Hybrid Gas-Electric Subproject Overview

Amy Jankovsky

NASA Interchange with Meggitt Aircraft Braking systems

Aug 31, 2016

Outline

- Overview of Strategic Thrust 4b Roadmap
  - What is the meaning of hybrid electric propulsion in this context?
  - Aeronautics Research Mission Directorate (ARMD) Overview – Thrusts
  - ARMD Strategic Thrust 4b – Electric/Hybrid Electric
- Overview of Hybrid Gas-Electric Subproject
- Hybrid electric propulsion research in Convergent Aeronautical Solutions Project

Electrified Aircraft Propulsion Terminology

- **Electrified Propulsion refers to the use of electric power for aircraft propulsion**
  - Could be all or partially electric propulsion
  - Extension of the technology required for “More electric” or “All electric” use of electric power for secondary systems on aircraft

- **Hybrid Electric has two meanings in aircraft context**
  - One meaning is the use of two power sources, such as turbine engine and electric energy storage, to drive the same fan or propeller shaft—hybrid electric powertrain
  - Another meaning is the combination of more than one propulsive sources such as traditional turbofan engines augmented with a non traditional propulsive power source—hybrid electric propulsion

- **Turboelectric Propulsion refers to on-air generated electric power for aircraft propulsion**
  - Turboelectric generation already provides electric power for secondary systems on aircraft
  - Options exist for either all or partially turboelectric propulsion

NASA Aeronautics

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

ARMD Roadmaps

ARMD's Aeronautical Research Taxonomy

Strategic Thrust 1
Safe, Efficient Growth in Global Operations

Strategic Thrust 2
Innovation in Commercial Supersonic Aircraft

Strategic Thrust 3
Ultra-Efficient Commercial Vehicles

Strategic Thrust 4
Transition to Low-Carbon Propulsion

Strategic Thrust 5
Real-Time System-Wide Safety Assurance

Strategic Thrust 6
Assured Autonomy for Aviation Transformation

Community Outcomes and Vision & Strategy

Near Term: 2015-2025
Mid Term: 2025-2035
Far Term: Beyond 2035

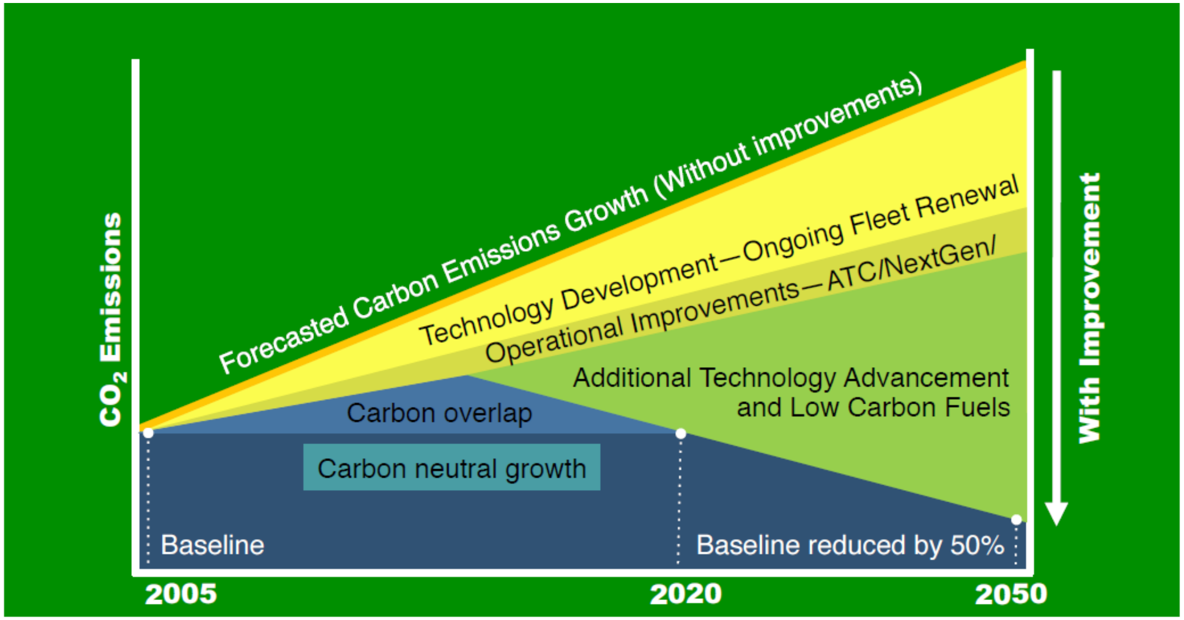
Benefits, Capabilities (Expanded Outcomes)

Research Themes
Long-Term Research Areas that will enable the outcomes (most outcomes encompass multiple research themes)

Roadmap and Overarching Technical Challenges
Specific measurable research commitments within the research themes (most research themes encompasses several technical challenges (TC); each ARMD program project list the TC's for which they are responsible.

