National Aeronautics and Space Administration

# Propulsion Technologies for Future Aircraft Generations: Clean, Lean, Quiet, and Green

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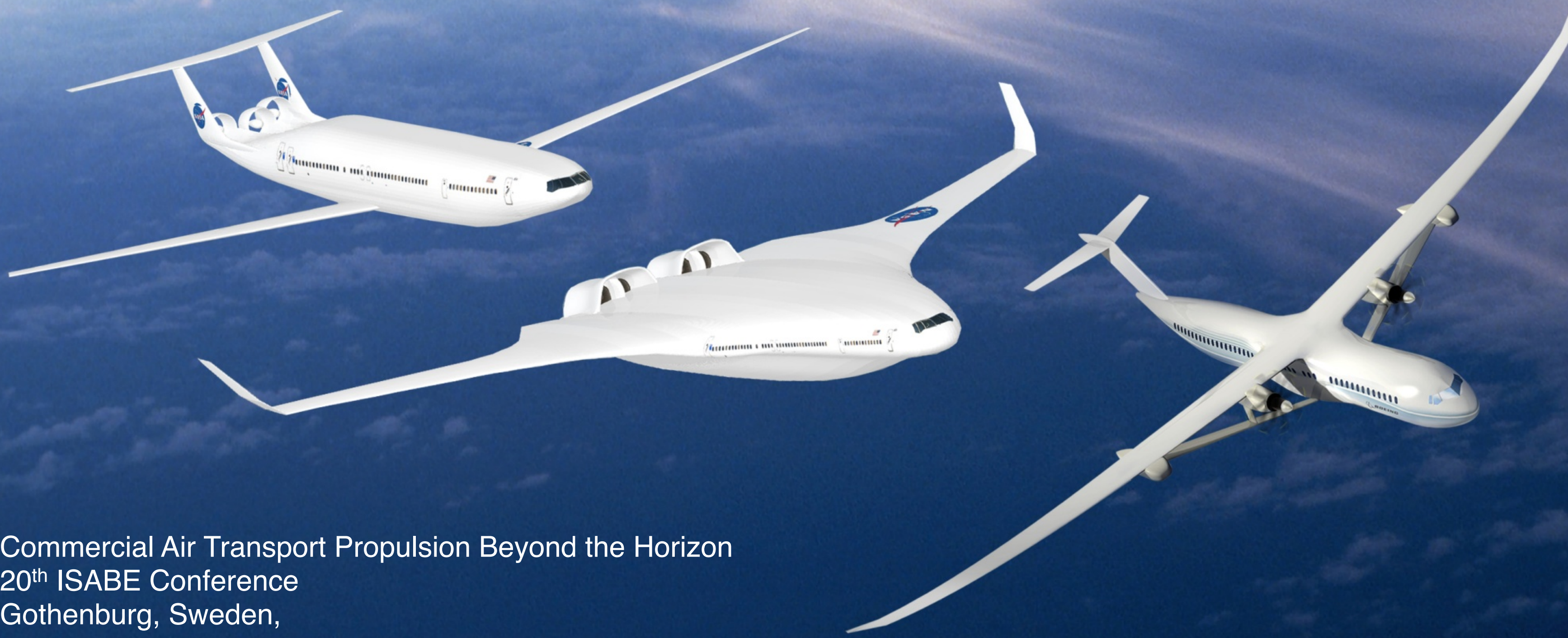


Commercial Air Transport Propulsion Beyond the Horizon
20th ISABE Conference
Gothenburg, Sweden,
12-16 September 2011

