NASA Investments in Electric Propulsion Technologies for Large Commercial Aircraft

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NASA Aeronautics Vision for Aviation in the 21st Century

3 Mega-Drivers

6 Strategic Thrusts

Safe, Efficient Growth in Global Operations
Enable full NextGen and develop technologies to substantially reduce aircraft safety risks

Transition to Low-Carbon Propulsion
Characterize drop-in alternative fuels and pioneer low-carbon propulsion technology

Innovation in Commercial Supersonic Aircraft
Achieve a low-boom standard

Real-Time System-Wide Safety Assurance
Develop an integrated prototype of a real-time safety monitoring and assurance system

Ultra-Efficient Commercial Vehicles
Pioneer technologies for big leaps in efficiency and environmental performance

Assured Autonomy for Aviation Transformation
Develop high impact aviation autonomy applications

U.S. leadership for a new era of flight

NASA Aeronautics Strategic Thrusts for Electrified Aircraft

Strategic Thrust 3: Ultra Efficient Commercial Vehicles

2015-2025

Aircraft on defined path to fleet-level carbon neutral growth relative to 2005 levels

Evolutionary

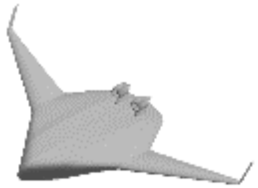
2025-2035

Aircraft improvements to achieve fleet-level carbon neutral growth relative to 2005 levels

Revolutionary

2035+

Aircraft enabling a 50% fleet-level carbon reduction reduction from 2005 levels



Transformational

Strategic Thrust 4: Transition to Low Carbon Propulsion

2015-2025

Low-carbon fuels for conventional engines and exploration of alternative propulsion systems

2025-2035

Initial introduction of alternative propulsion systems

2035+

Introduction of alternative propulsion systems for aircraft of all sizes

NASA Perspective on Electrified Aircraft Propulsion

Explore alternative propulsion systems that can *reduce carbon, noise, and emissions* from commercial aviation

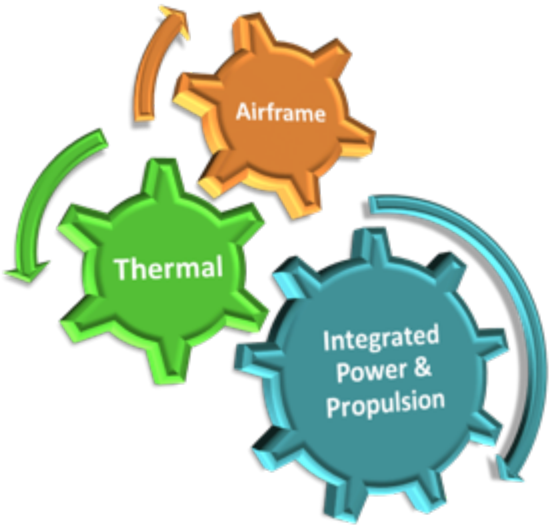
Cleaner, quieter systems

Potential for vehicle system efficiency gains (use less energy)

Leverage advances in other transportation and energy sectors

Address aviation-unique challenges (e.g. weight, altitude)

Recognize potential for early learning and impact on smaller or shorter range aircraft