Strategic Thrust 4 Low Carbon Propulsion

- The Low Carbon Propulsion challenge is to enable carbon-neutral growth in aircraft operations.
- The proposed answer is a combination of alternative fuels and alternative propulsion



2015 | 2025 | 2035

Introduction of Low-Carbon Fuels for Conventional Engines and Exploration of Alternative Propulsion Systems	Initial Introduction of Alternative Propulsion Systems	Introduction of Alternative Propulsion Systems to Aircraft of All Sizes

Example aircraft concepts

STARC-ABL concept

- 150 passenger plane with two turbines and 2.6MW electric motor driven tail cone thruster
- 7-12% fuel burn reduction
- Uses jet fuel, standard runways & terminals

IMPACT: Reduce fuel use and emissions of biggest aircraft segment

- Key Technologies
  - Aircraft System Analysis – modeling, analysis compared to key metrics
  - Engine technologies – >1 MW power extraction from turbofan
  - Propulsion/Airframe Integration – benefit of tail cone thruster (takeoff to 0.8 Mach)
  - Power – >1 MW efficient, high specific power
  - Materials – turbine, magnetic materials, cable materials, insulation

Thin Haul concept

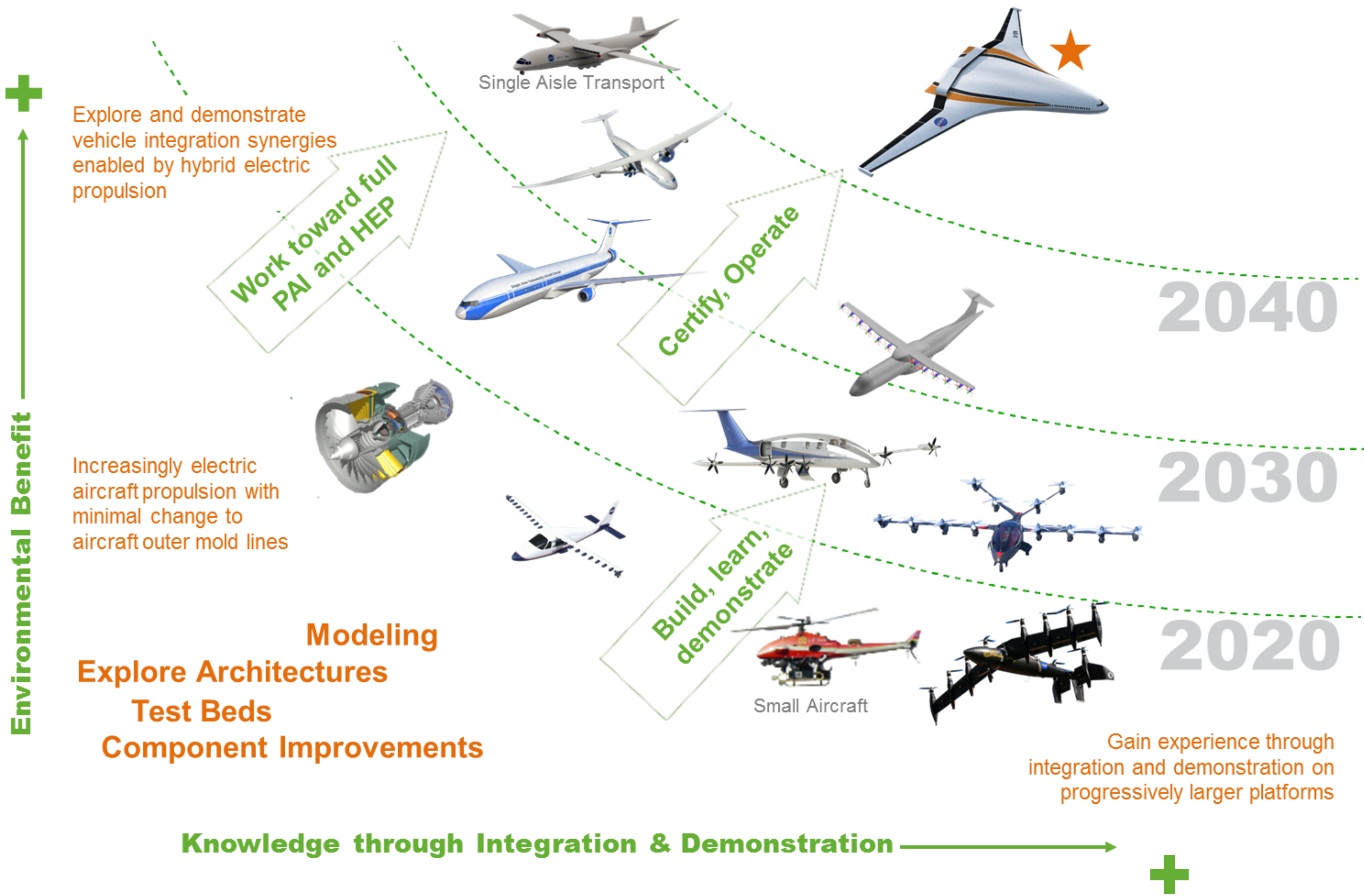
- 9 passenger plane, battery powered with turbine range extender
- Much more efficiency, cost effective and quiet than comparable aircraft

