National Aeronautics and Space Administration

Next Generation Aircraft Electrical Power Systems & Hybrid/All Electric Aircraft

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Hybrid Electric Propulsion (HEP) Vehicles

Develop and demonstrate technologies that will revolutionize commercial transport aircraft propulsion and accelerate development of all-electric aircraft architectures

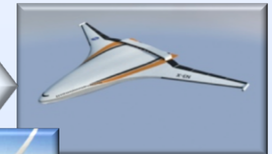
- Why electric?
  - Fewer emissions (cleaner skies)
  - Less atmospheric heat release (less global warming)
  - Quieter flight (community and passenger comfort)
  - Better energy conservation (less dependence on fossil fuels)
  - More reliable systems (more efficiency and fewer delays)
- Considerable success in development of “all-electric” light GA aircraft and UAVs
- Creative ideas and technology advances needed to exploit full potential
- NASA can help accelerate key technologies in collaboration with OGAs, industry, and academia

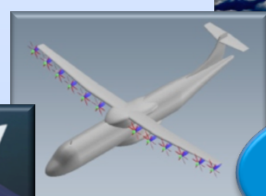
Projected Timeframe to Tech. Readiness Level 6

Technologies benefit more electric and all-electric aircraft architectures:

- High-power density electric motors replacing hydraulic actuation
- Electrical component and transmission system weight reduction

Superconducting Machines





>10 MW
- Turbo/hybrid electric distributed propulsion 300 PAX

5 to 10 MW
- Hybrid electric 150 PAX
- Turboelectric 150 PAX

2 to 5 MW class
- Hybrid electric 100 PAX regional
- Turboelectric distributed propulsion 150 PAX
- All electric 50 PAX regional (500 mile range)

1 to 2 MW class
- Hybrid electric 50 PAX regional
- Turboelectric distributed propulsion 100 PAX regional
- All-electric, full-range general aviation

kW class
- All-electric and hybrid-electric general aviation (limited range)