Address Key Challenges

Electrical system weight

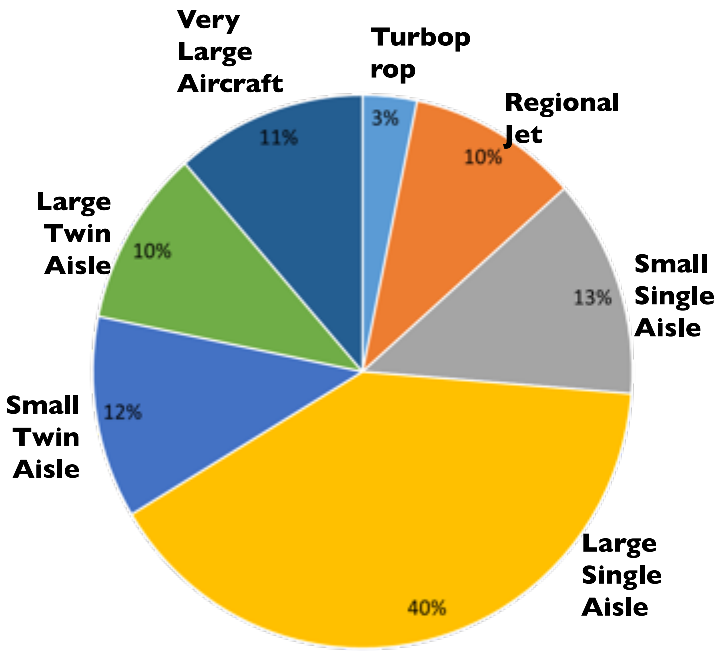
Energy storage capabilities

Thermal management

Flight controls

Safety

Certification



2012 Fuel Consumption, FAA US Operations Data. Analysis by H Pfaender, GA Tech

NASA New Aviation Horizons

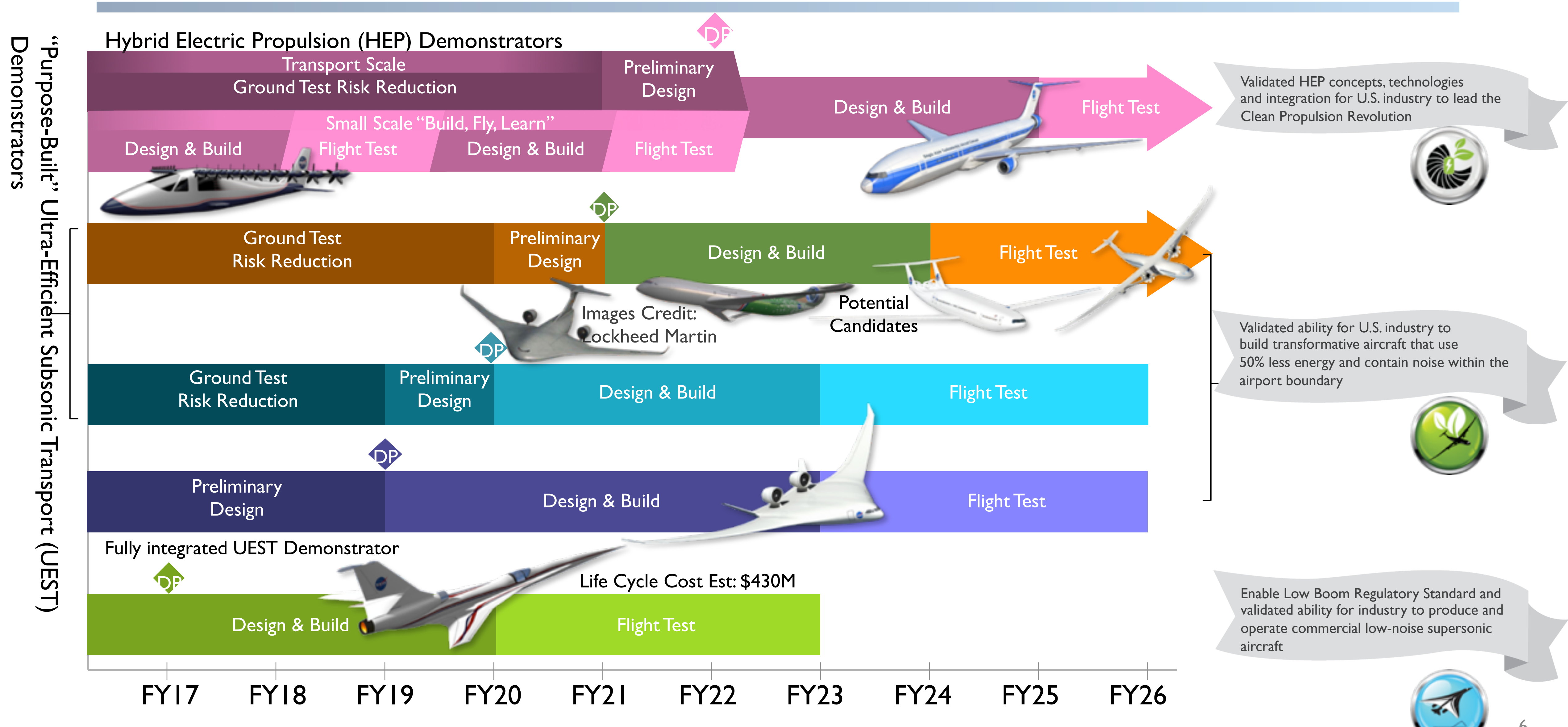
Laying the foundation for a future of sustainable aviation through wind tunnel testing of aircraft and engines and a renewed emphasis on flight testing