# Outline of Talk

Introduction

Historical Trends and Future Challenges

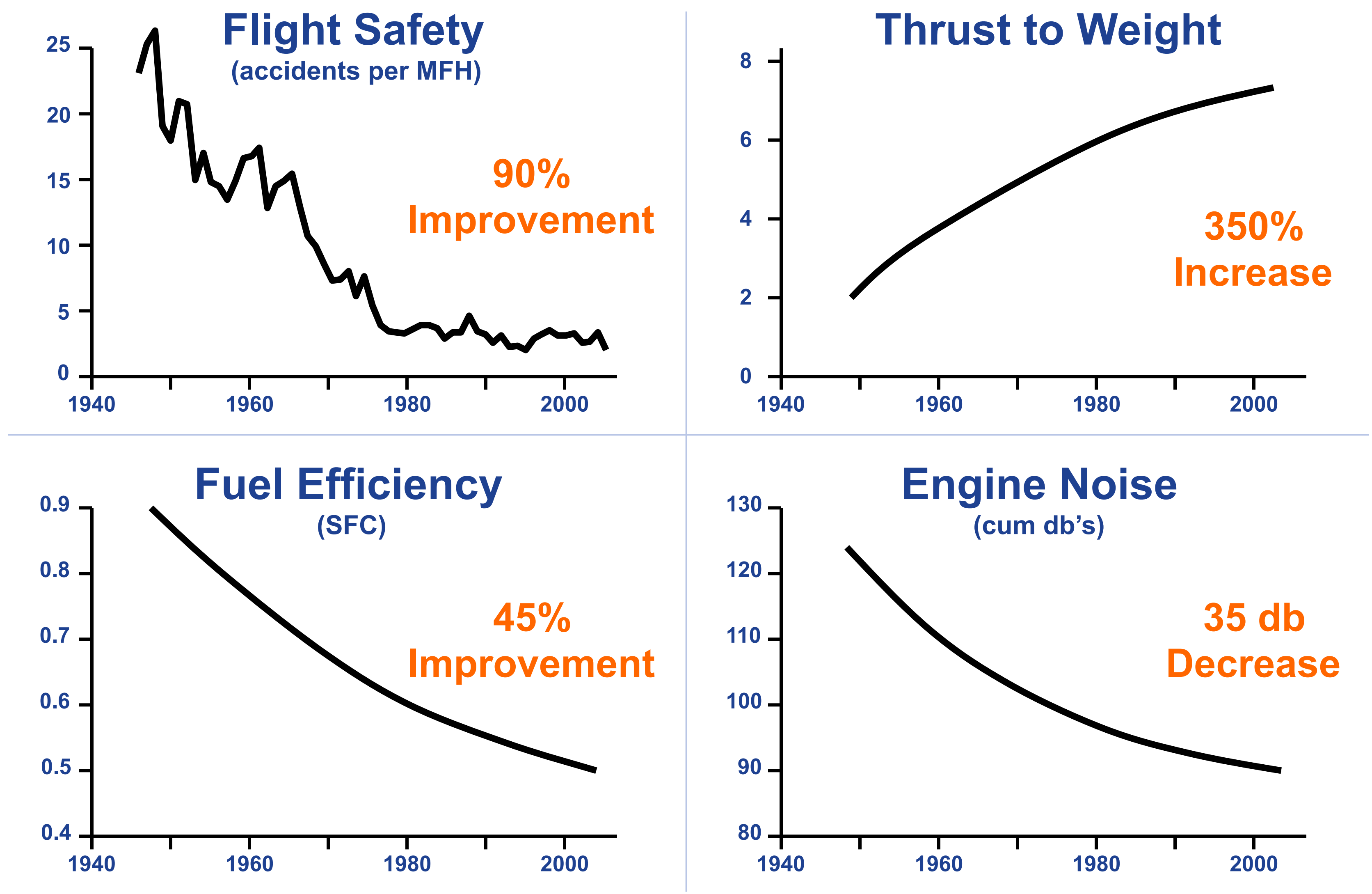
NASA Subsonic Transport Research

Future Propulsion Technologies

- NASA Gen N+3 Advanced Vehicle Concept Studies
- Improved Brayton Cycle-Based Technologies
- Towards Electric Propulsion
- Other “Far-Out” Propulsion Concepts

Concluding Remarks

# Gas Turbine Engines… The Past 50 Years

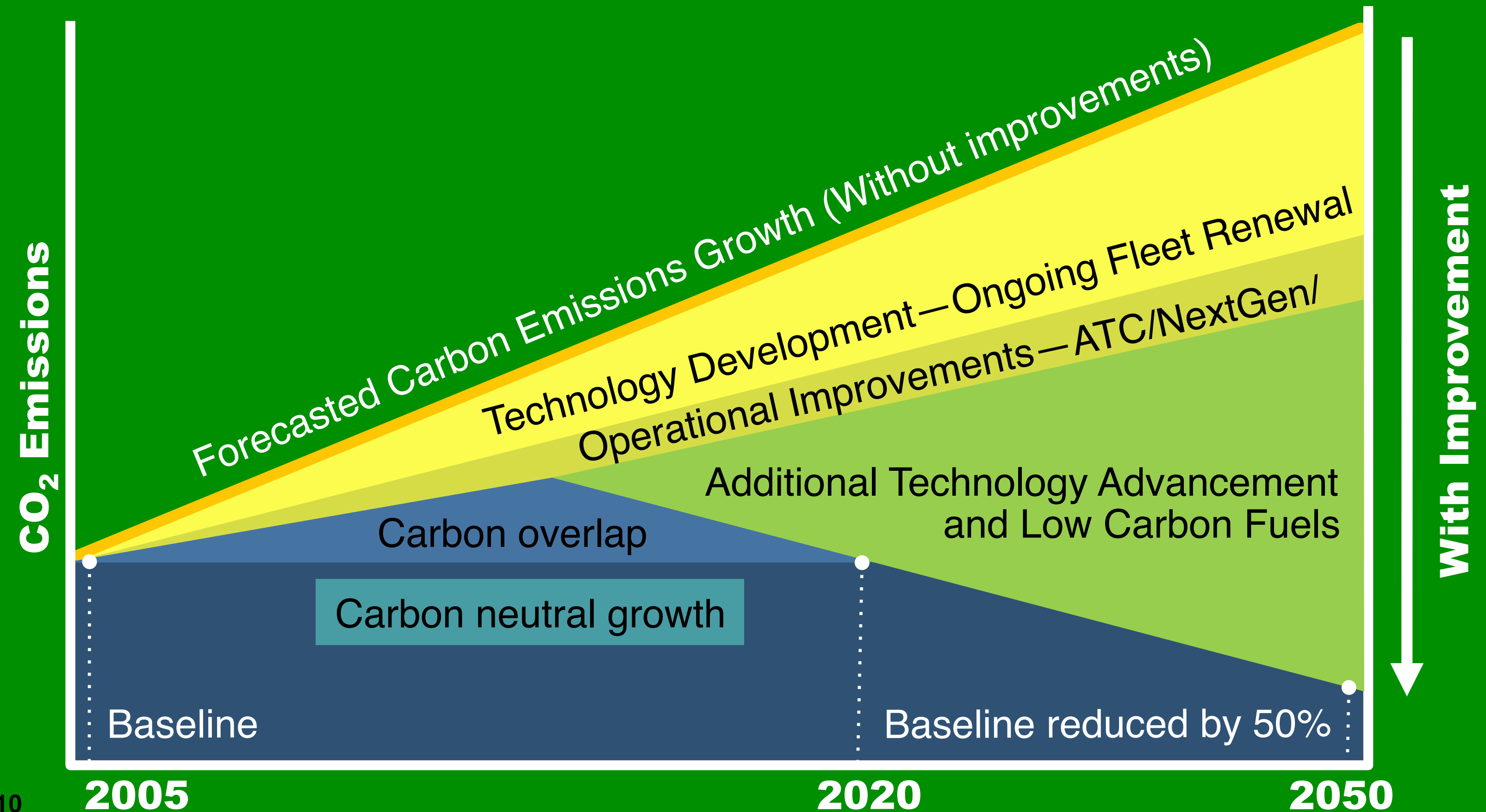





Dr. Dale Carson, GE Aviation (EAA Electric Flight Symposium, July 2011)

# Major Future Challenges for 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

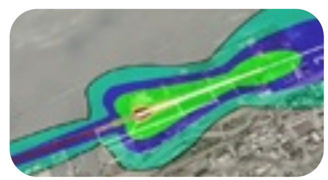


## Fundamental Aeronautics Program

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

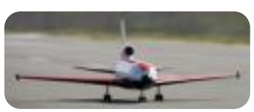
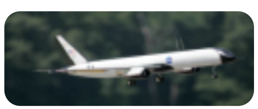
Conduct research at an integrated system-level on promising concepts and technologies and explore/assess/demonstrate the benefits in a relevant environment




## 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.





## 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.

# 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**

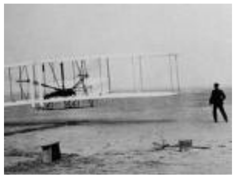
## Objectives

- 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 Subsonic Transport System Level Metrics

