A NASA Perspective on 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

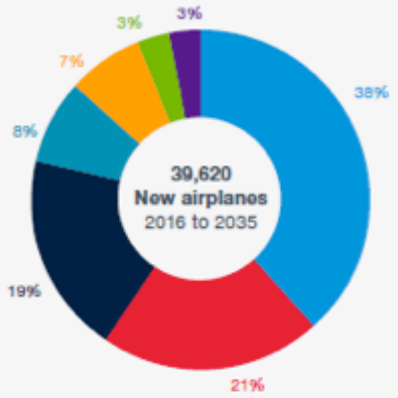
U.S. leadership for a new era of flight

Global Growth in Aviation

Tremendous opportunities
- Huge demand
- $5.9T market over next 20 years
- Need for speed

But stakes are high
- Competitiveness
- Environment
- Mobility
- Safety

Delivery demand is diverse

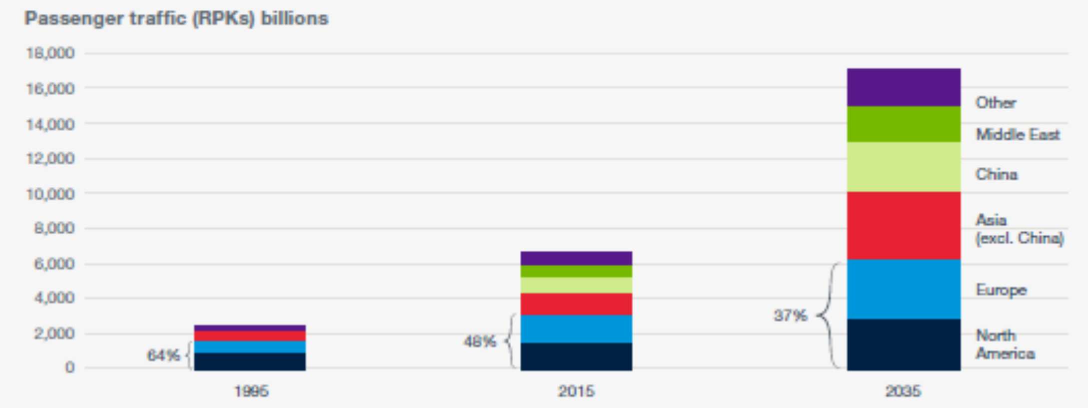


Region	New airplanes
Asia	15,130
North America	8,330
Europe	7,570
Middle East	3,310
Latin America	2,960
Africa	1,150
CIS	1,170
Total	39,620

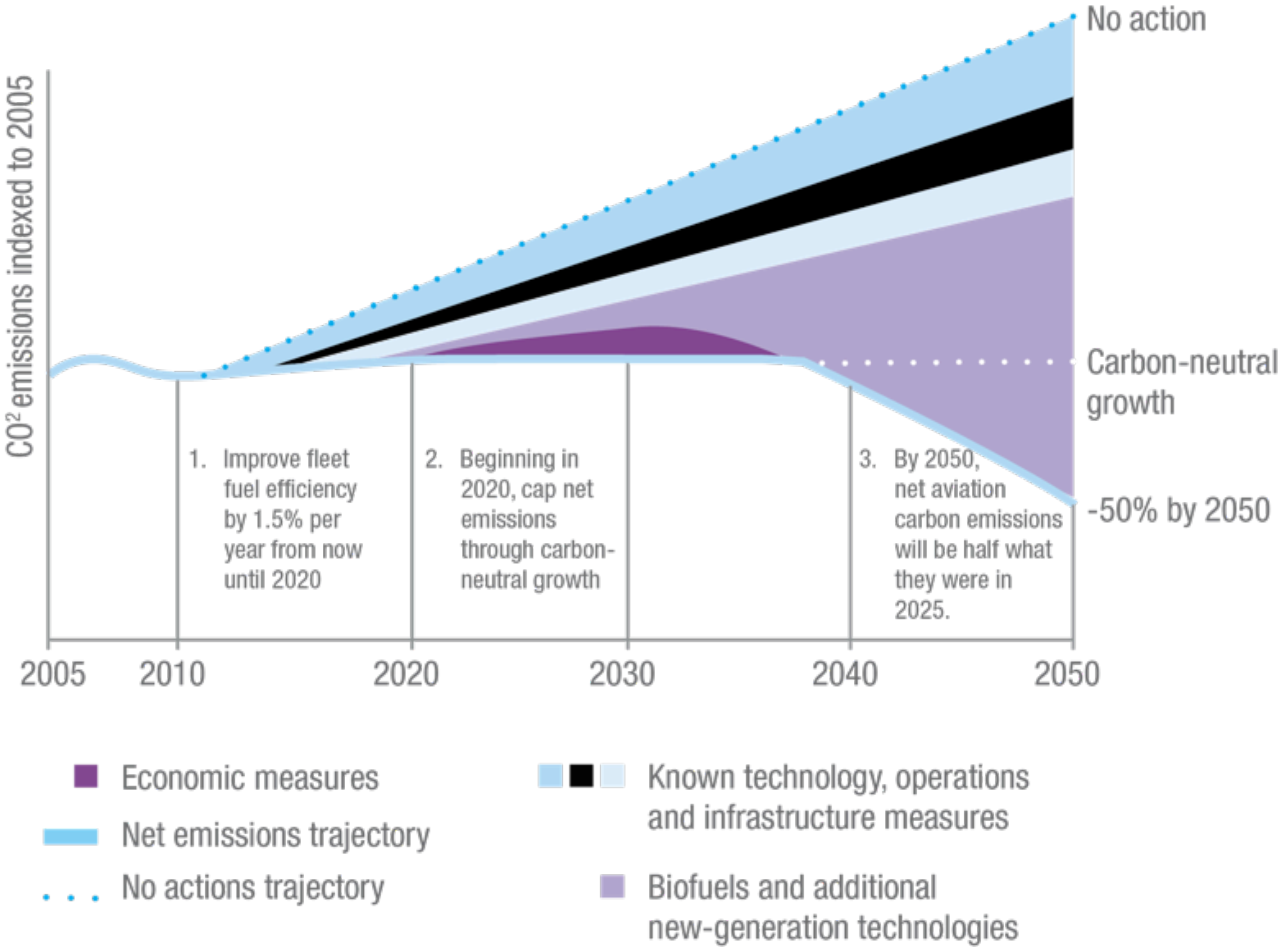
Over 39,000 New Aircraft required (replacement and growth) over the next 20 year period ($5.9T)