IMPACT: Drastically increase use of small and medium airports and cut emissions

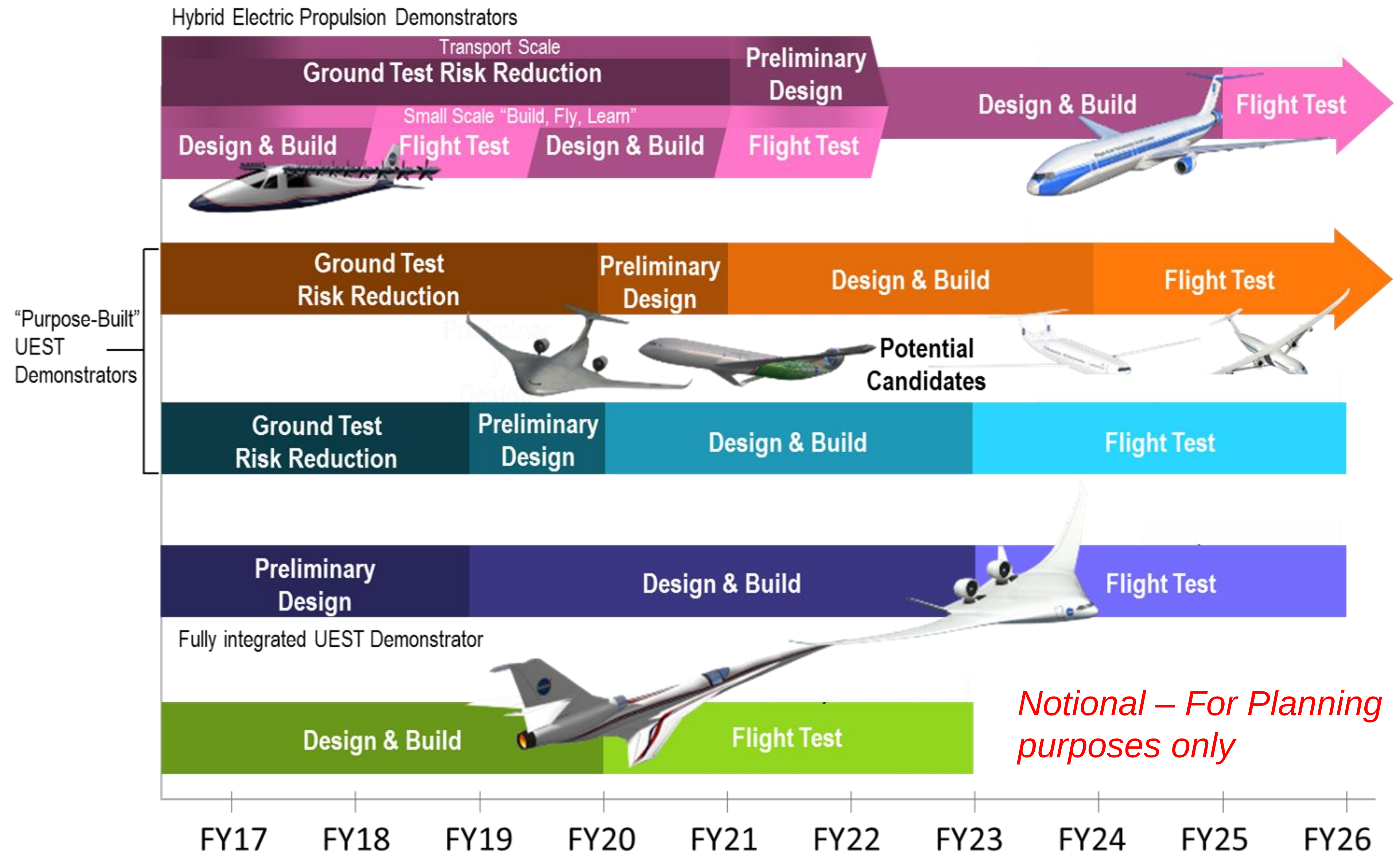
- Key Technologies
  - Aircraft System Analysis – modeling, analysis compared to key metrics
  - Propulsion/Airframe Integration – Blown wing and/or possible fuselage boundary layer ingestion (BLI) (0-200 knots)
  - Energy Sources – advanced batteries, structural batteries, fuel cells
  - Flight Controls – possible opportunities to reduce control surfaces

Hybrid Electric Propulsion

Prove Out Transformational Potential



Electrified Propulsion Flight Opportunities



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Hybrid Gas-Electric Propulsion Subproject (HGEP)
Motivation

