National Aeronautics and Space Administration

A NASA PERSPECTIVE ON ELECTRIC PROPULSION TECHNOLOGIES FOR COMMERCIAL AVIATION

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NASA Aeronautics Vision for the 21st Century

6 Strategic Thrusts

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

Innovation in Commercial Supersonic Aircraft
Achieve a low-boom standard

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

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

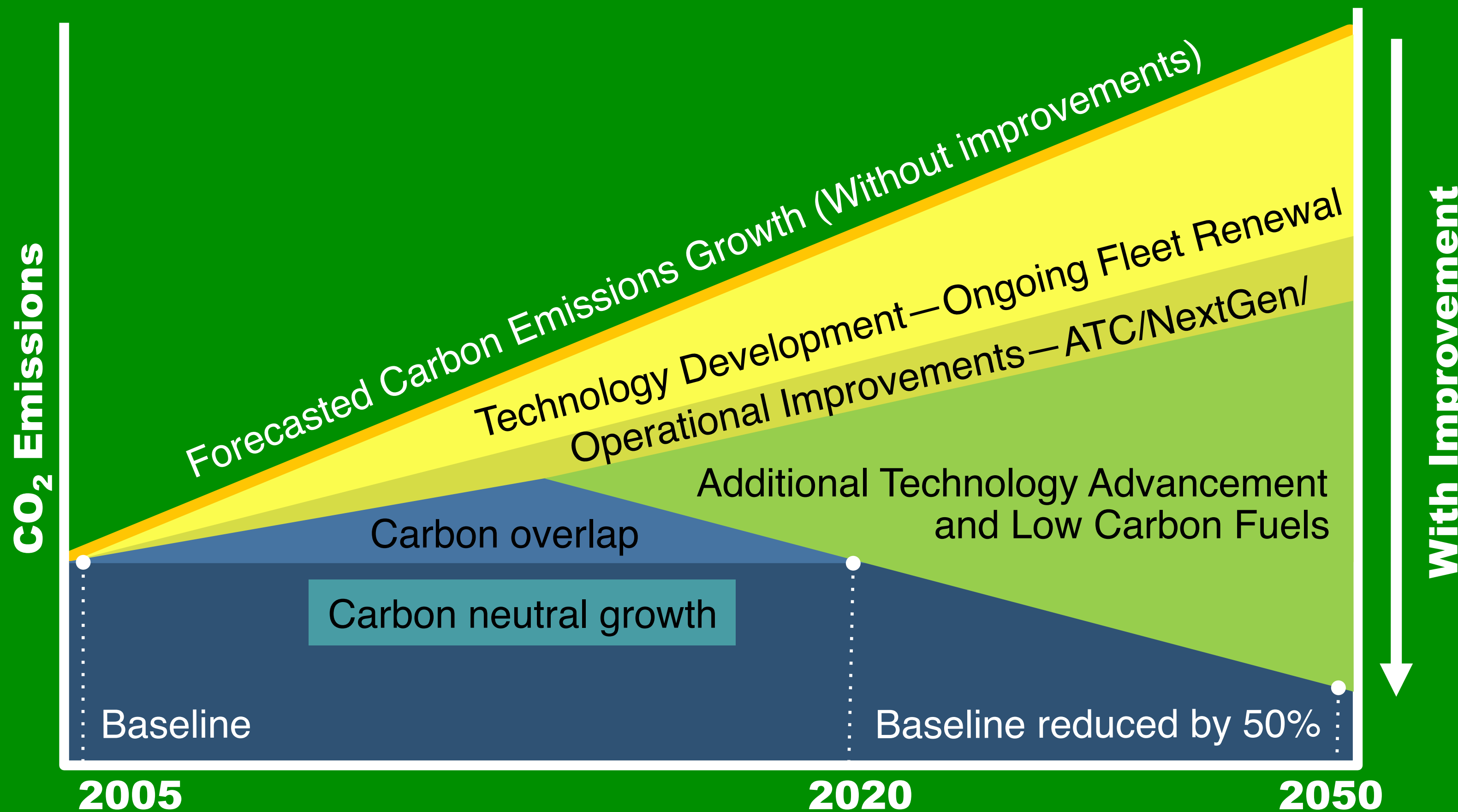
Real-Time System-Wide Safety Assurance
Develop an integrated prototype of a real-time safety monitoring and assurance system

Assured Autonomy for Aviation Transformation
Develop high impact aviation autonomy applications