Power Level for Electrical Propulsion

Today | 10 Year | 20 Year | 30 Year | 40 Year

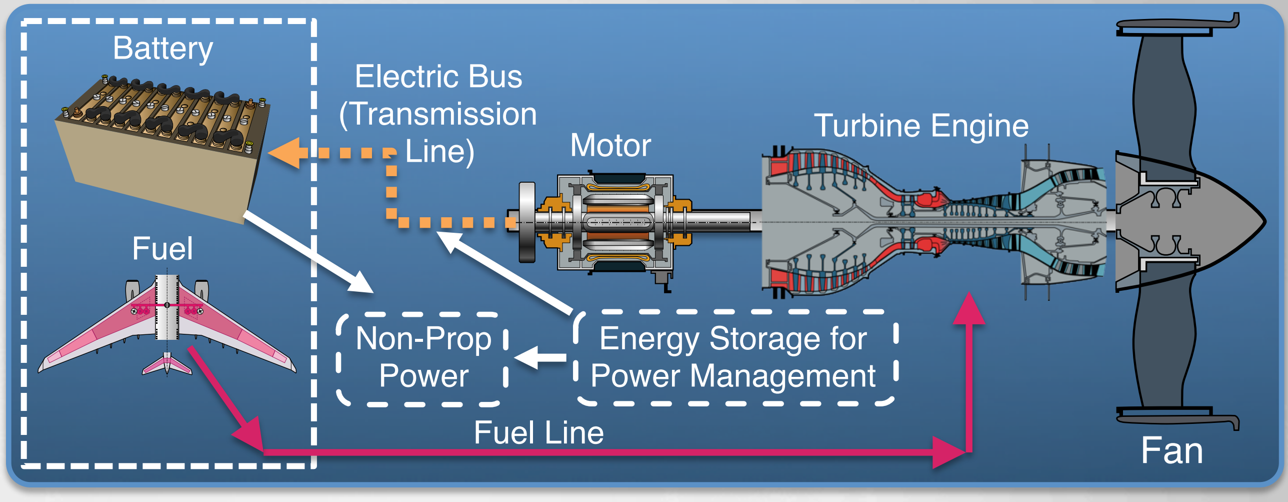
Hybrid Electric Propulsion Vehicles

NASA's Current Investments

- Advanced Air Transport Technology
  - Targets single aisle passenger aircraft
  - Goal of current work is to develop enabling technologies and to validate vehicle concepts
- Convergent Electric Propulsion Technology
  - Targets distributed propulsion vehicle architectures
  - Flight validation of transformational electric propulsion integration capabilities
- Vertical Lift Hybrid Autonomy
  - Targets long range, high endurance rotocraft missions
  - Goal of current work is to demonstrate cryogenic HEP power system to inform propulsion system models

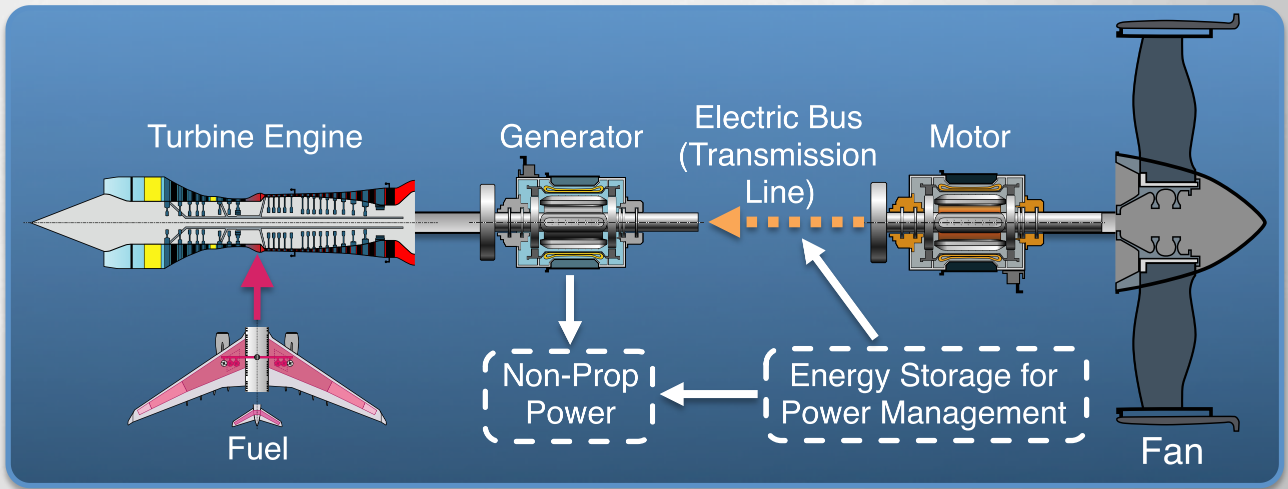
Possible Future Commercial Large Transport Aircraft Architectures

Hybrid Electric



Both concepts can use either non-superconducting motors or cryogenic superconducting motors

Turboelectric



Estimated Benefits From Systems Studies

SUGAR (baseline Boeing 737–800)

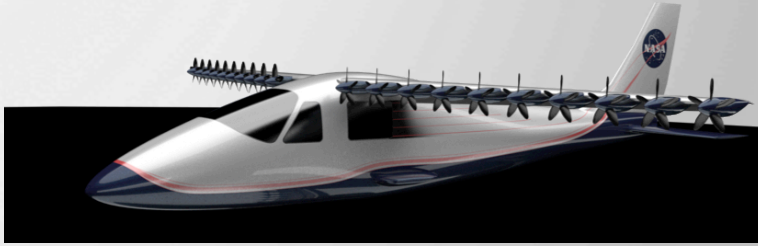
- ~60% fuel burn reduction
- ~53% energy use reduction
- 77 to 87% reduction in NOx
- 24-31 EPNdB cum noise reduction

