Visions of the Future:
Hybrid Electric Aircraft Propulsion

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Outline

- NASA's Motivation for Electrified Aircraft Propulsion Investment
- Strategic Thrust 4: Transition to Low Carbon Propulsion
- Hybrid and Electric Aircraft Propulsion Terminology
- NASA's Approach to Electrified Aircraft Propulsion
- Convergent Aeronautics Solutions: for High Risk and High Payoff
- SCEPTOR/X-57: Near Term Flight Demonstration
- Advanced Air Transport Technology: Long Term Aircraft Investment for Electrified Propulsion
- Summary

Electrified Aircraft Propulsion: Motivation

NASA Aeronautics Research Mission Directorate

Mega Drivers

Strategic Thrusts

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

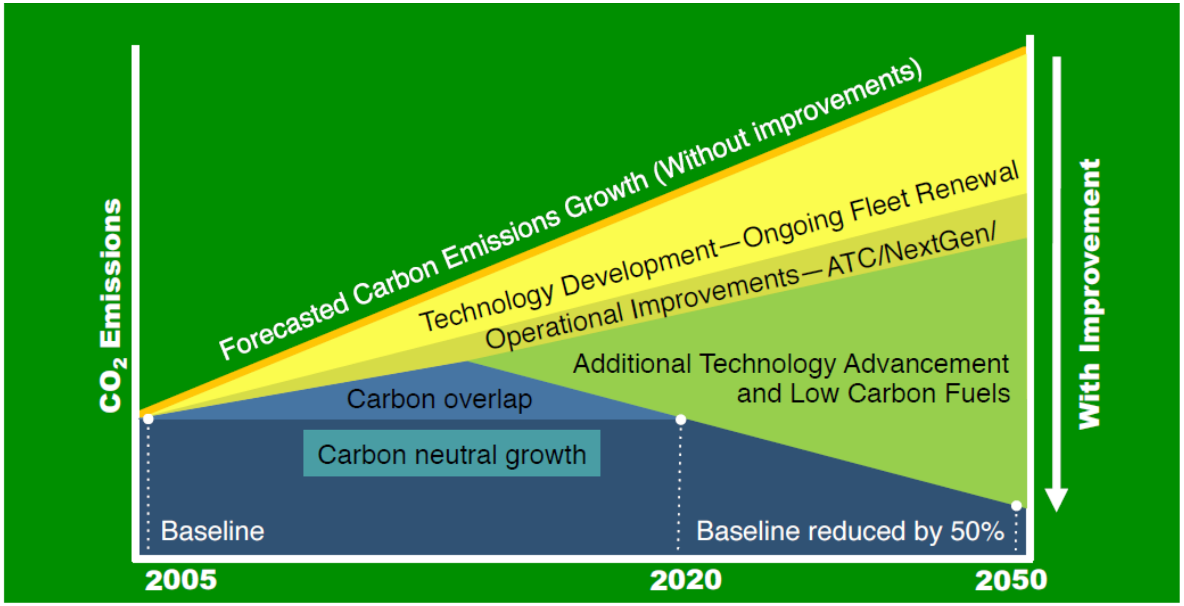
Assured Autonomy for Aviation Transformation
Develop high impact aviation autonomy applications