Green Aviation investments in
- Alternative Fuels
- New Configurations
- Emissions and Noise Reductions

Potential X-Planes
- Truss-braced wing
- Over-the-Wing Nacelle
- Boundary Layer Ingestion
- Blended Wing Body
- Turbo- and Hybrid-Electric Propulsion

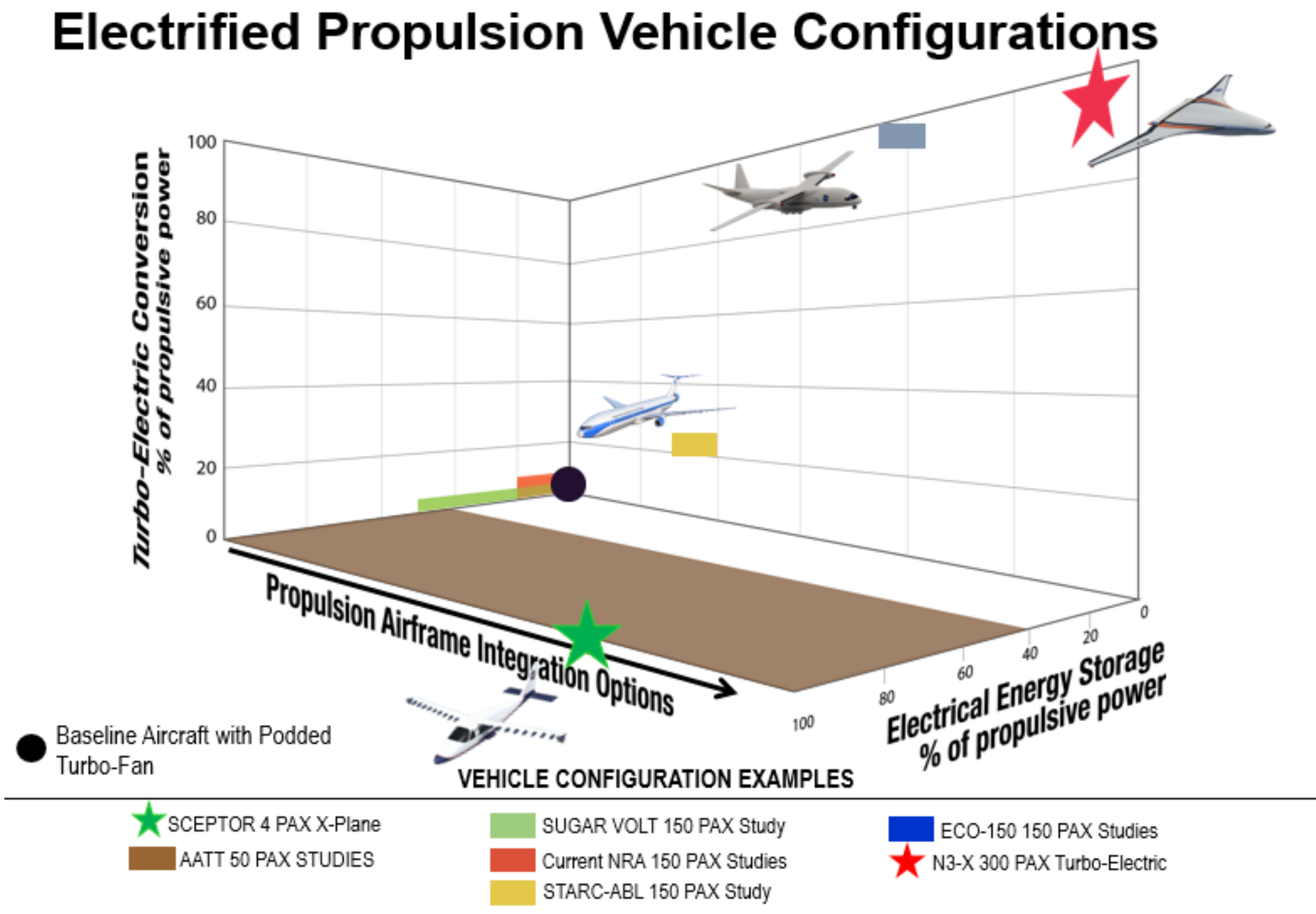
First Demonstrators
- Maxwell X-57
- QuESST