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

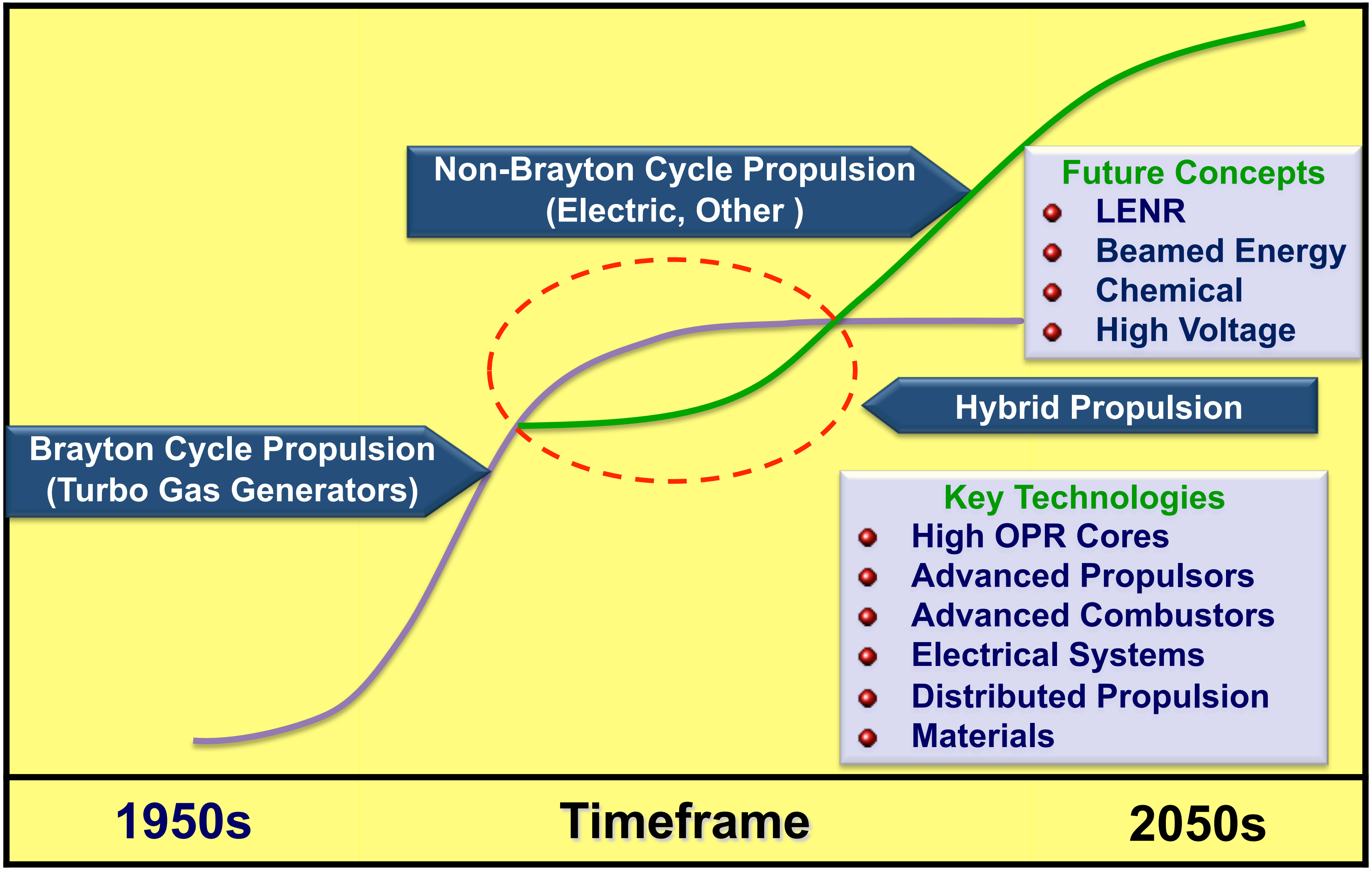
| TECHNOLOGY BENEFITS* | TECHNOLOGY GENERATIONS (Technology Readiness Level = 4-6) | | |
|---|---|---|---|
| | N+1 (2015) | N+2 (2020**) | N+3 (2025) |
| Noise (cum margin rel. to Stage 4) | -32 dB | -42 dB | -71 dB |
| LTO NOx Emissions (rel. to CAEP 6) | -60% | -75% | -80% |
| Cruise NOx Emissions (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

# Propulsion Systems of The Future






Modified Version of Slide from
Dr. Dale Carson, GE Aviation (EAA Electric Flight Symposium, July 2011)

# Gen N+3 Advanced Vehicle Concepts: Phase 1 Results

- Advanced concept studies for commercial subsonic transport aircraft for 2030-35 EIS
- Intended to stimulate far-term thinking towards future aircraft needs and identify key technologies needed
- Some key ideas emerged
  - Lower cruise speeds at higher altitude (~40-45k ft)
  - Heading toward BPR 20 (or propeller) with small, high efficiency core
  - Higher wing aspect ratio and laminar flow to varying degrees
  - Unique enablers (e.g., strut/truss, double bubble, hybrid-electric battery propulsion)
  - Broad technology advances needed (e.g., lightweight and hi-temp materials, gust load alleviation)
  - Conventional/biofuel energy most prevalent, some hybrid-electric
- Results being used to guide future SFW roadmaps and plans. Phase 2 investigations underway




# Northrop Grumman/Rolls Royce SELECT

"Revolutionary performance obtainable from cascading benefits"