Growth in Airline passenger traffic at annual rate of 4.8%, and Air Cargo traffic at 4.2% over the next 20 years

Air travel becoming more diverse geographically



The Aviation Grand Challenge: Cutting Carbon



Source: http://aviationbenefits.org/environmental-efficiency/aviation-and-climate-change/our-climate-plan/

NASA Perspective on Electrified Aircraft Propulsion

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

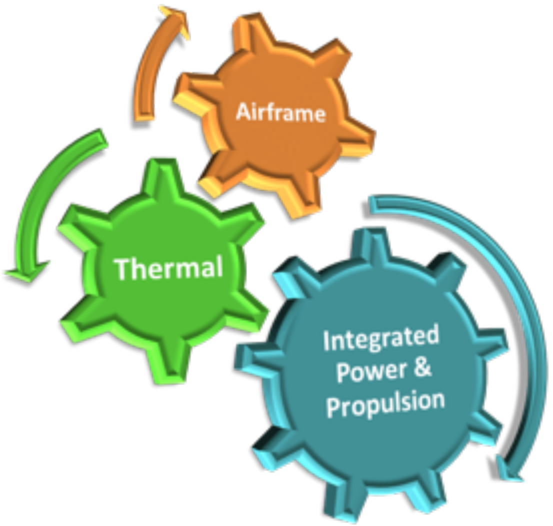
Promise of cleaner, quieter systems

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 aircraft