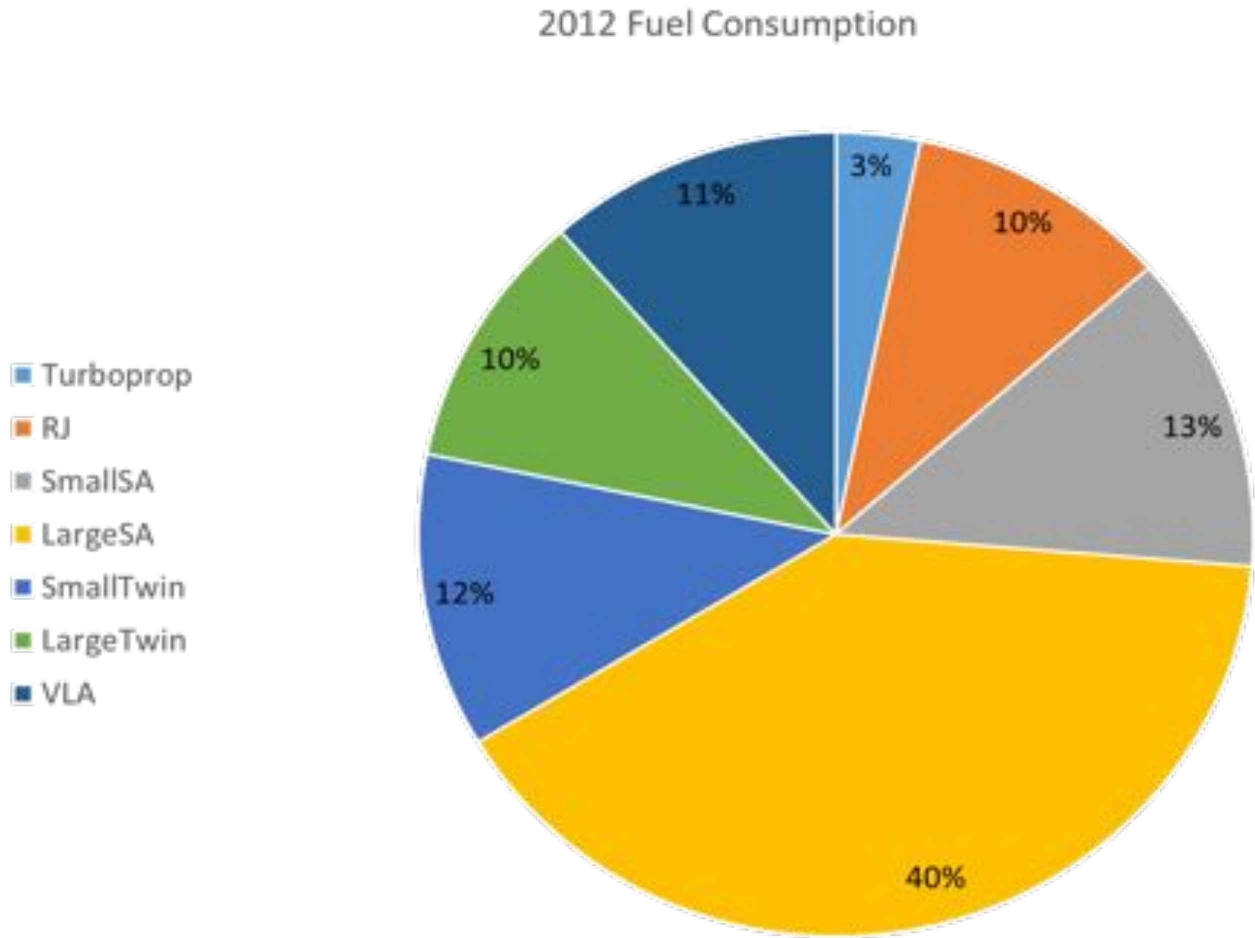
U.S. leadership for a new era of flight

Motivation: Addressing Aviation's Grand Challenge

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



Why Focus on Commercial Transports?



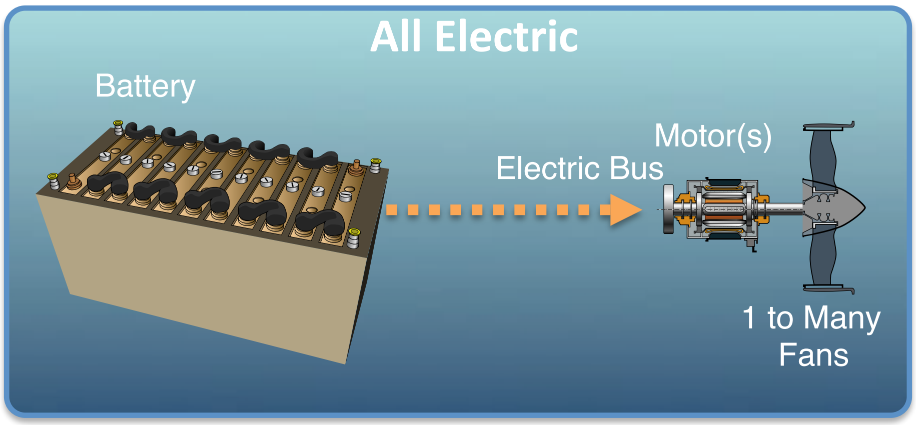
40% of fuel use is in 150-210 pax large single aisle class
87% of fuel use is in small single-aisle and larger classes (>100 pax)
13% of fuel use is in regional jet and turboprop classes