Electrified Aircraft offer compelling Environmental Advantages

- Energy sector convergent technology
- Promise of cleaner energy
- Potential for vehicle system efficiency gains (use less energy)
- Leverage advances in other transportation sectors
- Address aviation-unique challenges (e.g. weight, altitude)
- Recognize potential for early learning and impact on small aircraft

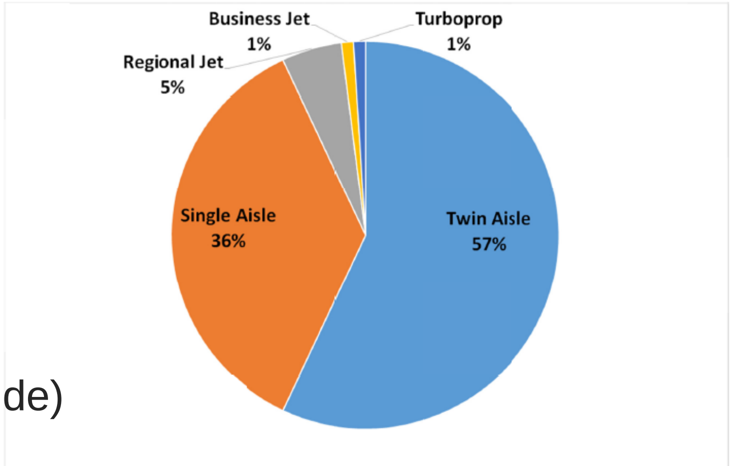
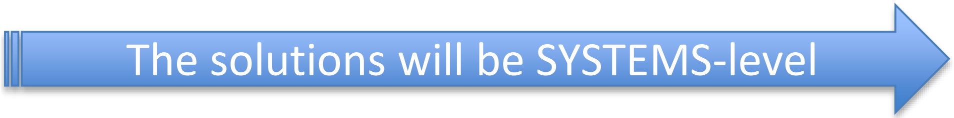
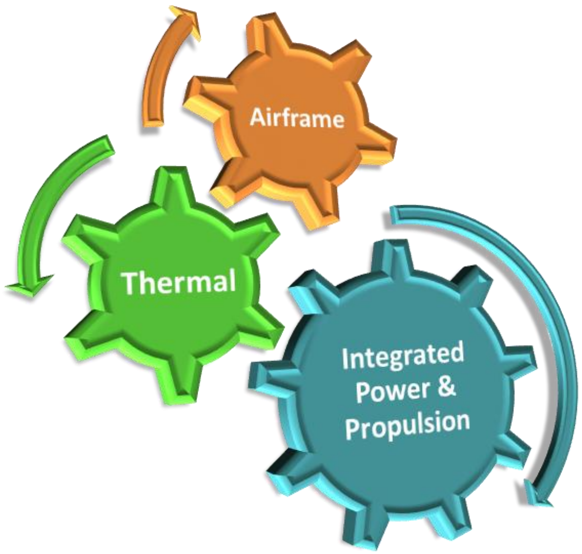


FIGURE 1.1 Global civil aviation fuel consumption. SOURCE: Data from B. Yutko and J. Hansman, 2011, *Approaches to Representing Aircraft Fuel Efficiency Performance for the Purpose of a Commercial Aircraft Certification Standard*, MIT International Center for Air Transportation, Cambridge, Mass.

Significant Challenges Remain

- Added weight and Electrical Systems losses
- Some concepts require Energy Storage advances
- How to integrate?
- How to control? How to fly?
- How to certify and maintain safety?

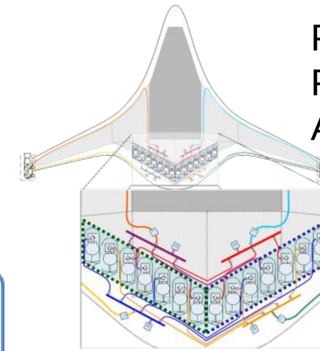




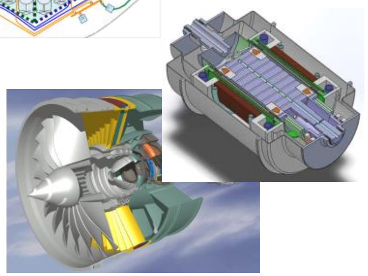
Hybrid Gas Electric Propulsion SubProject (HGEP)

Technical Areas:

- **Propulsion System Conceptual Design**
- **High Efficiency/Power Density Electric Machines**
  - Superconducting (cryo)
  - 1 MW Superconducting Motor Test
  - Non-superconducting
  - Superconducting Wire
- **Flightweight Power**
  - Power System Architecture & Modeling
  - Intelligent Motor Drive
  - NASA Electric Aircraft Testbed (NEAT)
- **Enabling Materials for Machines and Electronics**
  - Insulation
  - Advanced Magnetic Materials
  - Wide Bandgap Semiconductors
  - Conductors
- **Integrated Flight Simulation & Testing**
  - Hybrid Electric Integrated Systems Testbed (HEIST)
  - Piloted Sims