N3–X (baseline Boeing 777–200)

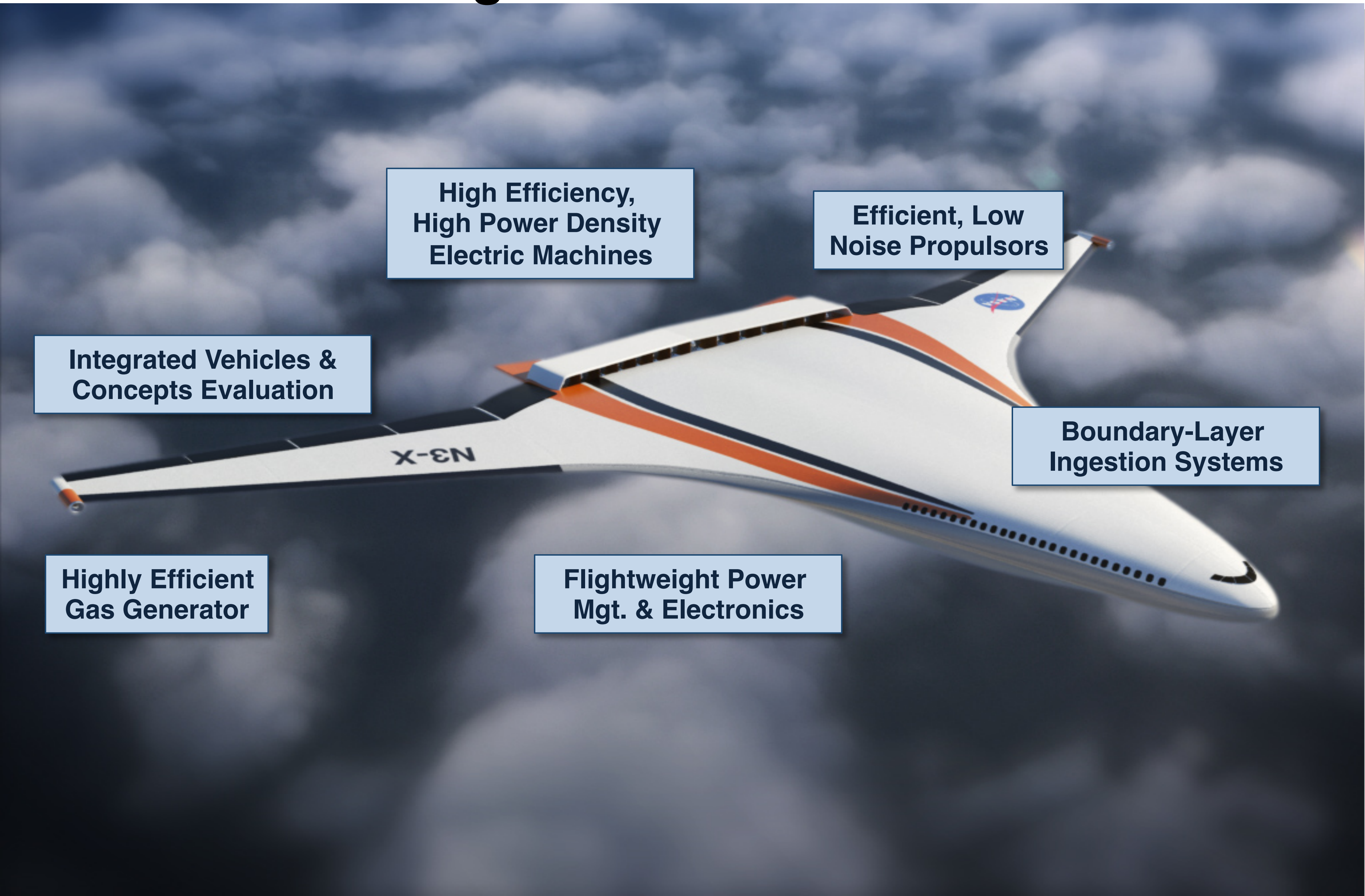
- ~63% energy use reduction
- ~90% NOx reduction
- 32-64 EPNdB cum noise reduction