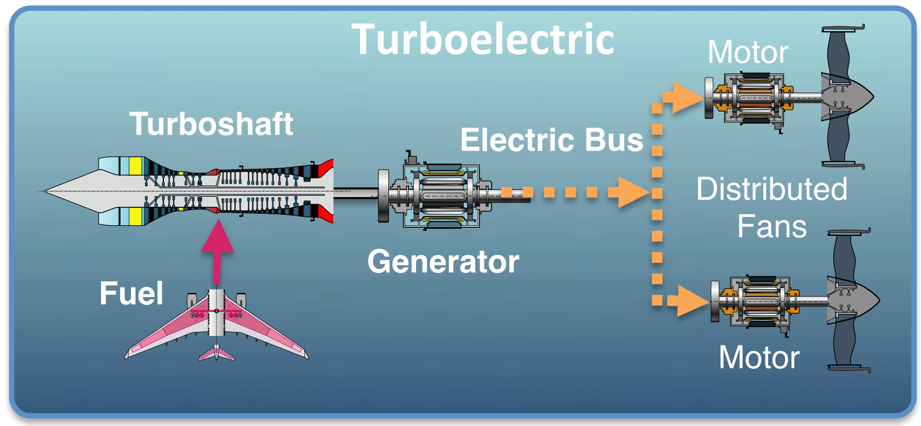
Analysis based on FAA US operations data provided by Holger Pfaender of Georgia Tech

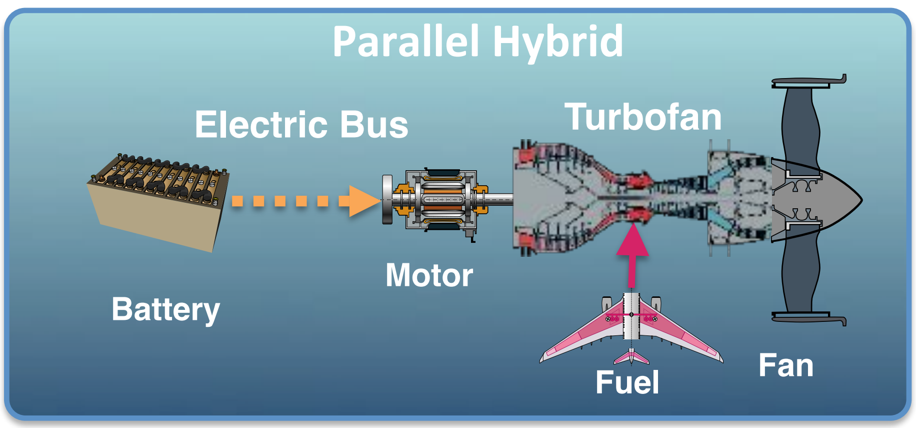
Why Hybrid Electric Propulsion?

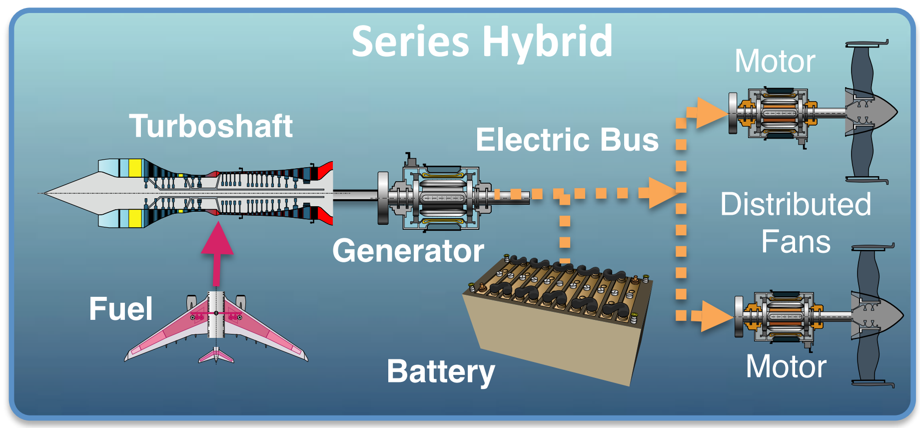
- Lower emissions, noise, and fuel burn
- Considerable recent success in all-electric UAVs and GAs
- Promising aircraft and propulsion systems identified in NASA-commissioned N+3/N+4 advanced concept studies
- Industry roadmaps acknowledge need to shift to electric technologies
- Creative ideas and technology advances needed
- NASA in collaboration with partners can help accelerate key technologies