Propulsion Power Grid Architectures

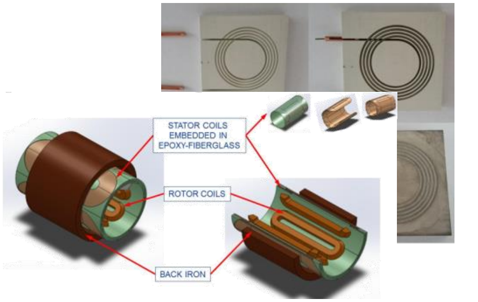


Machine TRL Advancement

Approach:

- Detailed assessment *of reference design concept* through modeling and analysis
- 200 kW Subscale System Demo's on *hardware-in-the-loop* testbed
- Select Component Demo's at *1-2 MW Level*
- Component maturations for key enabling materials and subcomponents

Hardware-in-the-Loop Testing



Electromagnetic Components & Materials

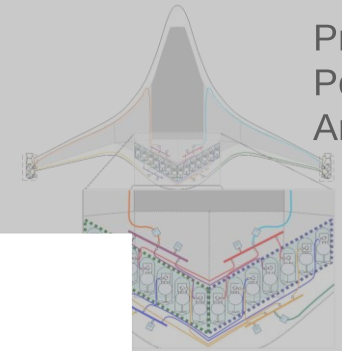
Hybrid Gas Electric Propulsion SubProject (HGEP)

Technical Areas:

- Propulsion System Conceptual Design
- High Efficiency/Power Density Electric Machines
  - Superconducting (cryo)
  - 1 MW Superconducting Motor Test
  - Non-superconducting
  - Superconducting Wire
- Flightweight Power
- Enabling Materials for Machines and Electronics
- Integrated Flight Simulation & Testing

Two New Technical Areas in FY17

- Aft Boundary Layer Ingestion *BLI2*
- Turbine/Generator Integration & Controls HGEP



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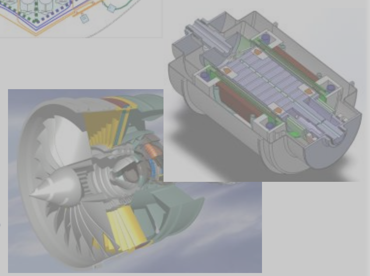

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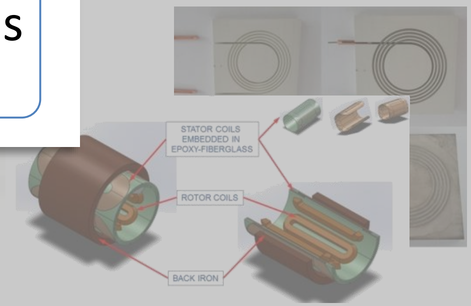
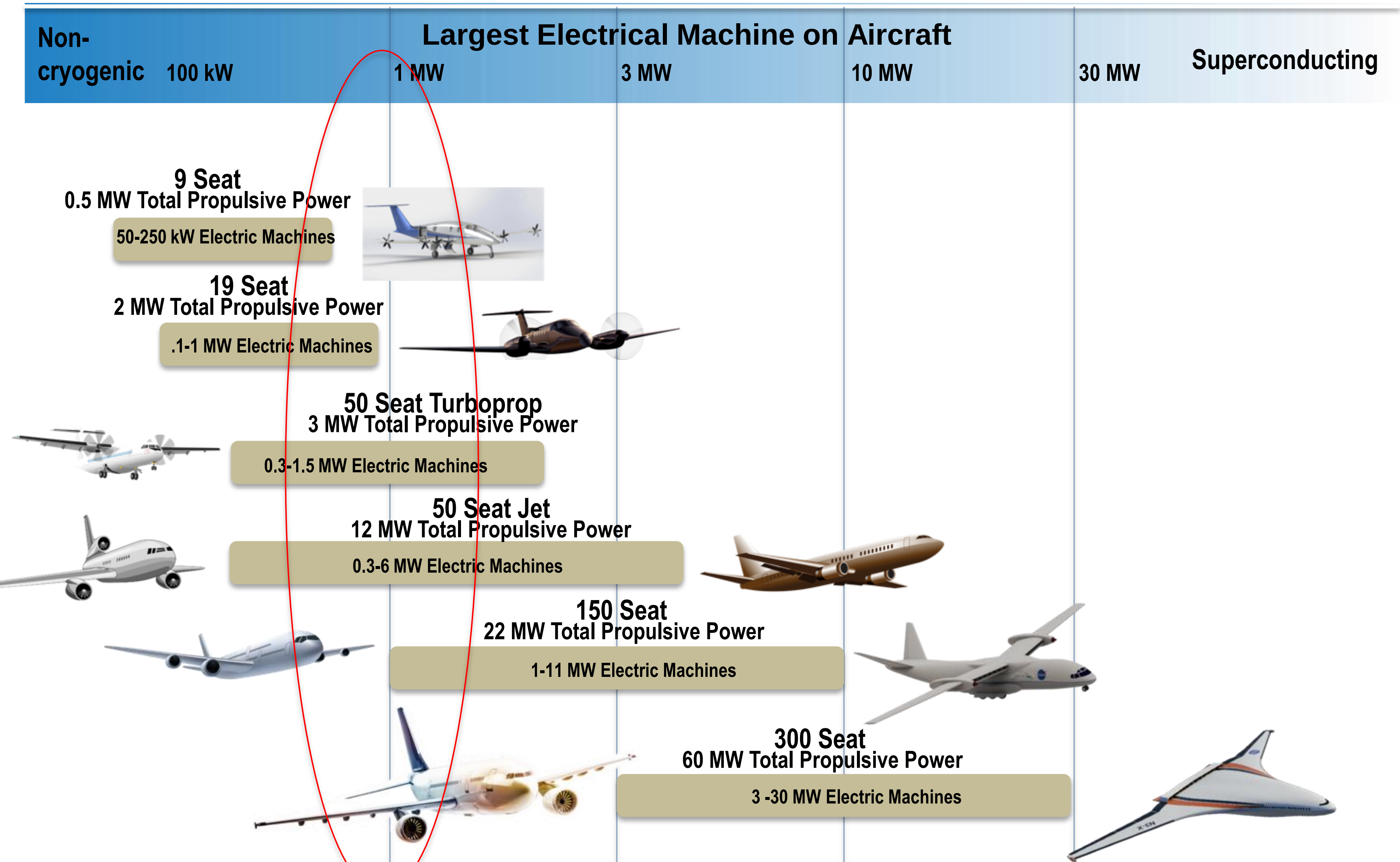