CEPT (baseline Tecnam P2006T)

- 5x lower energy use
- 30% DOC Reduction
- 15 dB lower community noise
- Propulsion redundancy, improved ride quality, and control robustness



Investment in Hybrid and Turbo-Electric Aircraft Technologies



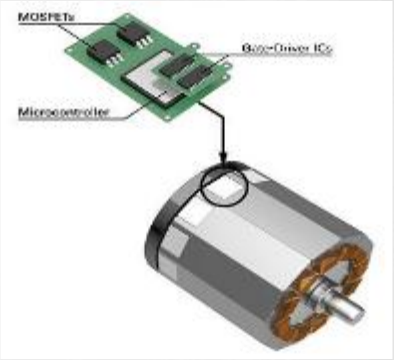
Flightweight Power Management and Electronics

- Multi-megawatt aircraft propulsion power system architecture
- 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

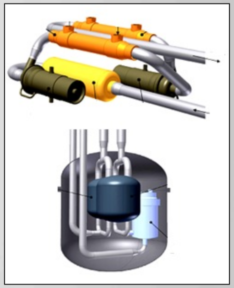
Superconducting transmission line

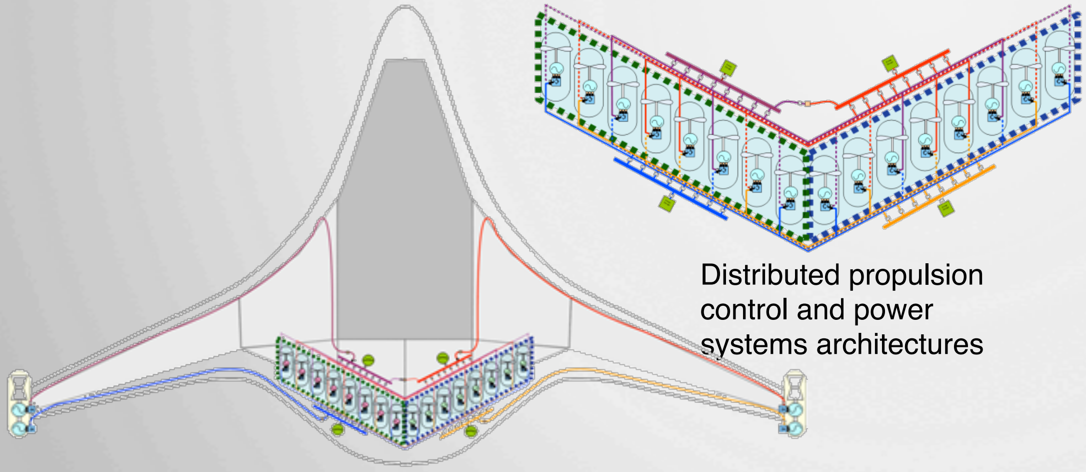
Lightweight power transmission

Integrated motor w/ high power density power electronics



Lightweight Cryocooler





Distributed propulsion control and power systems architectures

Lightweight power electronics

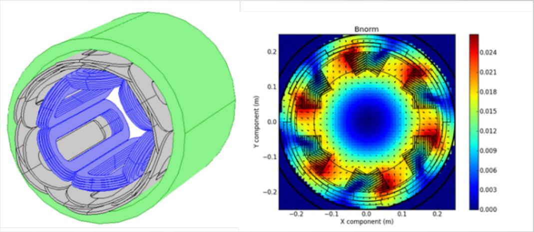
High Efficiency, High Power Density Electric Machines

- Develop High efficiency, high specific power electric machines
  - ➢ Cryogenic, superconducting motors for farther term
  - ➢ Non-superconducting motors for near and intermediate term
- Advance Materials and manufacturing technologies
- Design and test 1 MW non-superconducting electric motors starting in FY2015