Four Cardinal Electric Propulsion Architectures



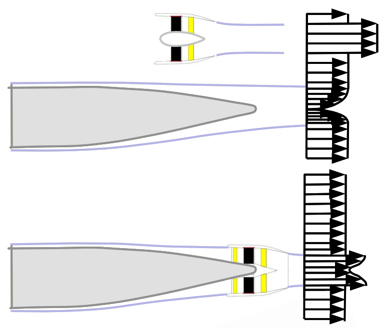




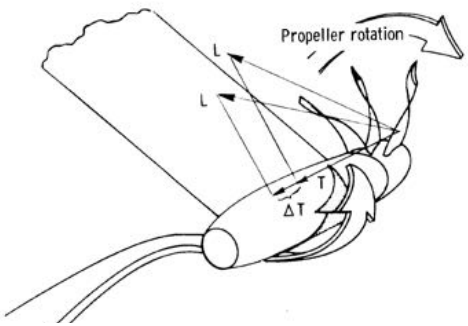


Hybrid Electric Propulsion Enables Exciting Configuration Options

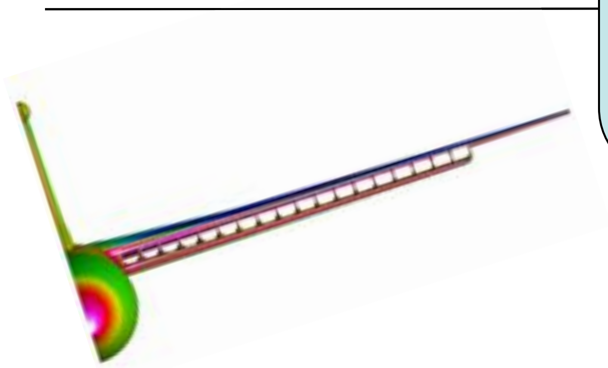
Boundary Layer Ingestion: Allows propulsion systems to energize boundary layers without distorted flow entering turbine core