NASA New Aviation Horizons Flight Demo Plan



Electrified Aircraft Design Space

- Electric, hybrid-electric, and turboelectric propulsion offers many new degrees of freedom
- Point designs help explore the potential
- Mission profiling, airport infrastructure, and nontraditional airspace operations additional considerations



NASA N3-X (Fully Turboelectric/Distributed/BLI)

Baseline is B777-200LR/GE90-115B

Wing-tip mounted superconducting turbogenerators

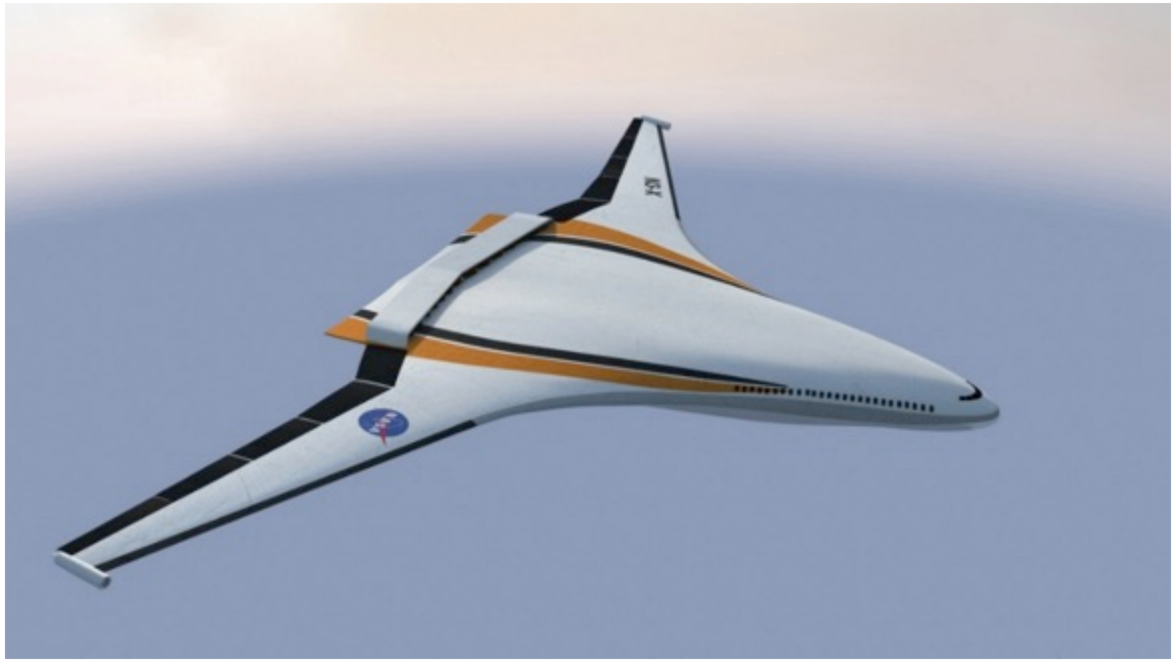
Power distributed electrically from turbine-driven generators to superconducting motors driving electric fans in a continuous nacelle