Address Key Challenges

Electrical system weight

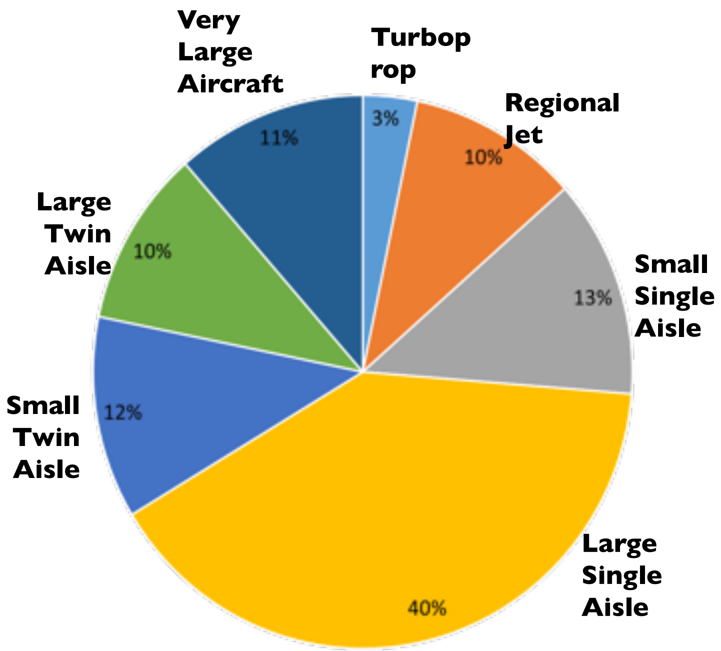
Energy storage capabilities

Thermal management

Flight controls

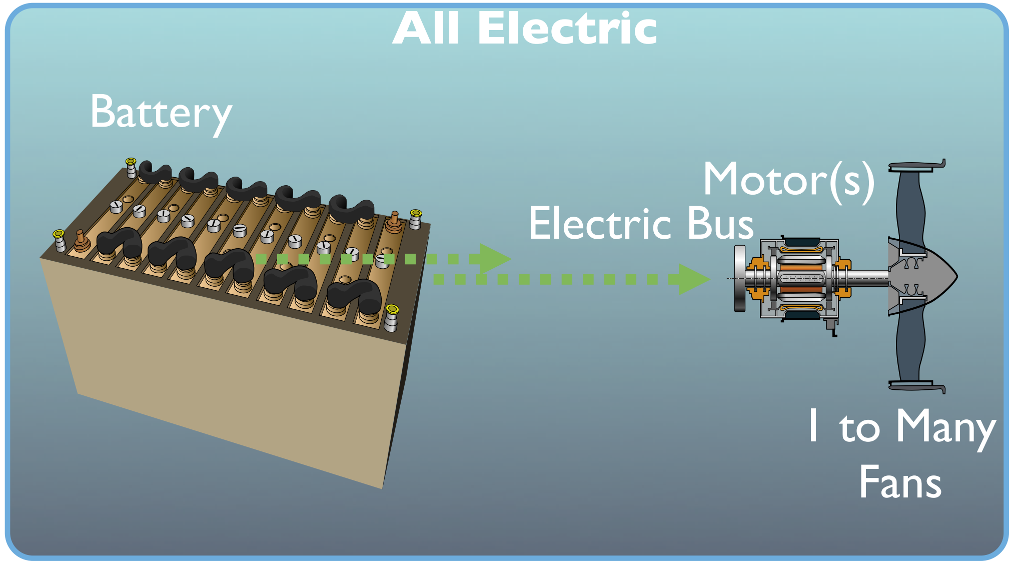
Safety

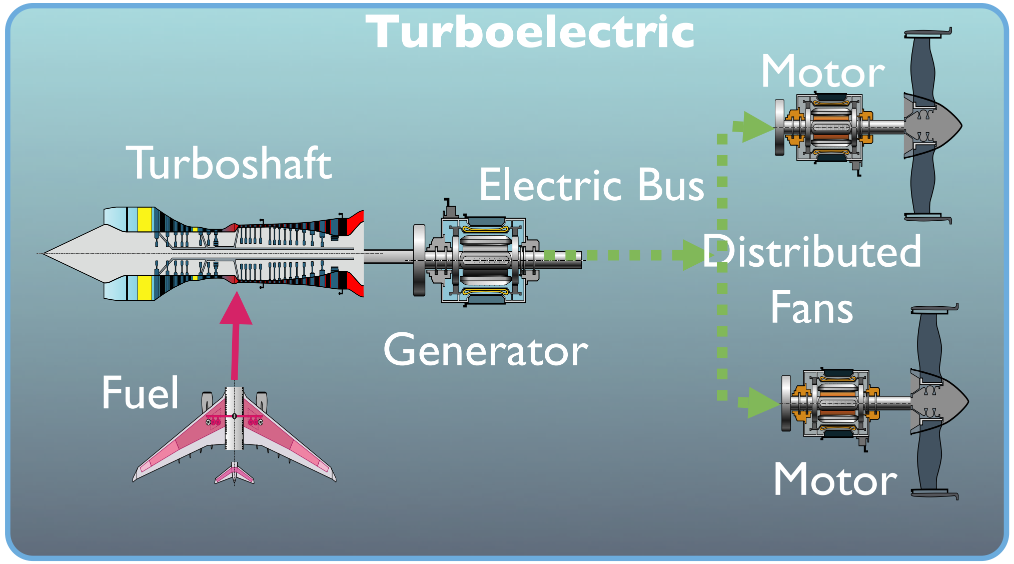
Certification

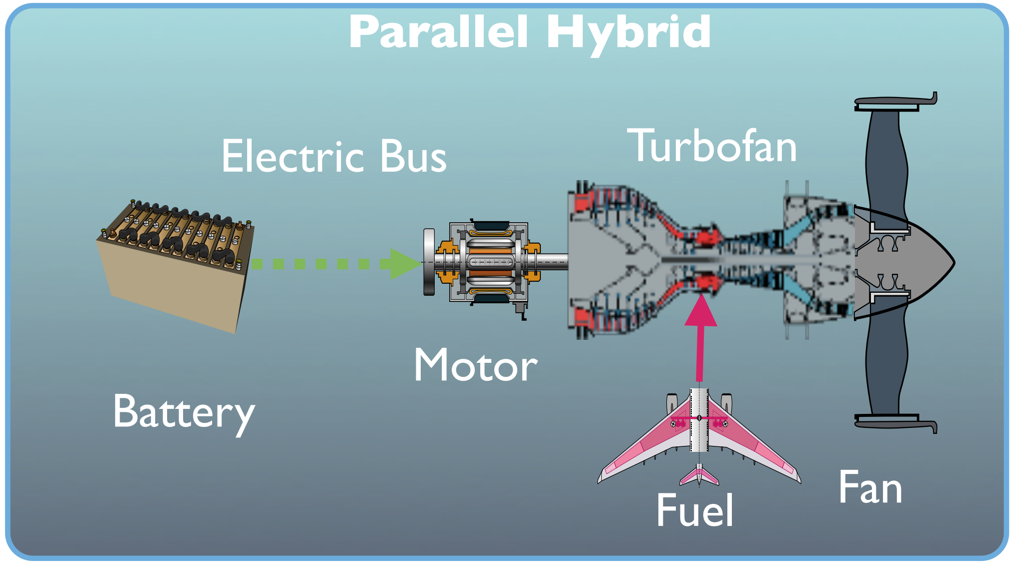


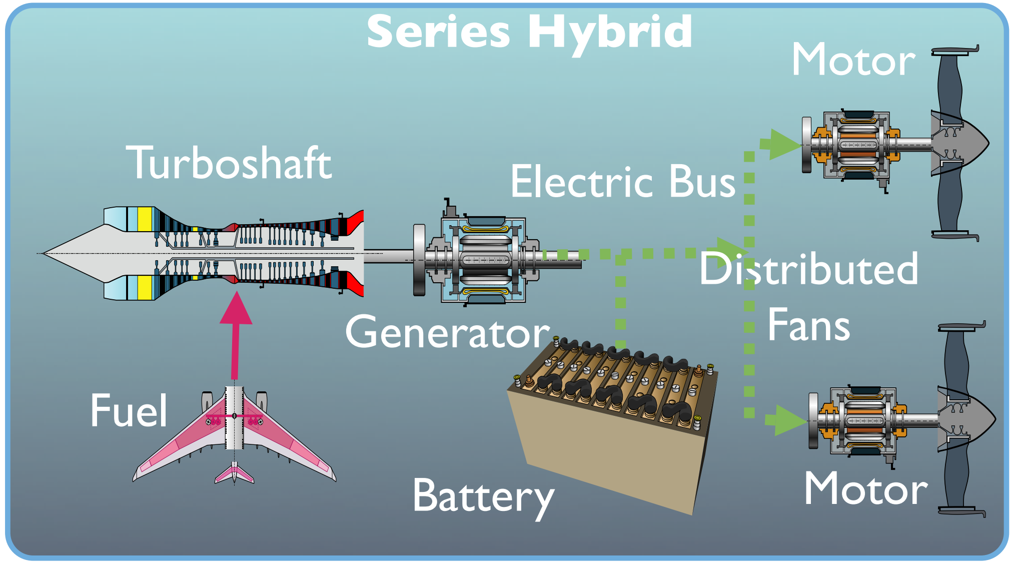
2012 Fuel Consumption, FAA US Operations Data. Analysis by H Pfaender, GA Tech

Four Cardinal Electric Propulsion Architectures



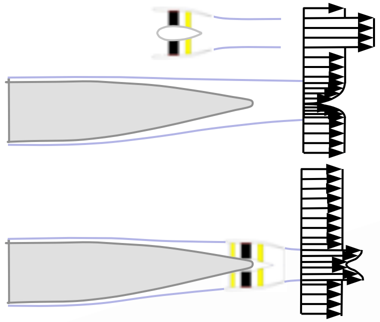