Electromagnetic Components & Materials

Machine Power with Application to Aircraft Class



Propulsion Systems & Conceptual Design

- Parallel Hybrid options studied in detail because podded configurations may allow fleet retro-fit or earlier entry into service
- Single Propulsor Distribution studied to explore minimal airframe modification

	Boeing SUGAR VOLT Cruise Hybrid	UTRC TO / Climb Hybrid	R-R NA Fleet Opt Hybrid	NASA Turboelectric Aft BLI
Study Fidelity / TRL	Detailed analysis down to subsystem	Detailed analysis down to subsystem	Detailed analysis down to subsystem	High level; airframe and prop. system
In-Flight Fuel Saving for 900nm	14%	6%	24%	7%
In-Flight Energy Saving for 900nm	0%	2.5%	7%	7%
In-Flight Emission Reduction	~ 14%	~ 6%	>24%	~ 7%
Noise Reduction Potential	Low, fan stays the same, but ground op. noise reduced with core size	Low, fan stays the same, but ground op. noise reduced with core size	Moderate, noise decrease with reduced fan & core size	Moderate, noise decrease with reduced fan & core size

These studies were performed with independent assumptions. Result comparisons are provided for reference only.

Propulsion Systems & Conceptual Design

Technology development needs determined from configuration studies

- Elucidate challenges associated with electrified propulsion development
- Inform research investments

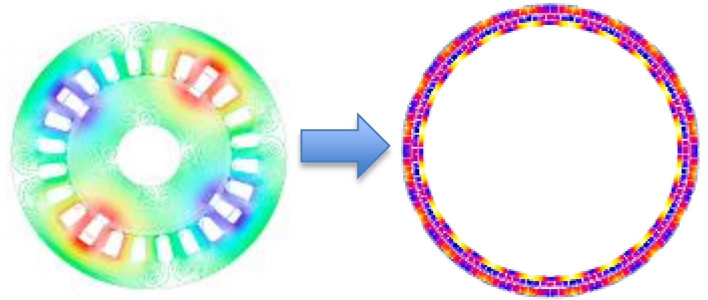
Energy Storage	Electrical Dist.	Turbine Integration	Aircraft Integration
Battery Energy Density	High Voltage Distribution	Fan Operability with different shaft control	Stowing fuel & batteries; swapping batteries
Battery System Cooling	Thermal Mang't of low quality heat	Small Core dev't and control	Aft propulsor design & integration
	Power/Fault Mang't	Mech. Integration	Integrated Controls
	Machine Efficiency & Power	Hi Power Extraction	
	Robust Power Elec.		