Fuel burn benefits relative to 2000 baseline

- 70% / 72% with cyrocooler / LH2 (relative to 2000 technology baseline)
- 18% / 20% with crycooler / LH2 (relative to N+3 HWB with UHB turbofans)

N3-X w/ MgB2 + LH2

Passengers:	300
Range:	7500 nm
Cruise Speed:	Mach 0.84
Generators:	2x30 MW
Motors:	14x4.3 MW



Ref: Kim, H.D., et al., Aircraft Engineering and Aerospace Technology Journal, Vol. 86, pp. 558-561, 2014

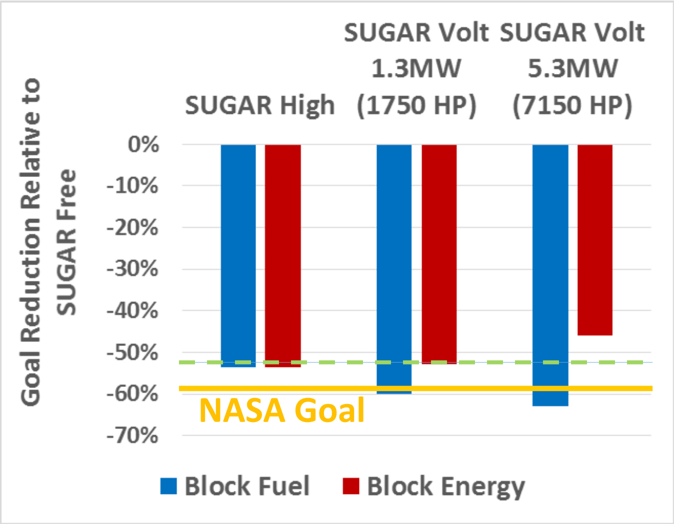
Boeing SUGAR Volt (Parallel Hybrid)

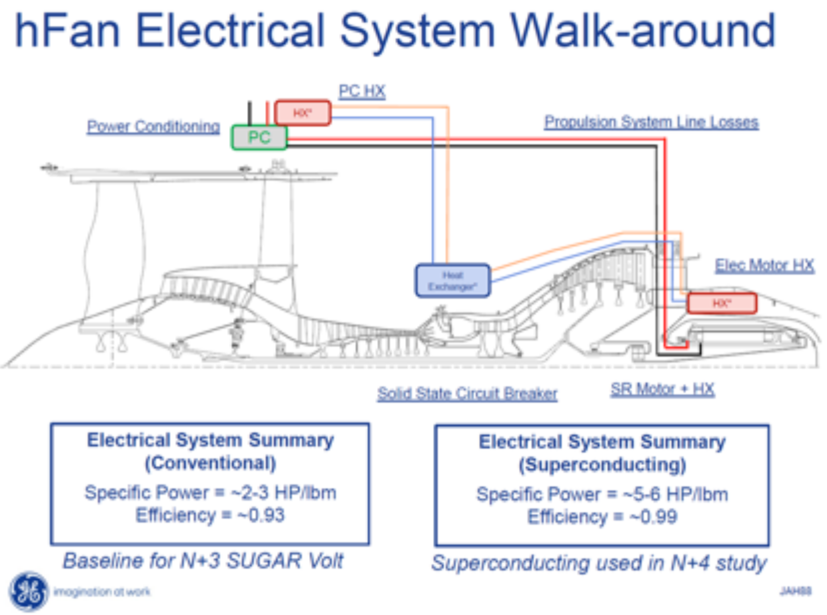
750 Wh/kg battery energy density assumed

1.3 MW reduces fuel consumption to meet NASA N+3 goal at the same energy consumption as SUGAR High

5.3 MW reduces fuel consumption further at the price of increased energy consumption compared to SUGAR High

TRL of 4-6 possible by 2025





Ref: Boeing N+3 Subsonic Ultra Green Aircraft Research (SUGAR) Final Report

Parallel Hybrids with Expanded Mission Optimization

Parallel hybrids (podded configurations) may allow fleet retro-fit or earlier entry into service