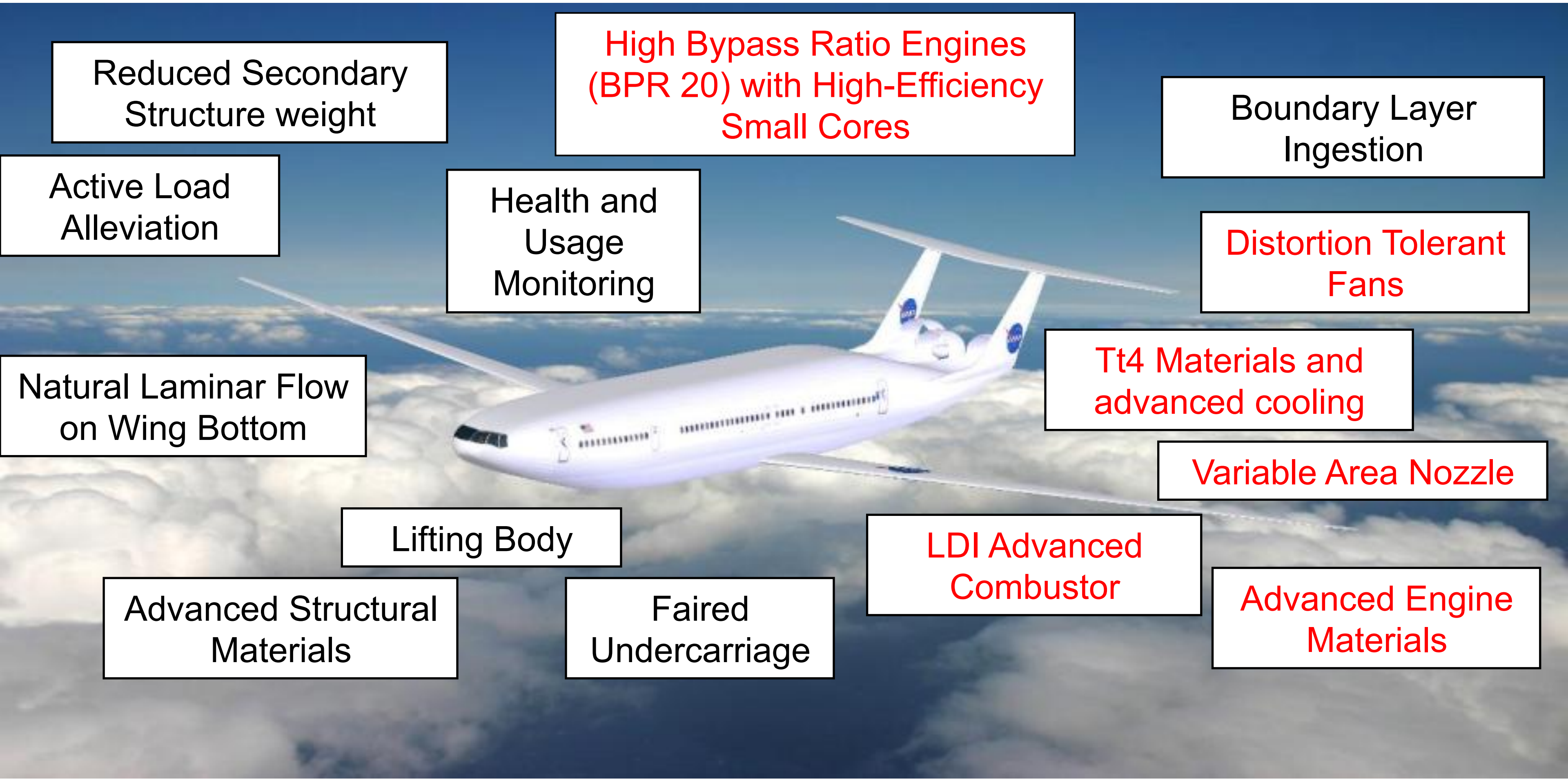
| Technology Suite |
|---|
| Three-Shaft Turbofan Engine |
| -Ultra-High Bypass Ratio ~18 |
| -CMC Turbine Blades |
| -Lean-Burn CMC Combustor |
| -Intercooled Compressor Stages |
| -Swept Fan Outlet Guide Vanes |
| -Fan Blade Sweep Design |
| -Lightweight Fan/Fan Cowl |
| -Compressor Flow Control |
| -Active Compressor Clearance Control |
| -Shape Memory Alloy Nozzle |
| Swept Wing Laminar Flow |
| Large Integrated Structures |
| Aeroservoelastic Structures |
| Ultrahigh Performance Fibers |
| Carbon Nanotube Electrical Cables |
| 3-D Woven Pi Preform Joints |
| Advanced Metallics |
| Landing Gear Fairings |
| Advanced Acoustic Inlet Liner |