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

Future Turboelectric Aircraft Concepts


ESAero ECO-150

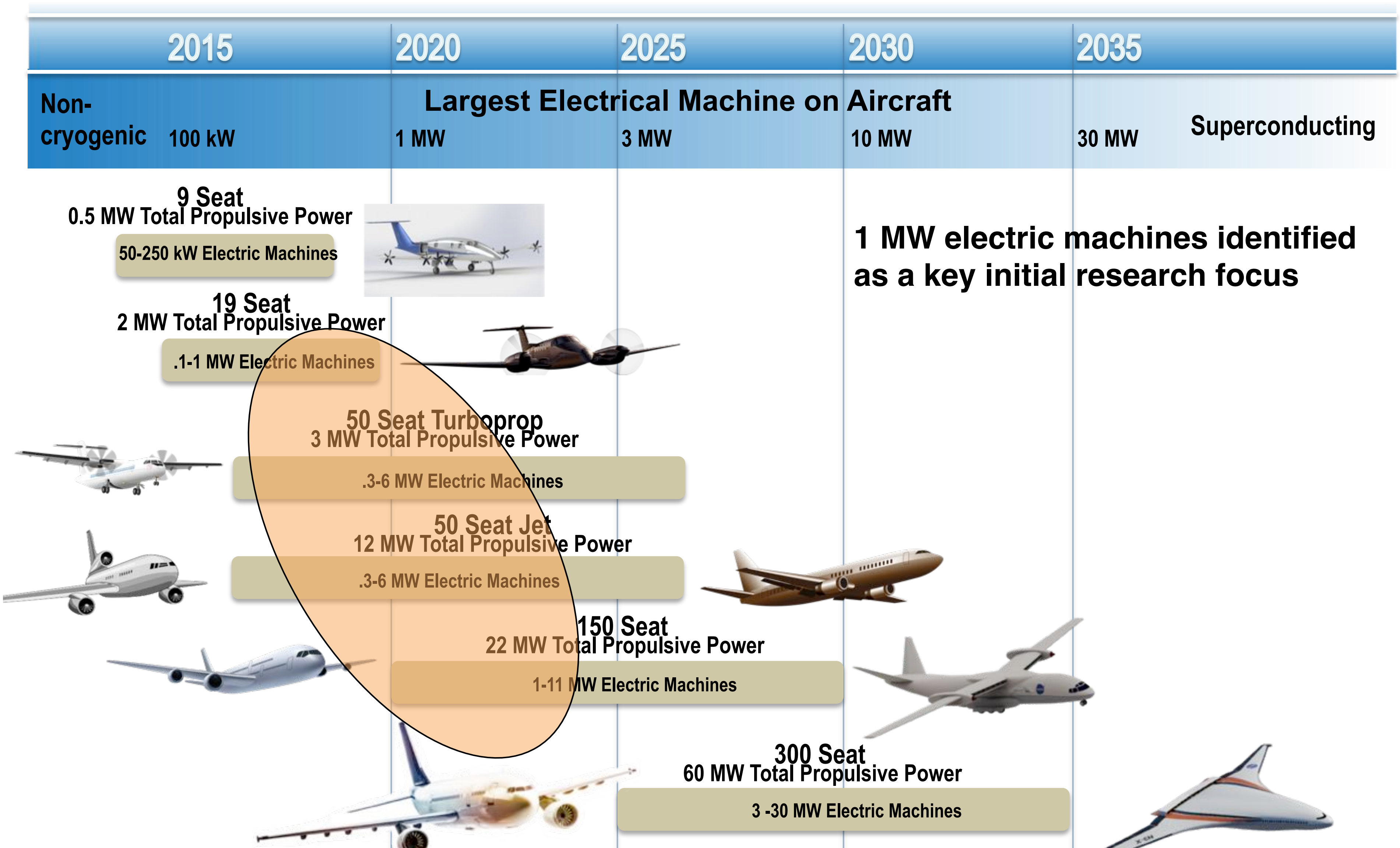

NASA N3X


Airbus/Rolls-Royce eThrust

NASA HEP Perspective for Commercial Aviation

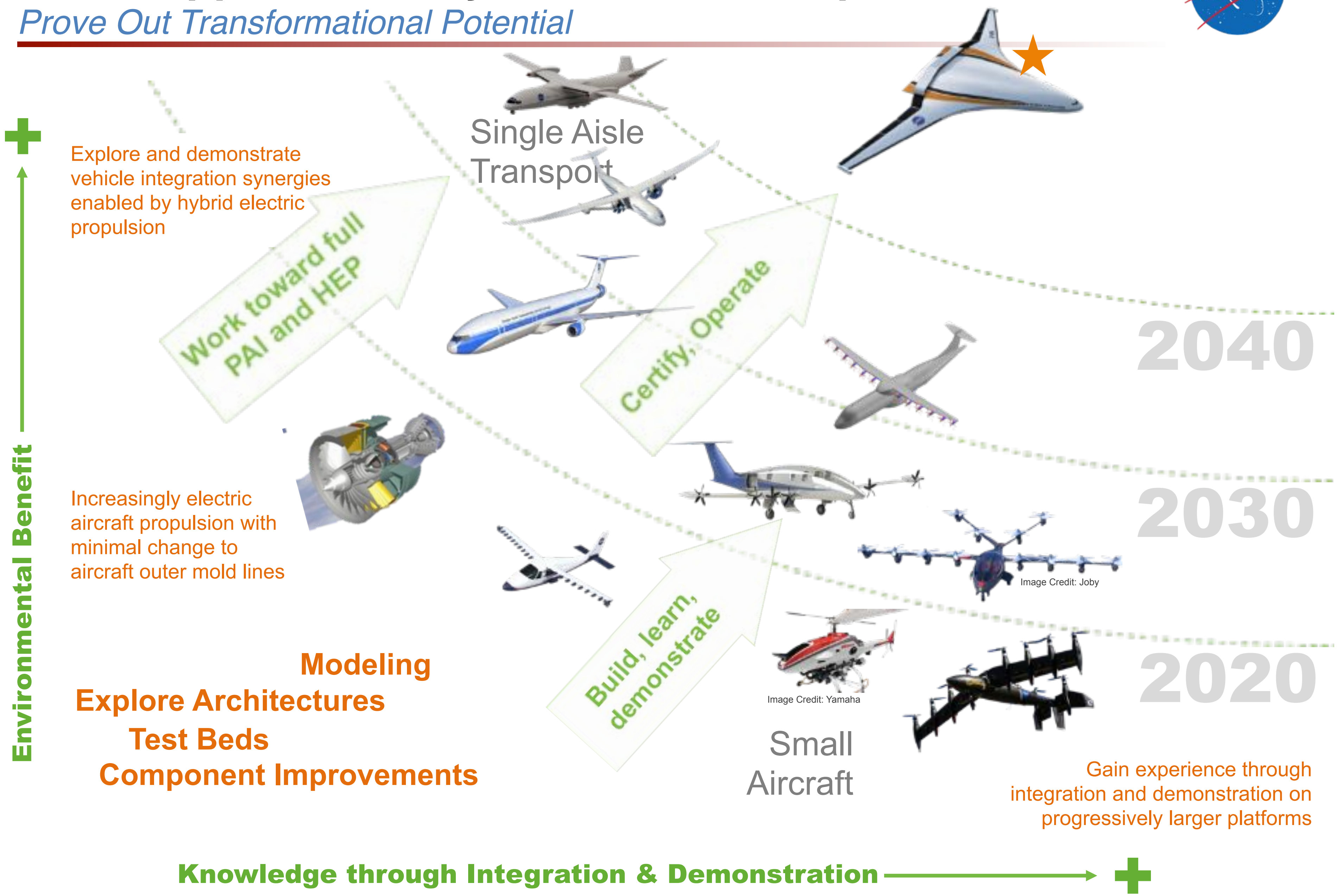
- Revolutionize commercial aviation by enabling radically different propulsion systems that can meet national energy and environmental goals
- Accelerate development of all-electric aircraft architectures
- Focus on future single-aisle twin(Boeing 737-class) and large regional jet aircraft for greatest impact
- Focus on hybrid-electric technologies since all-electric propulsion for large transports unlikely in N+3 time horizon
- Long-term research horizon with periodic spinoff potential
- Leverage investment in efficiency improvements in energy and other sectors
- Aviation application requirements unique