Three independent studies show interesting results

- Boeing SUGAR VOLT concept with hybrid propulsion during cruise
- UTRC concept with hybrid propulsion during take-off and climb
- Rolls-Royce (RR) concept using fleet-optimized hybrid architecture

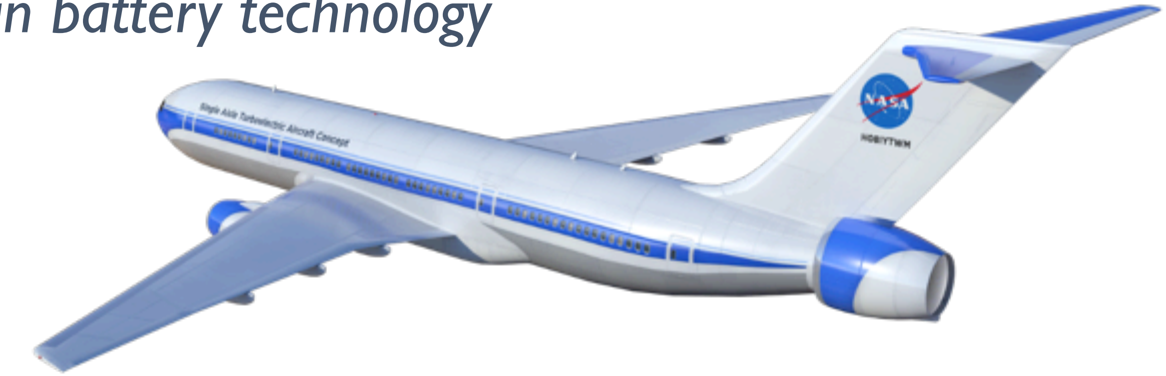
Each study made independent assumptions for future baseline vehicle to identify benefits resulting from hybridization

- 6-24% fuel burn savings for 900 nm mission
- 0% energy savings for Boeing; 2.5-7% energy savings for UTRC and RR concepts
- 6-24% emissions reductions also achievable
- Noise benefits low for Boeing and UTRC concepts (same fan, smaller core); moderate for RR concept (smaller fan and core)

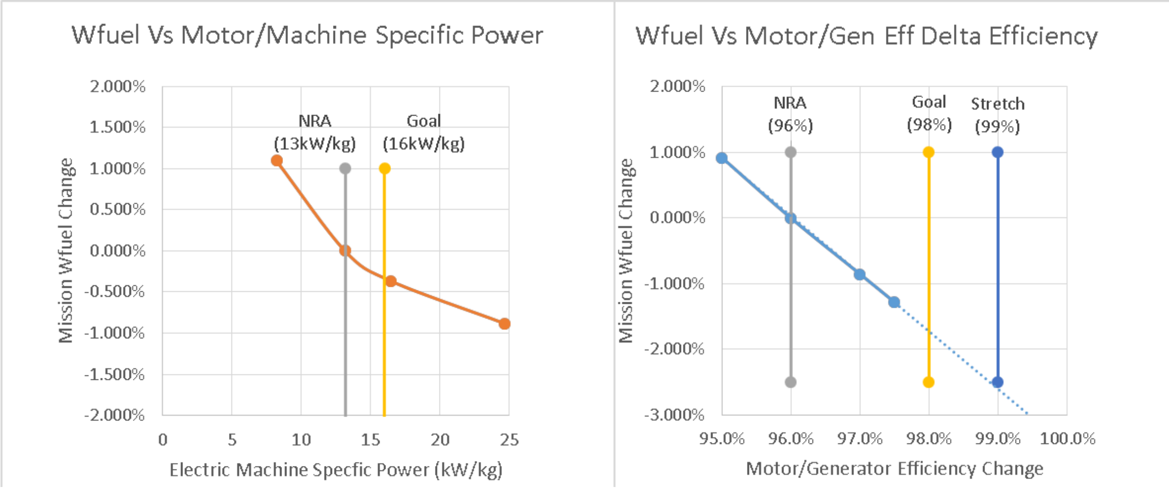
Important Note: These studies were performed with very different assumptions. Result comparisons are provided for reference only.

