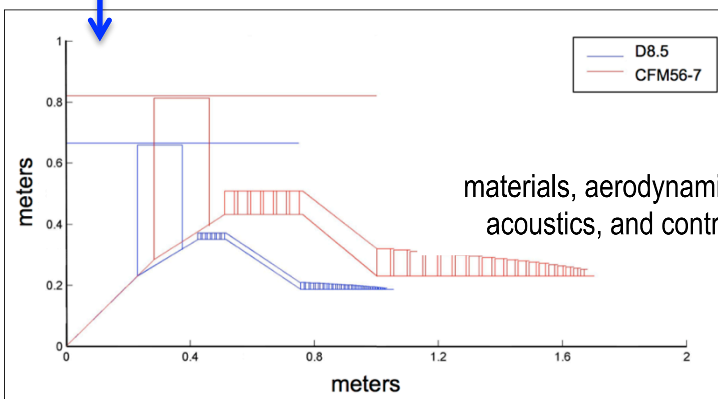


ducted fan

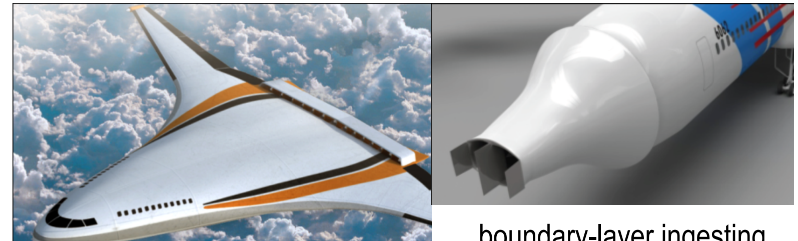
open fan

hybrid system

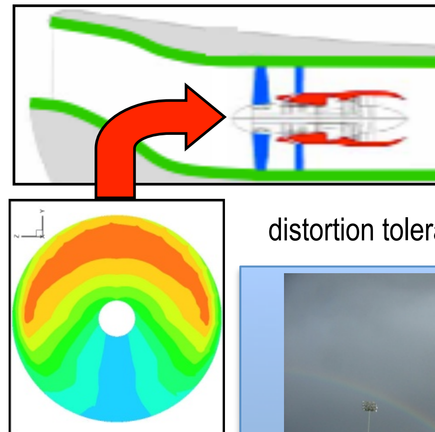




materials, aerodynamics, acoustics, and control

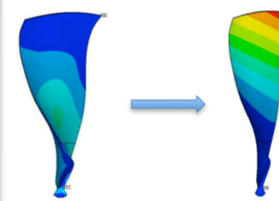


boundary-layer ingesting concepts thrust vectoring

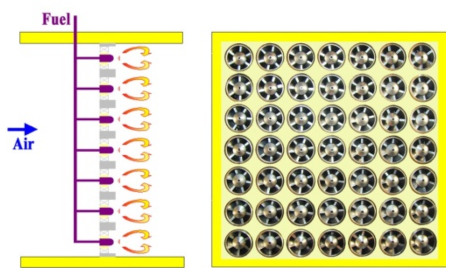


distortion tolerance

Alternative Aviation Fuel Experiment

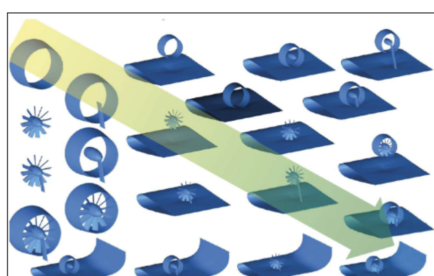


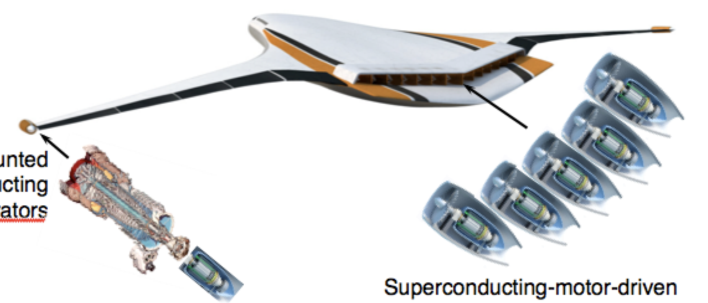
adaptive fan blades



multi-point lean direct injection

jet/surface interaction acoustics





Ving-tip mounted superconducting turbogenerators

Superconducting-motor-driven fans in a continuous nacelle

NASA