Legend		
Parallel Hybrid Specific	Common to both	Turboelectric Specific

Electric Machine Component Development

NASA Sponsored Motor Research

- 1MW
- Specific Power > 8HP/lb (13.2kW/kg)
- Efficiency > 96%
- Awards
  - University of Illinois
  - Ohio State University
- Phase 3 to be completed in 2018



Year 1 Technology Demo. Prototype Motor Parts

NASA In-House Motor Research

- Analytical Studies and Prototype Testing focused on ultra-high efficiency 99%

Electric Machine Component Development

NASA Sponsored Inverter Research

- 1MW, 3 Phase AC output
- 1000V or greater input DC BUS
- Ambient Temperature Awards
  - 3 Years (Phase 1, 2, 3)
  - GE – Silicon Carbide
  - Univ. of Illinois – Gallium Nitride
- Cryogenic Temperature Award
  - 4 years (Phase 1, 2, 3)
  - Boeing – Silicon CoolMOS, SiGe

Ambient Inverter Requirements

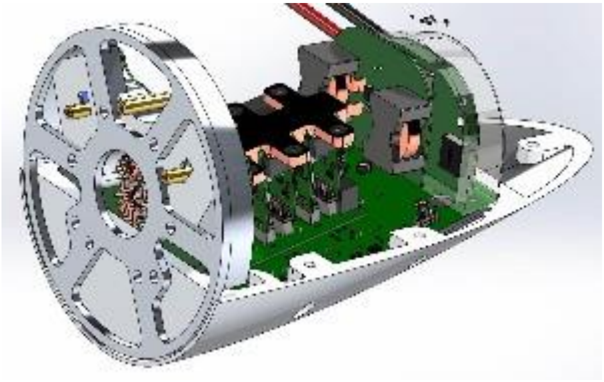
Key Performance Metrics	Specific Power (kW/kg)	Specific Power (HP/lb)	Efficiency (%)
Minimum	12	7.3	98.0
Goal	19	11.6	99.0
Stretch Target	25	15.2	99.5

Cryogenic Inverter Requirements

Key Performance Metrics	Specific Power (kW/kg)	Specific Power (HP/lb)	Efficiency (%)
Minimum	17	10.4	99.1
Goal	26	15.8	99.3
Stretch Target	35	21.3	99.4

NASA In-House Inverter Research

- Designing 14 kW Inverter based on HEIST motor and nacelle cooling and packaging requirements
  - 99% efficiency driven by cooling requirements



Enabling Materials

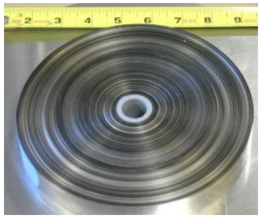
•Use composite materials systems and advanced manufacturing techniques
•Concurrently tailor component materials for hybrid/turbo electric applications *and* design power components that utilize advance materials

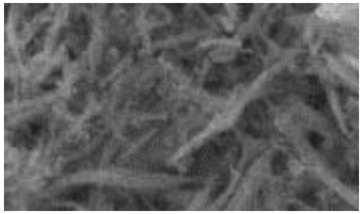
Dielectrics and Insulation
Improve electrical insulation systems
- Study interface functionalization to enable new composite formulations
- Increase both the thermal conductivity and high voltage stability

Nano-crystalline Magnetic Materials
Enable high frequency operation with low electrical losses
- Collaborate with industry and academia to produce nano-crystalline magnetic material
- Perform alloy development and microstructural stability of soft magnetic alloys
- Support power electronic component development using new alloys

High Conductivity Copper
High risk, high pay-off investment in carbon nano-tube (CNT)/copper composites
- Chemical engineered CNT interfaces
- Sorted CNTs to isolate the metallic conducting from semi-conducting
- SBIR investment in new manufacturing techniques