Timeline of Machine Power with Application to Aircraft Class



NASA Approach to Hybrid Electric Propulsion

Prove Out Transformational Potential



Hybrid Electric Propulsion Challenges

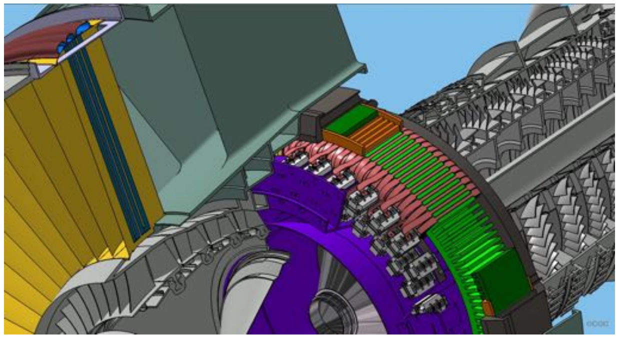
- **Weight**
- **Heat**
- **Safety**
- **Reliability**
- **Certification**

NASA Hybrid Electric Propulsion Research Themes

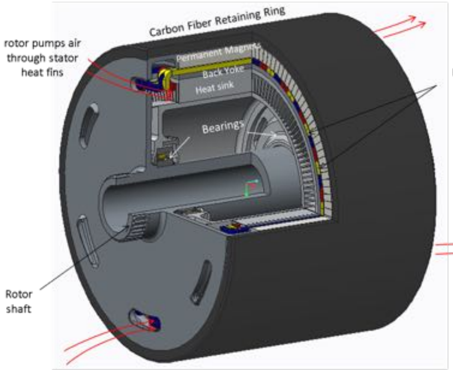
- Integrated Technology Concepts (Vehicle / Synergy)
- Power and Propulsion Architectures
- HEP Components / Enablers / Materials
- Modeling, Simulation, and Test Capability

High Efficiency, High Specific Power Electric Machines

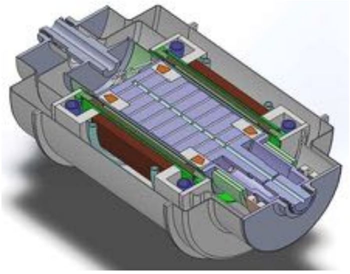
- Develop both conventional (near-term) and cryogenic, superconducting (long-term) motors
- Design and test scalable high efficiency and power density (96%, 8 hp/lb) 1 MW non-cryogenic motor for aircraft propulsion in collaboration with
    - Ohio State U
    - U of Illinois, UTRC, Automated Dynamics
- 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 Design



Fully superconducting motor

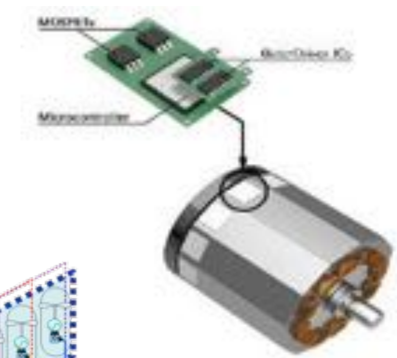
Flight-Weight Power Management and Electronics