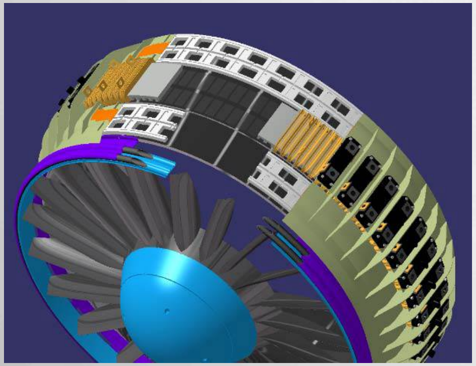
Low A/C loss superconducting filament

High thermal conductivity stator coil insulation

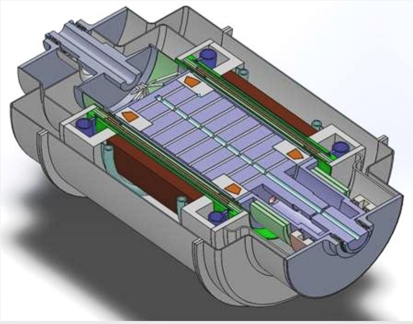
Superconducting electromagnetic model



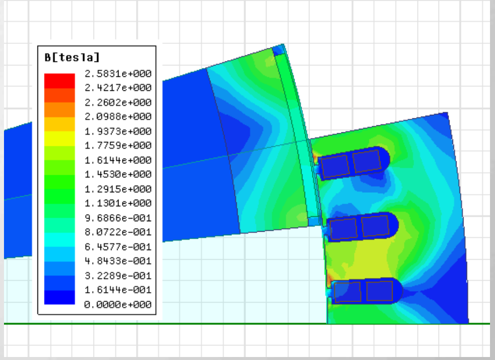
Normal conductor 1-MW rim-driven motor/fan



Fully superconducting motor



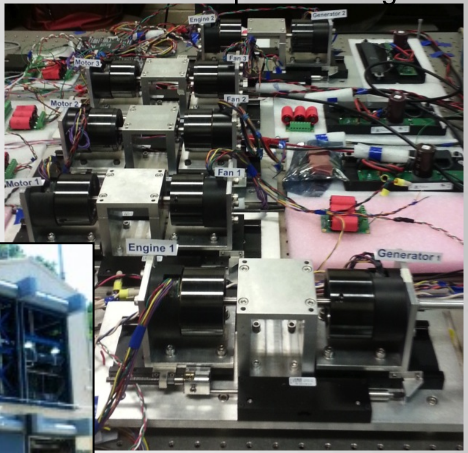
Flux density for rim-driven motor



Enabling System Testing & Validation

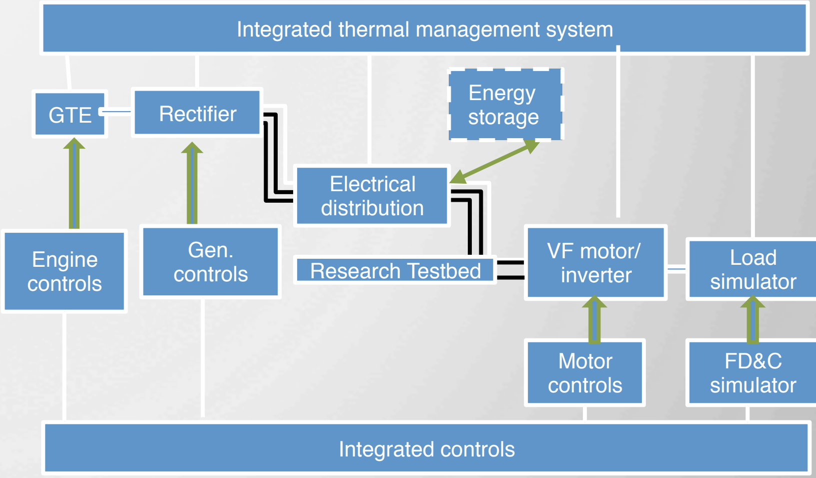
- Develop Megawatt Power System Testbed and Modeling Capability
- Key Performance Parameter-driven requirements definition and portfolio management
- Technology demonstration at multiple scales
- Identification of system-level issues *early*
- Develop validated tools and data that industry and future government projects can use for further development