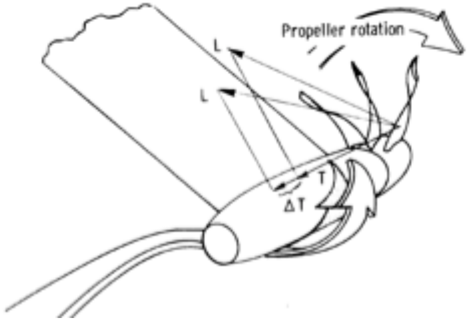


Electrified Propulsion Enables Exciting Configuration Options

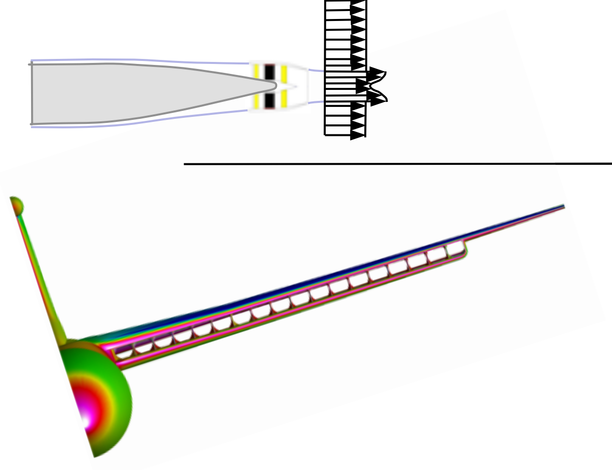
Boundary Layer Ingestion: Allows propulsion systems to energize boundary layers without distorted flow entering turbine core



Wing Tip Propulsors: Allows energization of wing tip vortices without penalty of small turbomachinery



Common Technology Requirement: *Increased efficiency and specific power in electric drive systems, thermal management systems, power extraction, and/or energy storage*