- 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

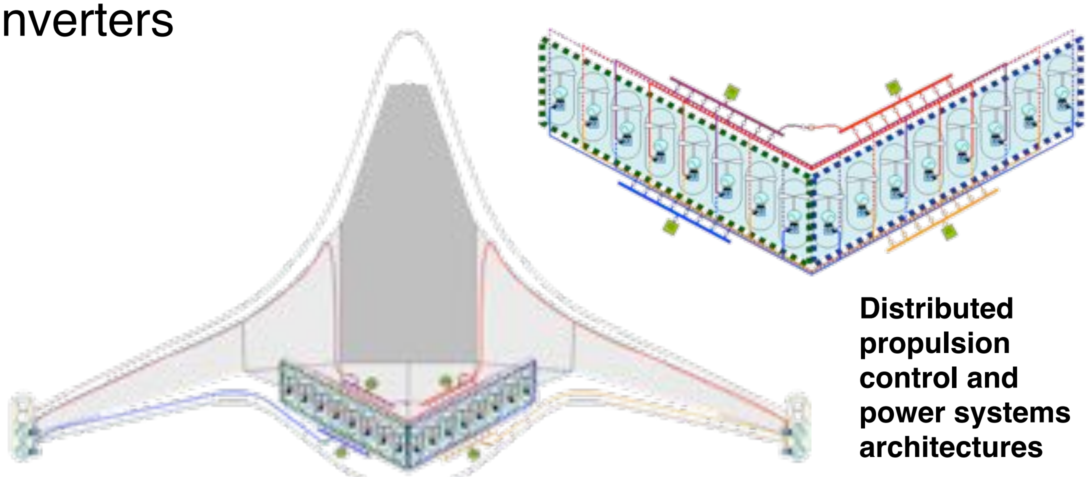
Superconducting transmission line

Lightweight power transmission

Integrated motor with high power density power electronics

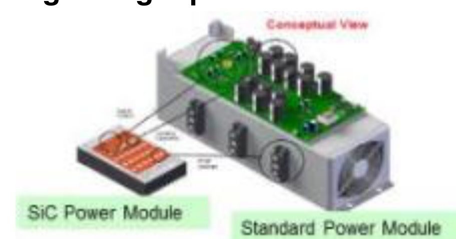


Lightweight Cryocooler



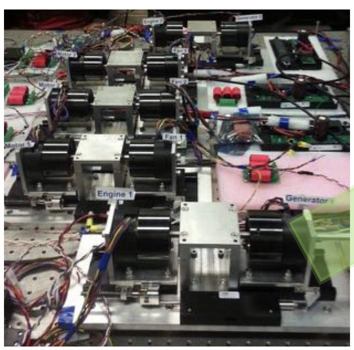
Distributed propulsion control and power systems architectures

Lightweight power electronics



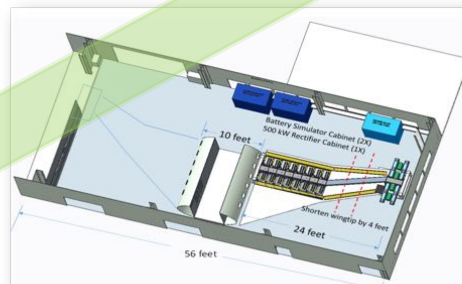
Integrated System Testing

- Study components and interactions to validate performance and matching at steady-state and transient operation
- Validate power system benefit predictions
- Develop flight control methodology for distributed propulsion
- Integrate power, controls, and thermal management into system testing



NASA-GRC PEGS
Software/Hardware emulation hardware-in-the-loop electrical grid

NASA-AFRC HEIST
200kW Ironbird → Flight Simulation Hardware in the Loop

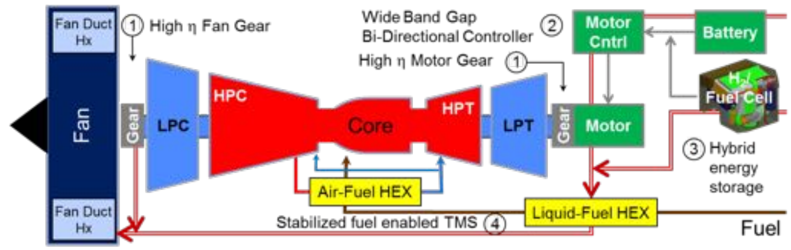


NASA GRC - NEAT
2MW Configurable Power Testbed

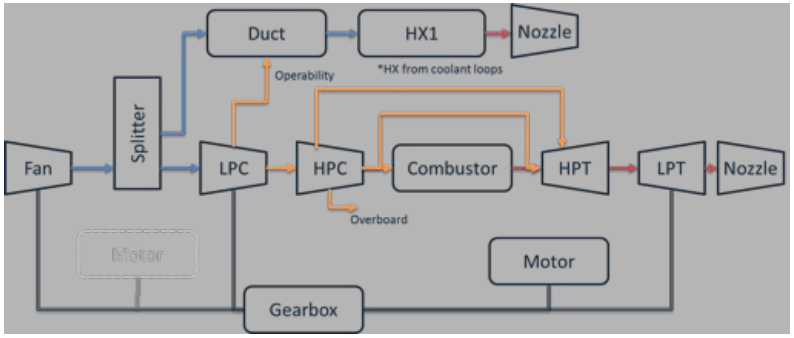
NASA-AFRC Flight simulator – Flight Dynamics

Conceptual Designs of Parallel Hybrids

- Hybrid-electric geared turbofan (hGTF) conceptual design (UTRC, P&W, UTC Aerospace Systems)
  - High efficiency drive gear integrating high speed motor and low pressure turbine
  - Bi-directional flow of power
  - Hybrid battery/fuel cell for energy storage
  - Combined fuel/fan thermal management system