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

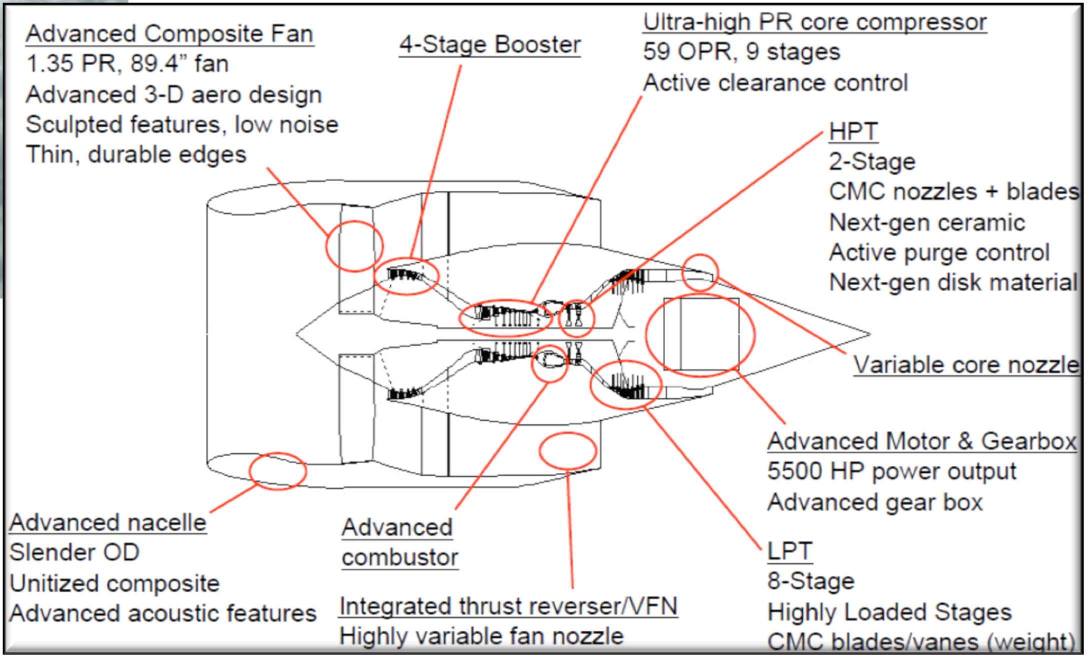



NASA-CR-2010-216794 Vol. 1 & 2

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

# Boeing/GE SUGAR "Volt"

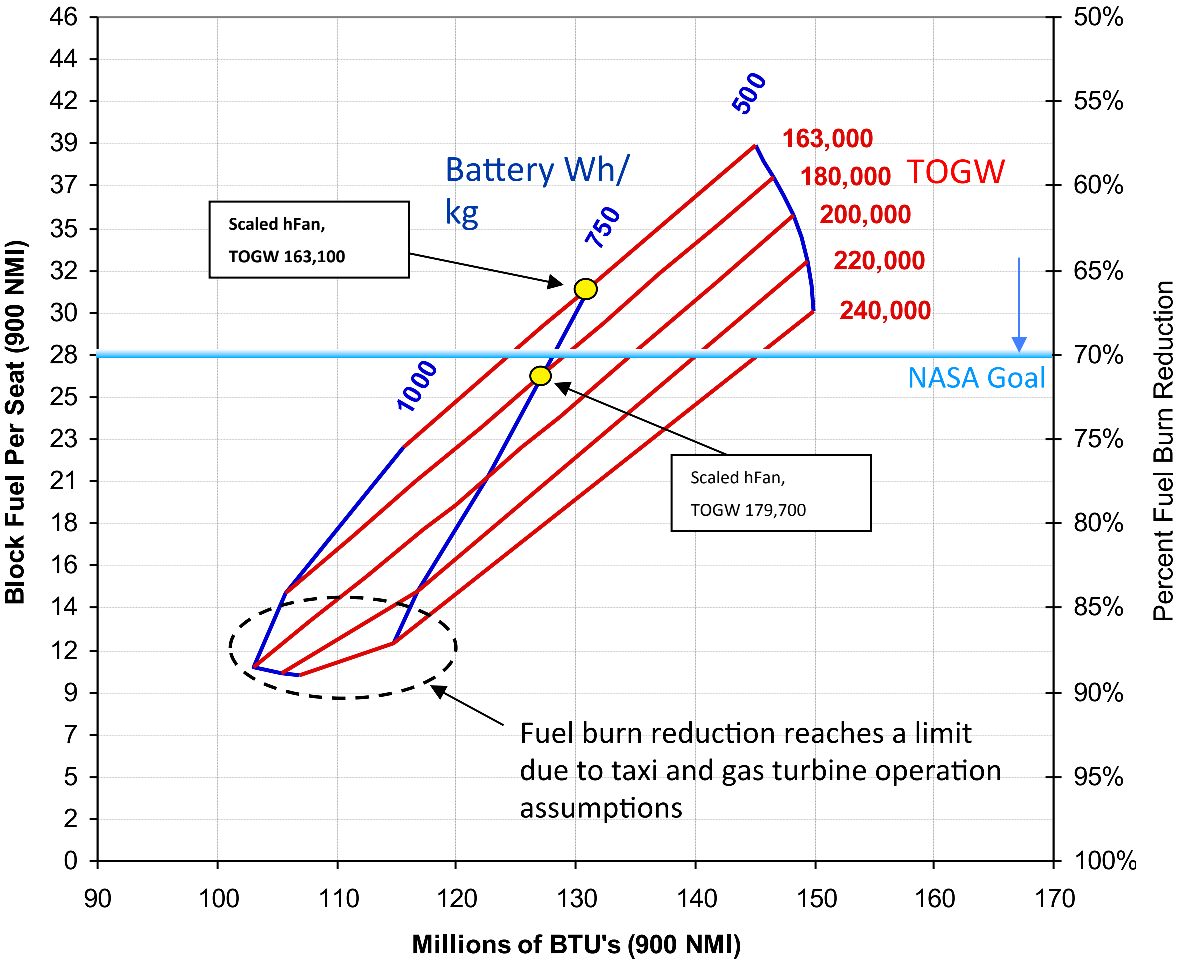
High Aspect Ratio Truss Braced  Wing
Hybrid Electric (Batteries) Propulsion Systems