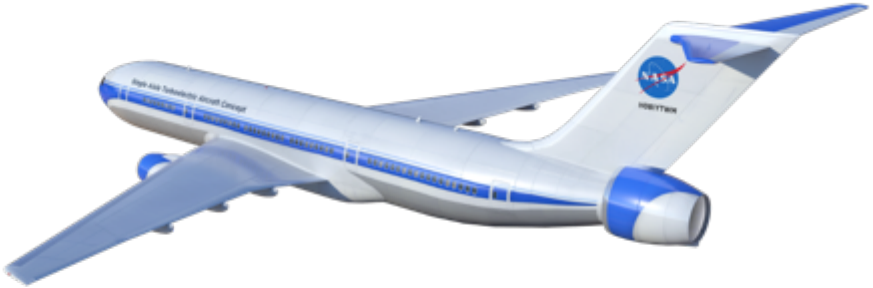


Distributed Propulsion: Allows effective increase in fan bypass ratio through distributed propulsors

Lower Carbon Designs: Reduces combustion-based propulsive power (and emissions) using electric motors and/or on-board "clean" energy storage

Potential Future Aircraft Concepts

Boeing Sugar Volt



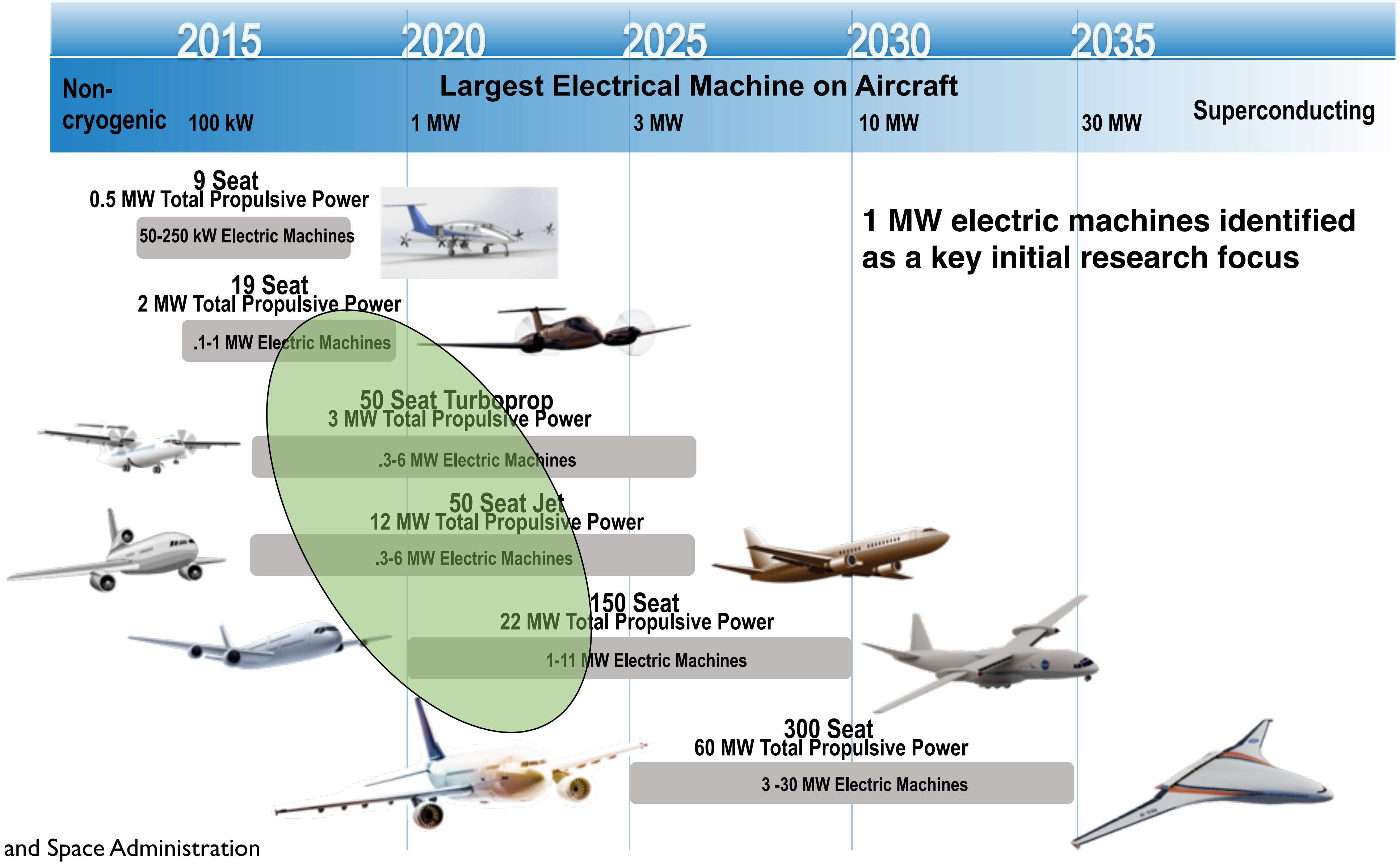
NASA STARC-ABL

ESAero ECO-150

NASA N3X

Airbus/Rolls-Royce eThrust

Timeline of Machine Power with Application to Aircraft Class

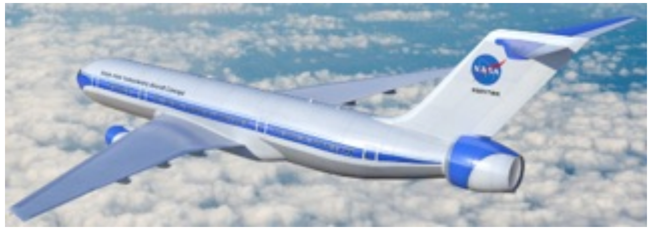


NASA Roadmap for Electrified Aircraft Propulsion