- Hybrid gas-electric propulsion system conceptual design (Rolls Royce, Boeing, GA Tech)
  - Identify best performing architecture based on engine cycles, motor, power conversion, energy storage, and thermal management
  - Innovative integration of novel gas turbine cycles and electrical drives
  - Potential side effects of system design considerations
  - Provide roadmap and tech maturation plan



Turboelectric Aft-BLI Aircraft Concept

Configuration

- 154 PAX tube and wing, M=0.7
- 2 downsized turbines: 80% takeoff thrust, 55% cruise thrust
- 1 electrically power aft propulsor: 20% takeoff thrust, 45% cruise thrust
- 2x1.4 MW Generators, 2.6 MW Motor
- Electric machines assume NASA NRA targets for efficiency and specific power

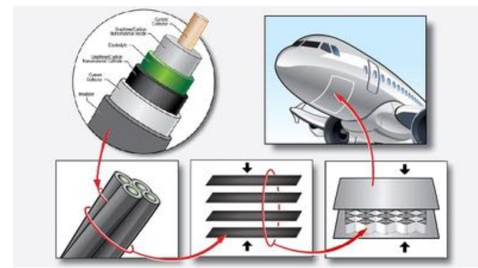
Key Features

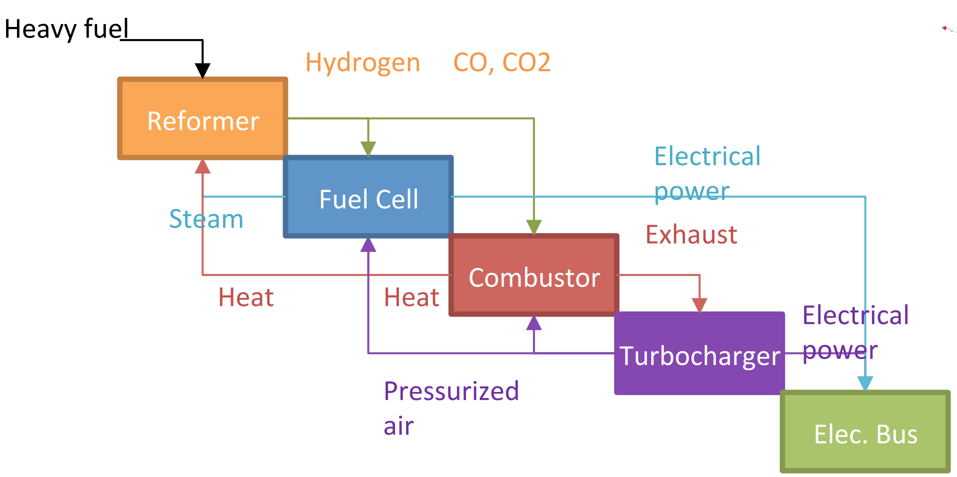
- Uses existing airport infrastructure
- SOA Batteries
- Configuration meets speed and range requirement of baseline aircraft
- 7-12% fuel (and energy) consumption reduction compared to baseline N+3 aircraft for 900-3500 nm mission

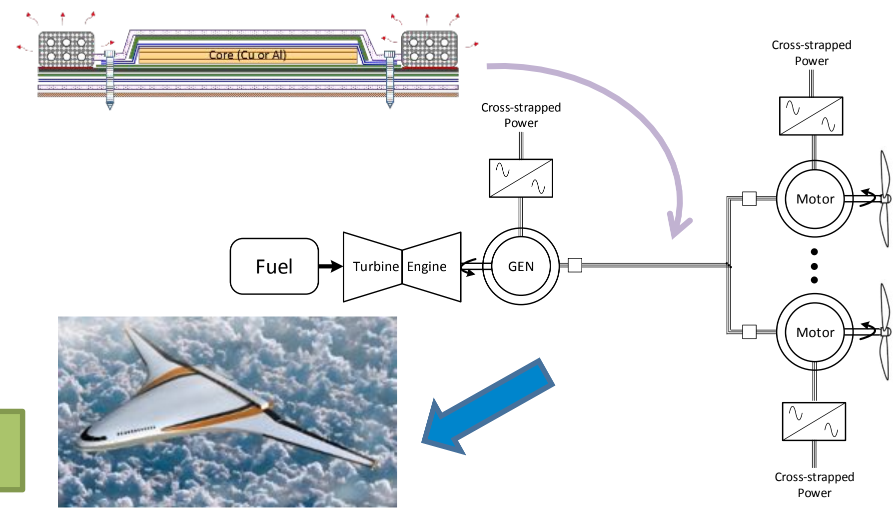
Welstead et al., Presented at AIAA SciTech, Jan. 2016

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
- Development of core technologies: turbine-coupled motors, generators, power system architecture, power electronics, thermal management, flight controls
- Simulation and modeling tools for propulsion, vehicle, electrical, and flight control systems
- Technology demonstrations of components and architectures
- Exciting times ahead