NASA-CR-2011-216847

Fundamental Aeronautics Program
Subsonic Fixed Wing Project

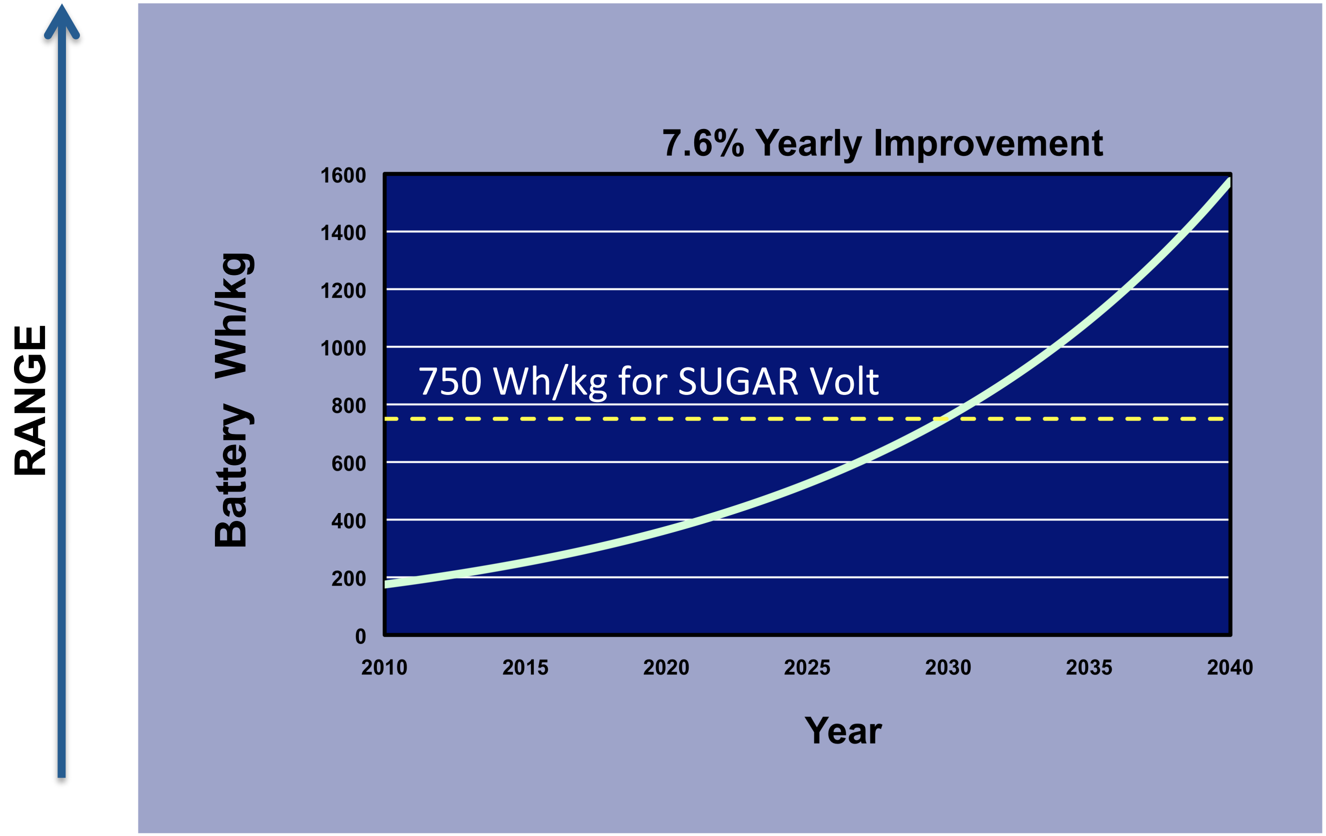
# SUGAR Volt – Opportunities




- 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

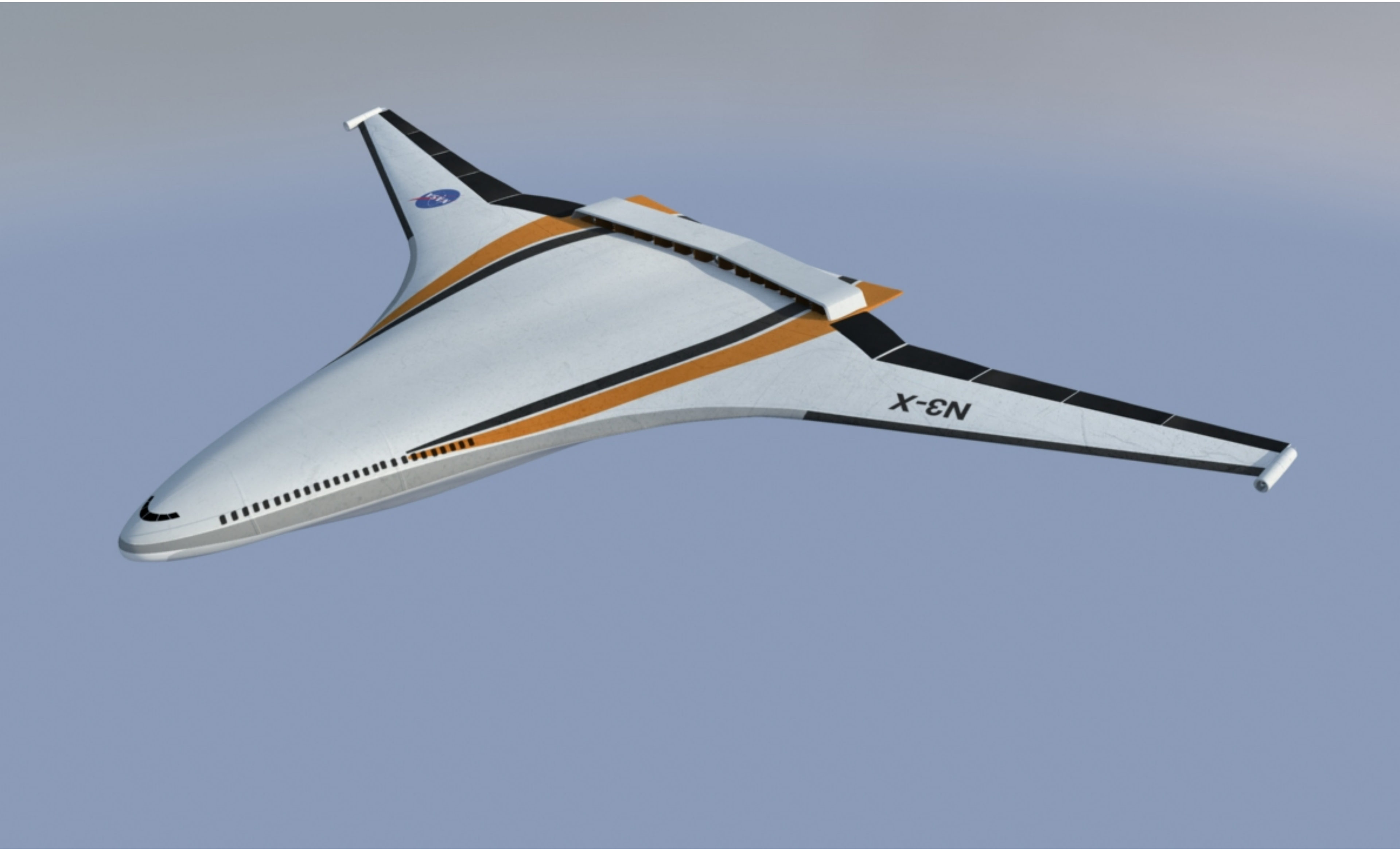
# Electrical Capability: Where Are We?

**Advances in Battery Technology Required**




- Present capabilities for batteries does not meet required levels for large commercial applications … similarly for fuel cells…
- Trend of progress is promising to meet hybrid concepts needs within the next 30 years