NASA Electrified Aircraft Propulsion R&T Investments

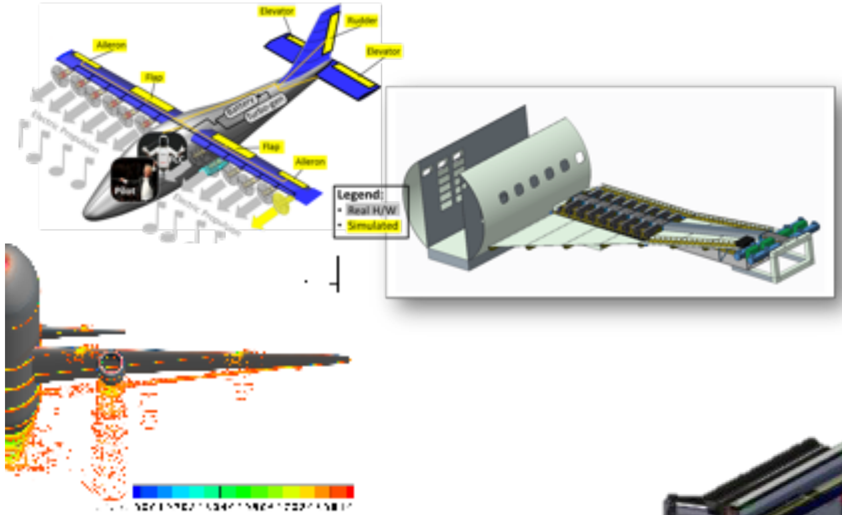
Technology development targeted toward large commercial aircraft

- 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

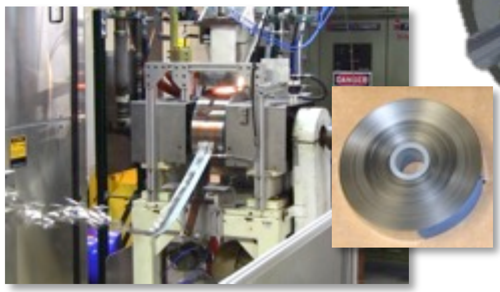


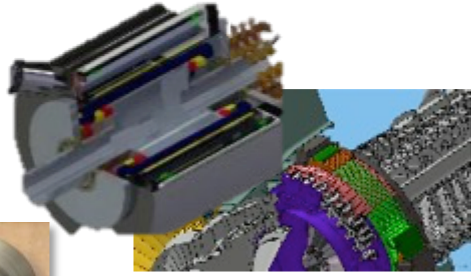
Exploring tube-and-wing architectures

Powertrain, Controls and Flight Simulation Testbeds and Advanced CFD



Advanced Materials and Novel Designs for Flightweight Power

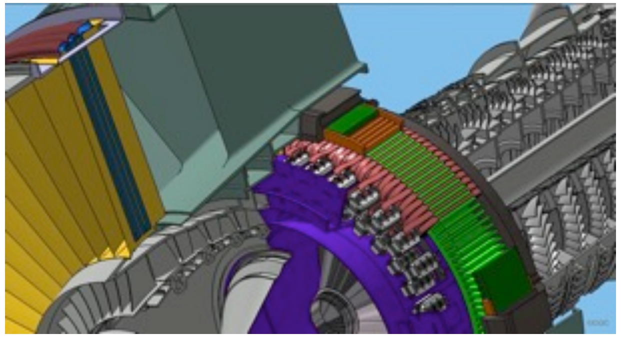




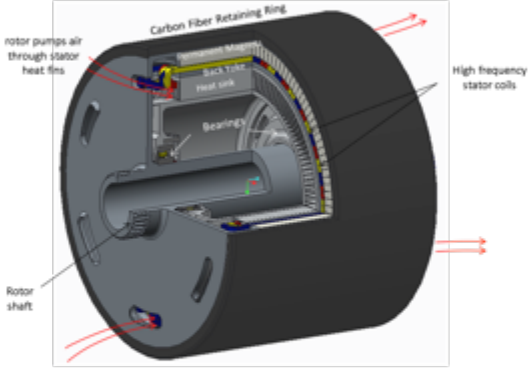
Superconducting and Ambient Motor Designs