NASA STARC-ABL—Partially Turboelectric / Distributed

Fuel burn and CO2 reductions without improvements in battery technology



- 154 PAX, M=0.7 Concept
- Downsized engines provide 80% of takeoff and 55% of cruise thrust
- Electrically power aft propulsor provides 20% of takeoff and 45% of cruise thrust
- 2x1.4 MW Generators, 2.6 MW Motor
- Configuration meets speed and range requirement of baseline aircraft
- Uses existing airport infrastructure
- 7-12% fuel (and energy) savings relative to baseline advanced technology aircraft for 900-3500 nm mission



Electrical Machine Specific Power and Efficiency Sensitivities

Ref: J.Welstead, and J. Felder, AIAA Sci Tech, Jan. 2016; Motor sensitivity analysis by J. Felder

ESAero ECO-150—Fully Turboelectric / Distributed

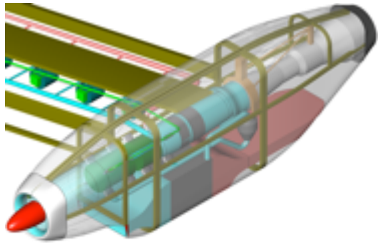
150 PAX, M=0.8, 3500 nm range, concept

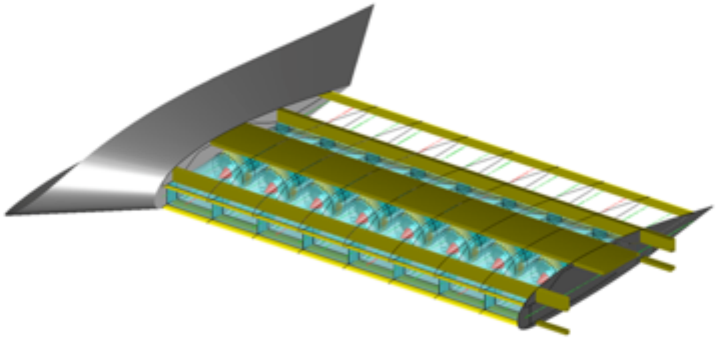
"Split-wing" turboelectric system with 2 turbogenerators and 16 motor driven fans embedded in wing

Initial studies considered superconducting motors and generators

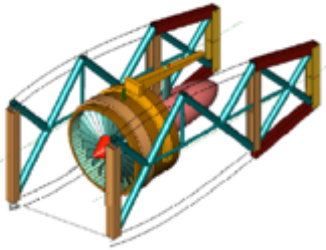
Recent studies focused on conventional (ambient temp) non-superconducting systems

Propulsor with non-cryo motor





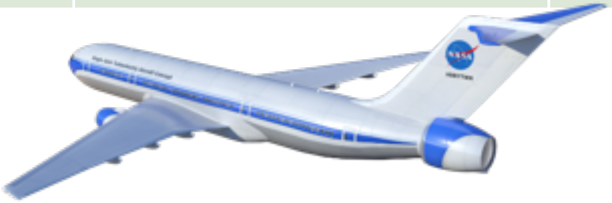
Propulsor with superconducting motor

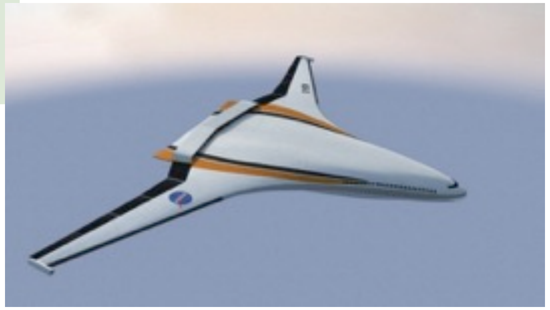


Ref: Empirical Systems Aerospace: SBIR Phase I 2008, 2009, 2013

Single-Aisle Electrified Aircraft Design Examples

	CO_2 reduction from current baseline	TRL 4-6
ECO-150	44%	2020
STARC-ABL	59%	2025
SUGAR Volt	59%	2025
SUGAR Freeze	68%	2030
N3-X (Twin-Aisle)	70%-75%	2030