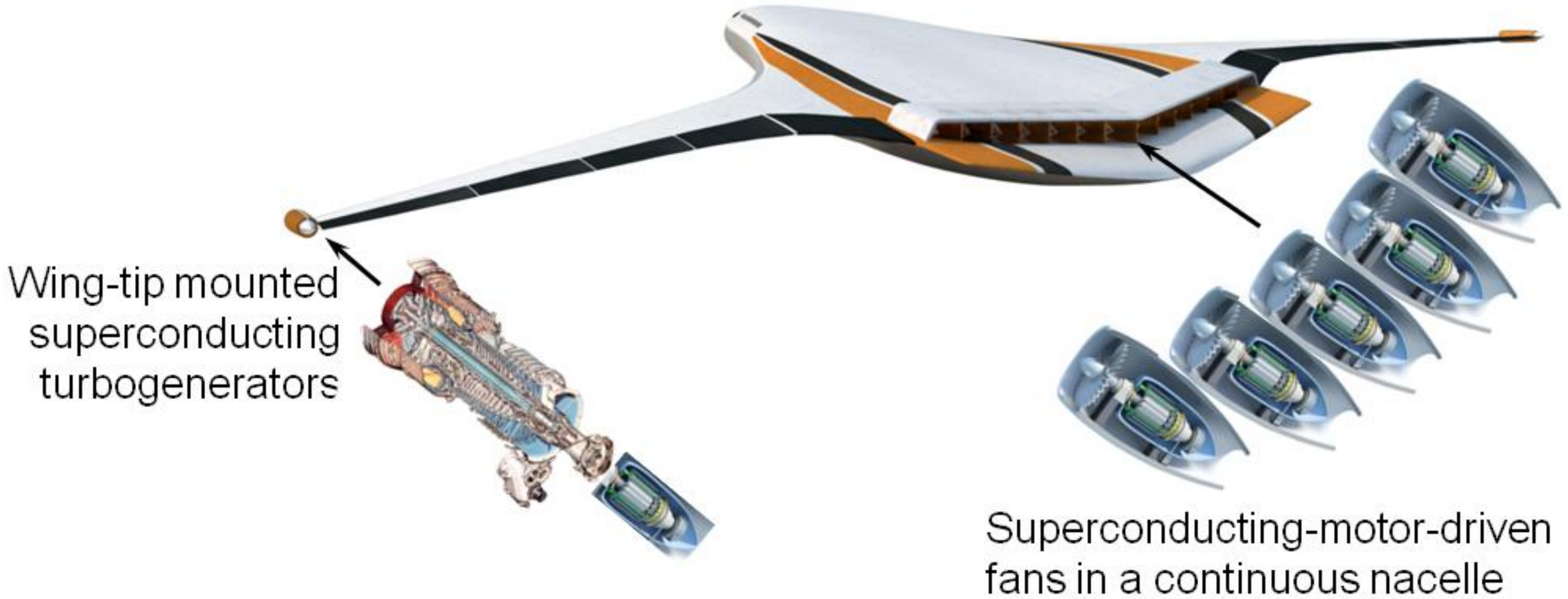
# NASA Turboelectric Distributed Propulsion N3X



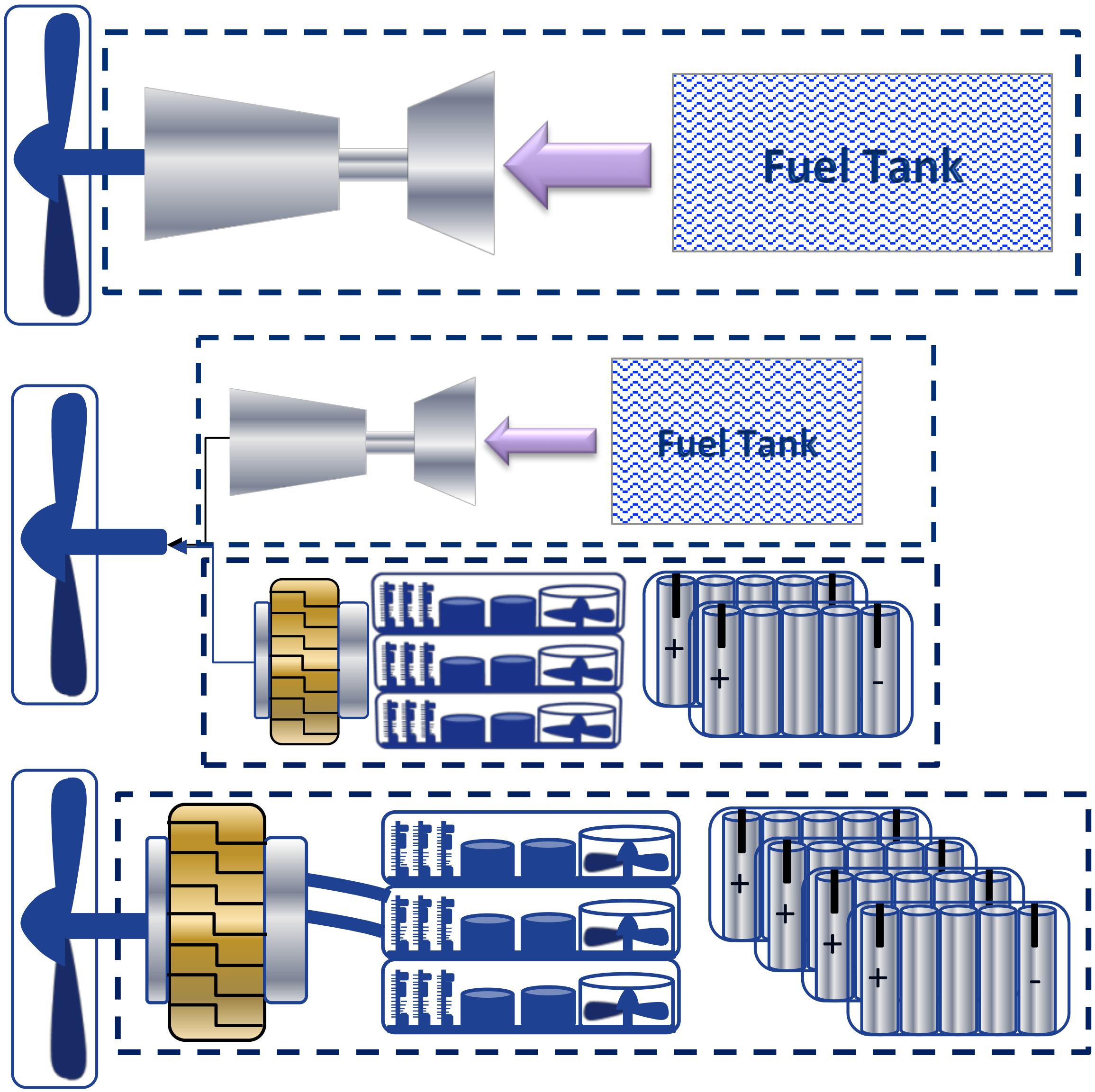
Felder; ISABE-2011-1440 “Turboelectric Distributed Propulsion in a Hybrid Wing Body Aircraft”

# N3-X Concept Description

- TeDP-HWB: Turboelectric Distributed Propulsion– Hybrid Wing Body
- Decoupled propulsive producing device from power producing device
- Two wingtip mounted turboshaft engines driving superconducting generators
- Superconducting electrical transmissions
- Fifteen superconducting motor driven propulsors embedded in fuselage
- Two cooling schemes, cryo-cooled and LH2-cooled