High Efficiency, High Specific Power Electric Machines

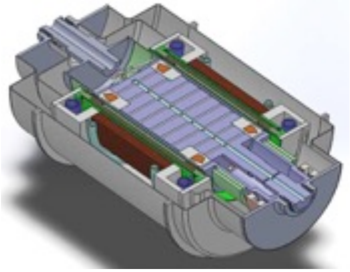
- Develop both conventional (near-term) and cryogenic, superconducting (long-term) motors
- Design and test scalable high efficiency and power density (96%, 8 hp/lb) 1 MW non-cryogenic motor for aircraft propulsion in collaboration with
  - Ohio State U
  - U of Illinois, UTRC, Automated Dynamics
- Reduce AC losses and enable thermal management for SC machines: models and measurement techniques, SC wires, flight-weight cryo-coolers
- Design and test fully superconducting electric machine test at 1 MW design level in FY17-18
  - Collaboration with Navy, Air Force, Creare, HyperTech, Advanced Magnet Lab, U of FL
  - Detailed concept design completed of 12MW fully superconducting machine achieving 25 hp/lb
- Develop materials and manufacturing technologies



Ohio State U Motor Design



U of Illinois Motor Design



Fully superconducting motor

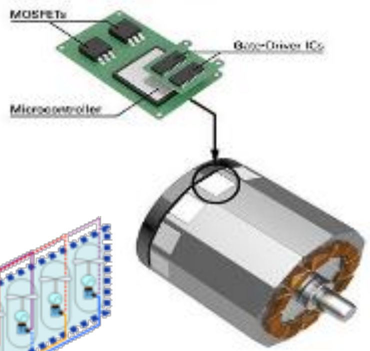
Flight-Weight Power Management and Electronics

- Multi-KV, Multi-MW power system architecture for aircraft applications
- Power management, distribution and control at MW and subscale (kW) levels
- Integrated thermal management and motor control schemes
- Flightweight conductors, advanced magnetic materials, and insulators
- Collaborations with GE Global Research, Boeing, U of Illinois on flight-weight 1 MW inverters

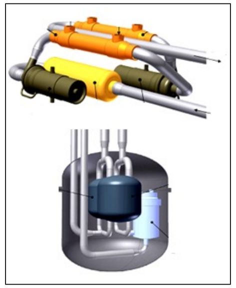
Superconducting transmission line

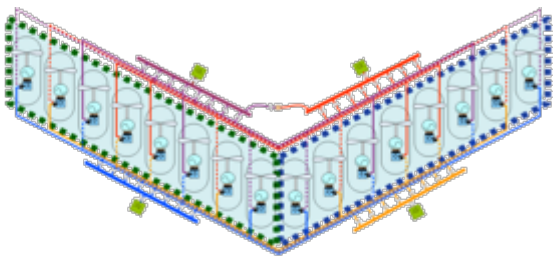
Lightweight power transmission

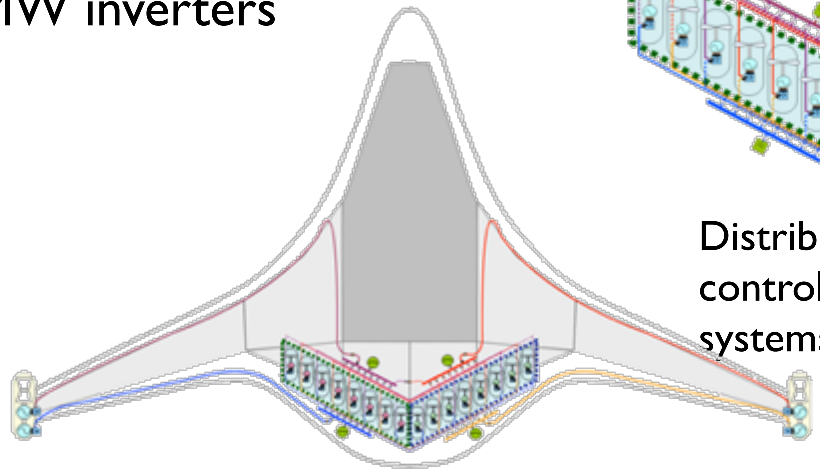
Integrated motor with high power density power electronics



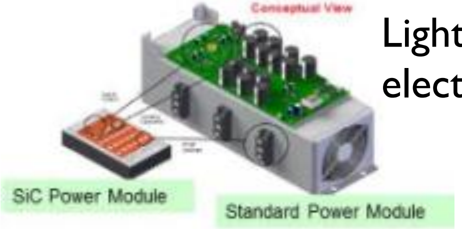
Lightweight Cryocooler







Distributed propulsion control and power systems architectures

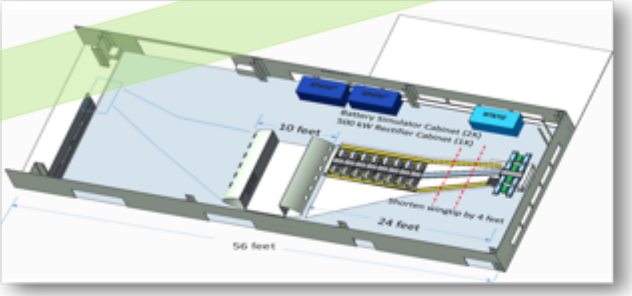


Lightweight power electronics

Integrated System Testing

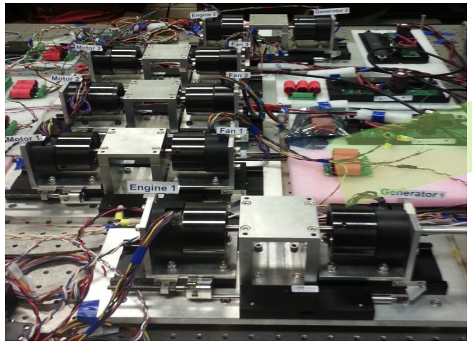
- Study steady-state and transient component operation and interactions
- Validate power system benefit predictions
- Develop flight control methodology for distributed propulsion
- Integrate power, controls, and thermal management into system testing