Hi Voltage Dielectric Testing

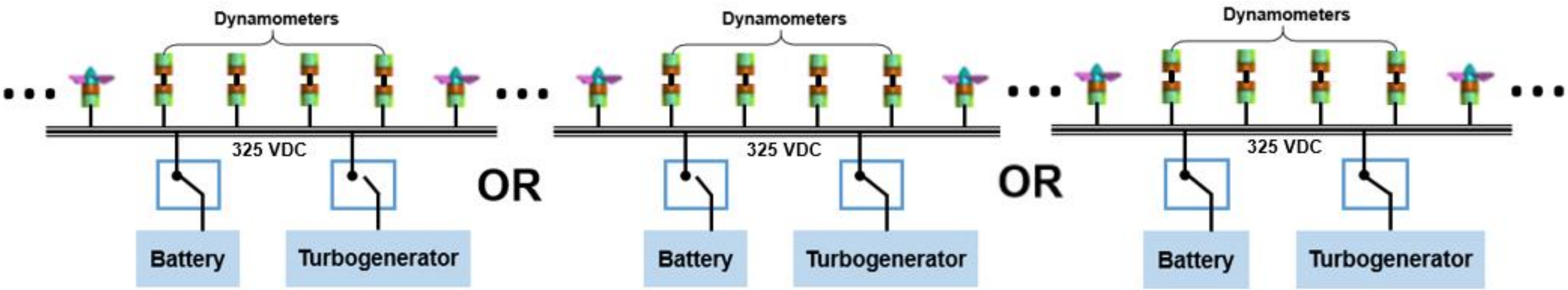

0.75 miles of continuous soft magnetic ribbon


Cu-coated CNT's

Power System Architectures

HEIST: Hybrid Electric Integrated Systems Testbed

Flight controls integrated with Electrified Aircraft Hardware in the Loop

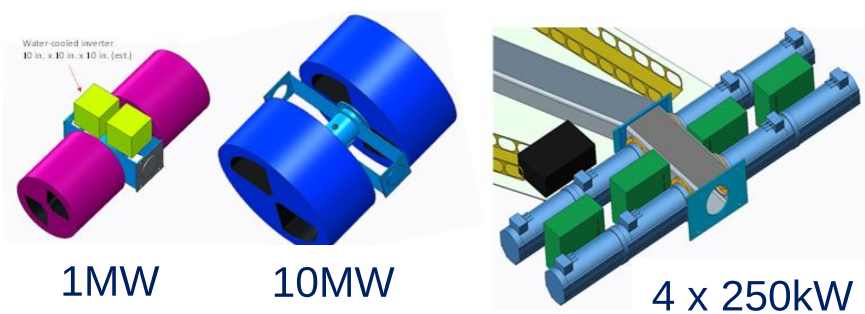


Battery Powered **Turbine Powered** **Hybrid Power Sharing**

NEAT: NASA Electric Aircraft Testbed

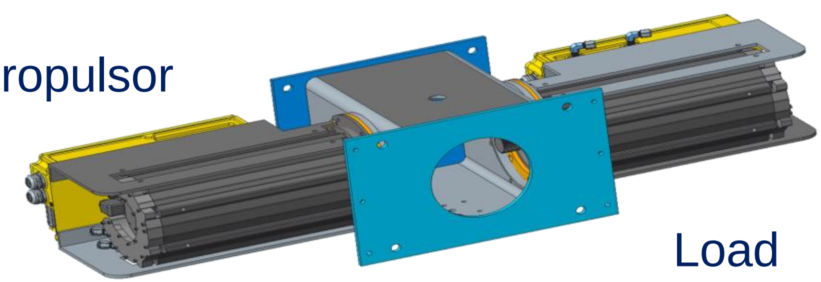
High power ambient and cryogenic flight-weight power system testing

Designed for modularity



1MW 10MW 4 x 250kW

Propulsor



Load

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Convergent Aeronautics Solutions Project
Aircraft Hybrid Electric Propulsion Activities

- **M-SHELLS – Multifunctional Structures for High Energy Lightweight Load-bearing Storage**
  - Integrates hybrid battery/supercaps into aircraft structure to increase effective specific power & specific energy
  - Converges advanced electrochemistries, microstructures, manufacturing, and nano-technologies
- **LION – Integrated Computational-Experimental Development of Li-Air Batteries for Electric Aircraft**
  - Investigates "electrolyte engineering" concepts to enables Li-Air batteries with high practical energy densities, rechargeability and safety
  - Converges advances in predictive computation, material science, and fundamental chemistry
- **HVHEP – High Voltage Hybrid Electric Propulsion**
  - Variable-frequency AC, kV, power distribution with DFIM machines for multi-MWe DEP applications
  - Minimizes constituent weights of power electronics, TMS, and fault protection
- **Compact High Power Density Machine Enabled by Additive Manufacturing**
  - 2 to 3x increase in specific power of electric machines for DEP enabled by additive manufacturing
  - Compact, lightweight motor designs/topologies, integrated cooling, and multi-material systems/components.
- **DELIVER – Design Environment for Novel Vertical Lift Vehicles – cryo-cooling HEP task**
  - Maximizing efficiency and power density of electronic components by cryogenic LNG-fuel cooling
  - Longer-range hybrid/electric UAS with reduced fuel-burn and emissions (CO2, sulfur, particulates)
- **FUELEAP – Fostering Ultra-Efficient, Low-Emitting Aviation Power**
  - GA aircraft / early-adopter application of JP-fueled SOFC power plant for clean, hybrid/electric architecture
  - Zero NOx electric power production at ~2x typical combustion efficiencies
- **SCEPTOR – Scalable Convergent Electric Propulsion Technology and Operations Research**
  - Seeks 5x reduction in cruise-energy-use by aerodynamic benefits of DEP & batteries in place of engines
  - DEP enables high efficiency wing & high performance wingtip motors for cruise

SCEPTOR X-57 Research Objectives

NASA SCEPTOR Primary Objective

- Goal: 5x Lower Energy Use (Comparative to Retrofit GA Baseline @ 150 knots)
  - Motor/controller/battery conversion efficiency from 28% to 92%   (3.3x)
  - Integration benefits of ~1.5x (2.0x likely achievable with non-retrofit)

NASA SCEPTOR Derivative Objectives

- ~30% Lower Total Operating Cost (Comparative to Retrofit GA Baseline)
- Zero In-flight Carbon Emissions

NASA SCEPTOR Secondary Objectives

- 15 dB Lower community noise (with even lower true community annoyance).
- Flight control redundancy, robustness, reliability, with improved ride quality.
- Certification basis for DEP technologies.