# How about all Electric?




## Gas Turbine Engine Propulsion

- Engines ~15,000 lbs
- Fuel ~8,000 lbs
- Total ~ 23,000 lbs

## Hybrid Turbo-Electric Propulsion

- Engines ~15,000 lbs
- Fuel ~5,000 lbs
- Motors + Converters~ 2000 lbs
- Batteries ~ 25,000 lbs
- Total ~47,000 lbs

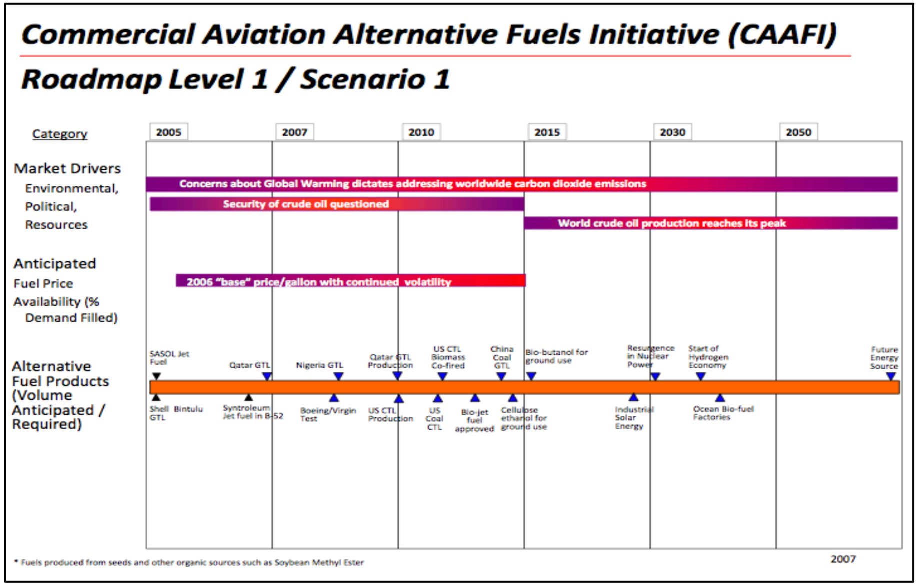
## All Electric Propulsion

- Fans + Nacelles ~ 6000 lbs
- Motors + Converters~ 11,000 lbs
- Batteries ~ 55,000 lbs
- Total ~72,000 lbs

***Example for Narrow-Body Application***

**Dr. Dale Carson, GE Aviation (EAA Electric Flight Symposium, July 2011)**

# Alternative Fuels: Are They Part of the Solution?




*From Previous Boeing Study*

These require large, pressurized, fuel tanks

**Gaseous**
- Methane
- Propane
- Hydrogen ← Must be used in liquid form and be produced from some other source of energy

**Liquid, renewable**
- Ethanol ← Poor performance
- Bio-Jet Fuels
  - 1st Generation – food crops (soybeans)
  - 2nd Generation – non-food sources (algae, jatropha, halophytes)
  - 3rd Generation – bio-engineered bacteria

**Drop-In, not renewable**
- GTL & CTL Synthetic Jet
- Oil-derived Jet Fuel (Oil sands & Shale Oil)

Seamless to the user "Drop-In"

GTL = gas to liquids; CTL = coal to liquids; BTL = biomass to liquids; CBTL = combination coal & biomass to liquids

IGAR_Phase_2_Kick_Off.ppt | 41
03/18/2011

**Alternative Fuel Viability**

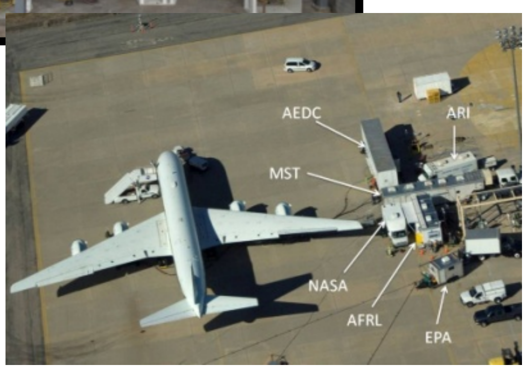
- Viability of Fuel Composition
  - Is the fuel compatible with the current fleet of transportation vehicles?
- Viability of Fuel Pathway
  - Fuel pathway comprised of feedstock, processing technique and fuel composition
  - Are fuel feedstock and processing techniques amenable to large-scale production?
  - Determined (in no particular order) by life cycle GHG emissions, land usage, impact on local environment, fresh water withdrawal and consumption, air quality impacts, economics

Jim Hileman, MIT/PARTNER (NASA Green Aviation Summit, 2010)

# Alternative Fuels Research Effort

**National Plan Goals…**
**Energy and Environment Goal 1: Enable new aviation fuels**
**Energy and Environment Goal 3: Technologies and operational procedures to decrease Environmental Impact of Aviation**

**Technical Challenge:**
**Reduced Emission of Aircraft - Enable concepts and technologies to dramatically reduce or eliminate harmful emissions affecting local air quality/health and global climate change attributable to aircraft energy consumption.**




**Alternative Fuels Research Objectives:**
- **Characterize the performance and emissions of alternative & bio-fuels in aircraft propulsion systems.**
- **Predict the combustion performance and emissions characteristics to enable more effective design of combustors utilizing alternative fuels and bio-fuels.**

# Other Breakthrough Ideas

- Propulsion
  - Low Energy Nuclear Reaction
  - Beamed Energy
  - Chemical Propulsion
  - Thomson Propulsion Device
  - High Voltage Propulsion in Air and Vacuum
- Energy Storage and Conversion
  - Enhanced Superconducting Magnetic Energy Storage
  - Supercapacitors and Ultraconductors
  - Zero-Point Energy Concepts
  - Motionless Electromagnetic Generators
  - Longitudinal Electric Waves
- Physics
  - Gravity and Gravitational Waves
  - Aharonov-Bohm Effect
  - Theoretical Electrodynamics

**From D. S. Alexander, "Advanced Energetics for Aeronautical Applications," NASA CR-2003-212169, Feb 2003**

# Concluding Remarks

- Revolutionary ideas needed in a variety of areas
- Brayton cycle-based propulsion technologies
  - Alternative fuels/biofuels research also key
- Materials
  - Lighter weight, higher temperature
- Electric and hybrid-electric propulsion
  - High power density energy storage
  - Cryogenics and superconducting technologies
  - High efficiency, high density electric machines
  - Prime reliable electrical components
- Highly Integrated Systems
- Vehicles, Propulsion, Energy, Operations

NASA