hardware-in-the-loop electrical grid



Fully cryogenic motor testing NASA GRC

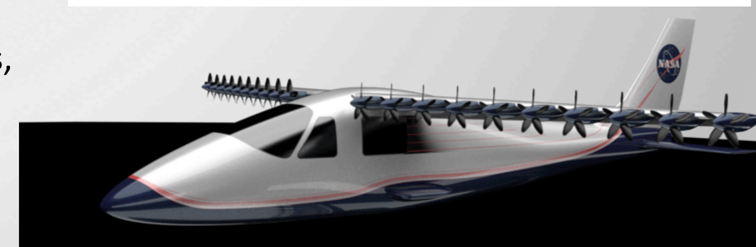
Eventual flight simulation testing at NASA Armstrong Flight Research Center



Technologies that can enable or accelerate hybrid, turbo- and all electric Aircraft

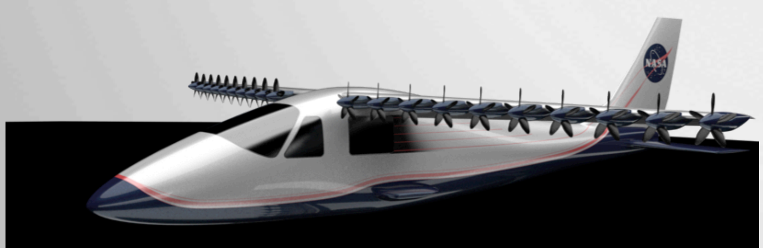
- Electric Machine Topologies:
  - Higher efficiency designs: reduce the losses in the motor through better topologies without sacrificing power density
  - Ironless or low magnetic loss
  - Concepts which allow motor to be integrated into the existing rotating machinery (shared structure)
  - Concepts which decouple motor speed and compressor speed
- Electric Machine Components and Materials
  - Flux diverters or shielding to reduce AC loss or increase performance
  - Composite support structures
  - Improvements in superconducting wire: especially wire systems designed for lower AC losses
  - Rotating Cryogenic seals
  - Bearings: cold ball bearings, active & passive magnetic bearings; hydrostatic or hydrodynamic or foil for systems w/ a pressurized LH2 source
  - Flight qualification of new components
- Cryocoolers
  - Flight weight systems for superconducting and cryogenic machines, converters and transmission lines

Vehicle and thermal management concepts need to be defined alongside propulsion systems to assure that the full system is lightweight and thermally balanced.



Technologies that can enable or accelerate hybrid, turbo- and all electric Aircraft

- Power electronics
  - More efficient topologies
  - Compact, highly integrated controller electronics
  - Flight certifiable, high voltage devices
  - Cryogenic compatible devices
- Power transmission
  - Light weight, low-loss power transmission
  - Light-weight, low-loss protection and switching components
- Better conductors
  - Carbon nano-tube or graphene augmented wires
  - Robust, high temperature superconducting wires
- Energy storage
  - increased battery energy density
  - multifunctional energy storage
  - rapidly charging and/or rapidly swapable



- Thermal Management

Transport class HE aircraft will need to reject 50 to 800 kW of heat in flight

  - Cooling for electric machines with integrated power electronics
  - Advanced lightweight cold plates for power electronics cooling
  - High performance light-weight heat exchangers
  - Lightweight, low aerodynamic loss, low drag heat rejection systems
  - Materials for improved thermal performance
- System-level enablers
  - Flight-weight, air cooled, direct shaft coupled turbo-electric generation in the above 500kW range
  - Regenerative power absorbing propeller and ducted fan designs (efficient wind-milling)