Flight Simulator – Flight Dynamics



NEAT 2MW Configurable Power Testbed

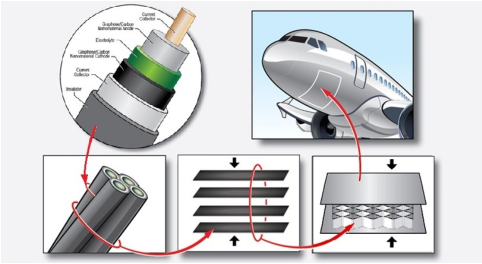
HEIST 200kW Ironbird Flight Simulation Hardware in the Loop

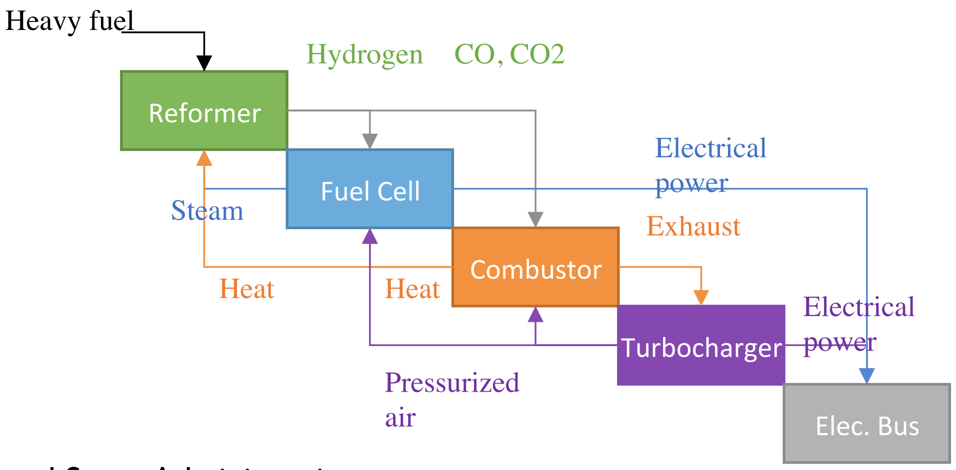


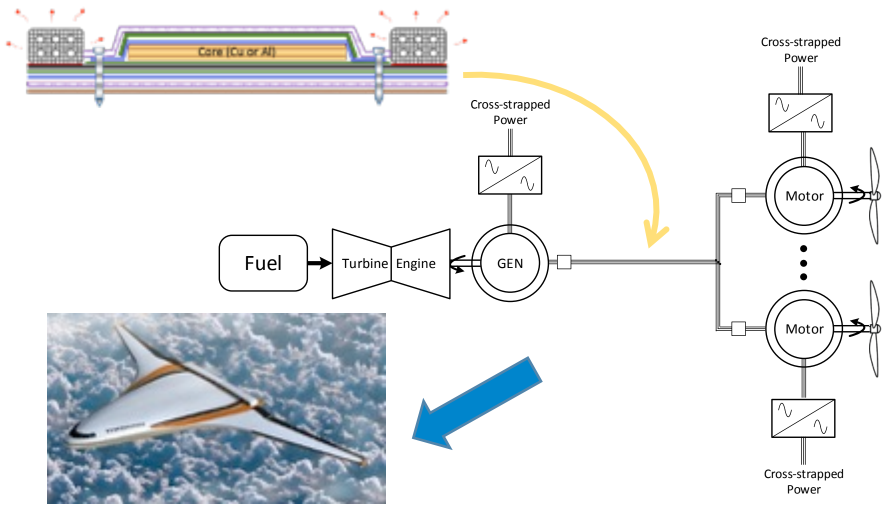
Software/Hardware emulation hardware-in-the-loop electrical grid

Other Related NASA HEP R&T Investments

- Scalable Convergent Electric Propulsion Technology Operations Research (SCEPTOR)
- Multifunctional Structures for High Energy Lightweight Load-Bearing Storage (M-SHELLS)
- High Voltage Hybrid Electric Propulsion
- Heavy Fuel Hybrid-Electric SOFC for Airborne Applications







The Path Forward…

- Focus on future single-aisle twin engine and large regional jets
- Viable concepts with net reduction in energy use
- Core technology development: turbine-coupled motors, generators, power system architectures, power electronics, thermal management, flight controls
- Modeling/Simulation tools for propulsion, vehicle, electrical, and flight control systems
- Technology demonstrations of components, subsystems, and systems

Exciting times ahead!

NASA New Aviation Horizons: Back to Building X-Planes

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