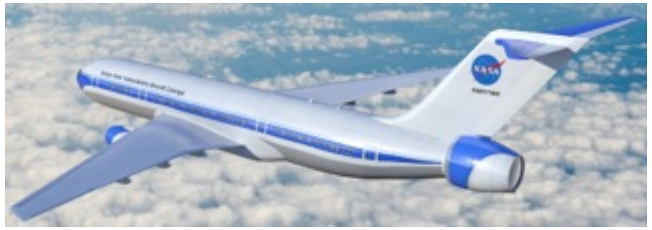




NASA Electrified Aircraft Propulsion R&T Investments

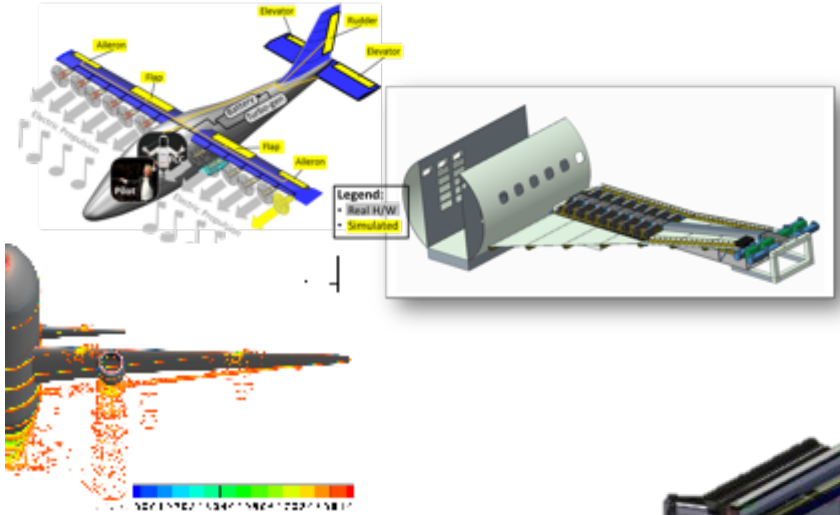
Technology development targeted toward large commercial aircraft

- Propulsion System Conceptual Design
- High Efficiency/Specific Power Electric Machines
- Flight-weight Power Systems and Electronics
- Integrated Flight Simulations and Testing
- Enabling Materials for Machines and Electronics
- Turbine/Generator Integration and Controls

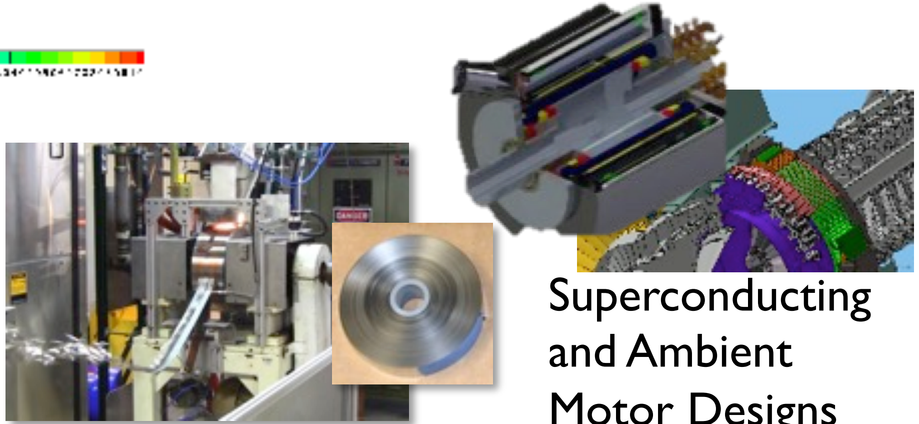


Exploring tube-and-wing architectures

Powertrain, Controls and Flight Simulation Testbeds and Advanced CFD



Advanced Materials and Novel Designs for Flightweight Power



Superconducting and Ambient Motor Designs

NASA Roadmap for Electrified Aircraft Propulsion