Electrified Aircraft Propulsion: Motivation

Strategic Thrusts Guide Investment Targets

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

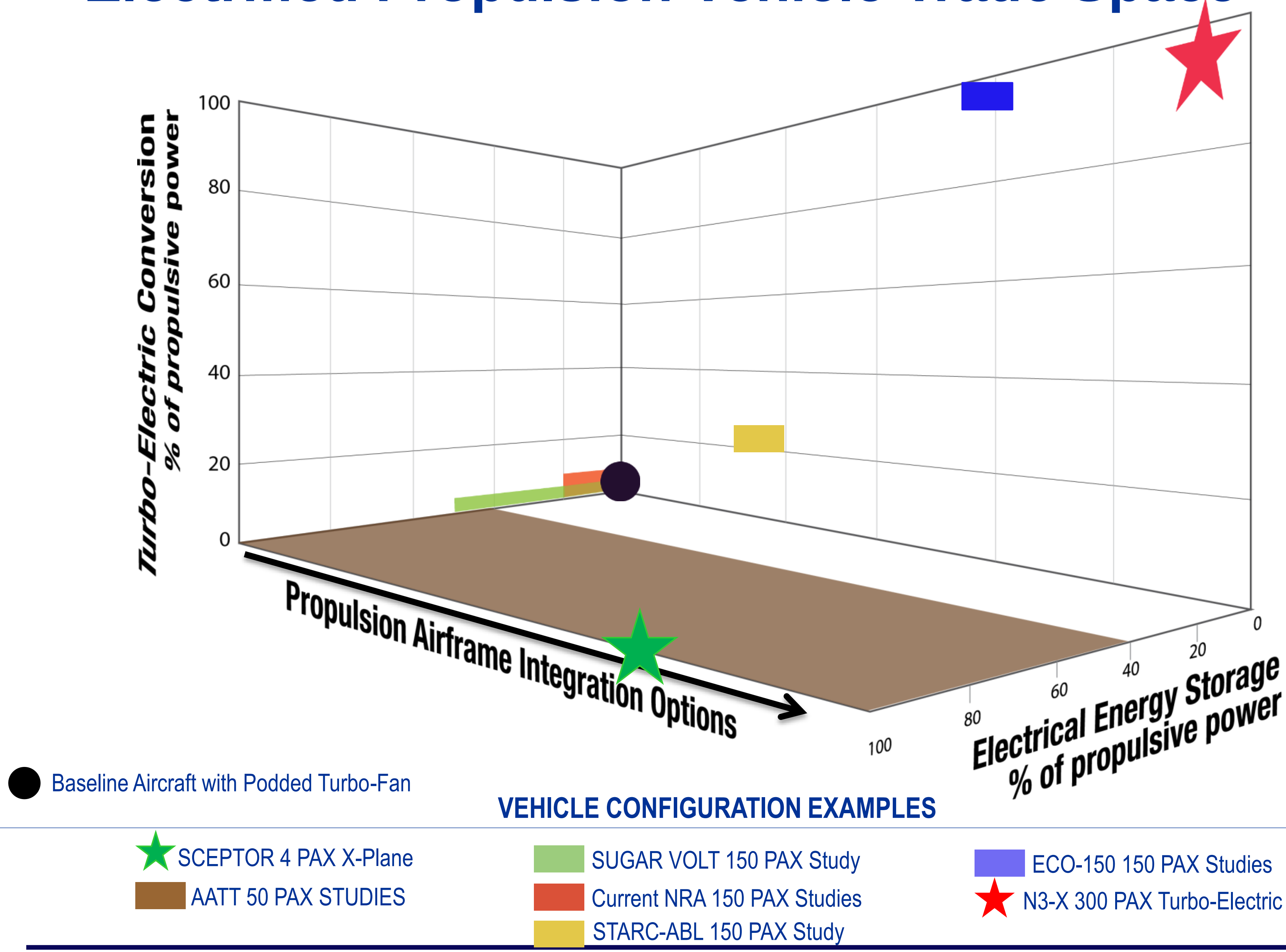
The Low Carbon Challenge is to enable carbon-neutral growth in aircraft operations:



Electrified Aircraft Propulsion Terminology

- **Electrified Propulsion refers to the use of electric power for aircraft propulsion**
  - Could be all or partially electric propulsion
  - Other aircraft development programs use the terms "More electric" or "All electric" as the use of electric power for secondary systems on aircraft such as control surfaces and wing de-icing
- **Hybrid Electric has two meanings in aircraft context**
  - One meaning is the use of two power sources, such as turbine engine and electric motor, to drive the fan (or propeller) on an aircraft—hybrid electric powertrain
  - Another meaning is the combination of more than one propulsive sources such as engines, turboelectric energy generation, fuel cells energy generation, or battery energy storage—hybrid electric prolusion
- **Turboelectric Propulsion refers to on-air generated electric power for aircraft propulsion**
  - Turboelectric generation already provides electric power for secondary systems on aircraft
  - Fully turboelectric propulsion means that all turbine power goes to electricity
  - Partially turboelectric propulsion means a turbofan engine with some fraction of generated electric power going to propulsion

Electrified Propulsion Vehicle Trade Space



Electrified Propulsion: NASA's Approach

Build, Test, Mature Enabling Technologies and Knowledge Bases

Electrified Propulsion Development

Goal: Enable the paradigm shift to electric, hybrid electric, and turboelectric propulsion for reductions in energy consumption, emissions, and noise

Path:

- **Identify promising propulsion / vehicle configurations**
- **Buy-down risk for crucial technologies in**
  - **Flight Control: new knobs in vehicle and subsystems**
  - **Power Conversion: electric machines & electronics**
  - **Power Control: vehicle electric grid management**
  - **Fundamental Enablers: materials and analysis**
- **Demonstrate results in purpose-built flight demonstration**

Multiple Paths to Carbon Reduction

All Electric, Hybrid Electric, Distributed Propulsion

- On Demand Mobility Focus
- Small Plane Focused

Enable New Aero Efficiencies

Power Sharing

Distributed Thrust Control

Certification Trailblazing

Energy & Cost Efficient, Short Range Aviation

Turbo Electric, Distributed Propulsion

- Low Carbon Propulsion
- Transport Class Focused

Enable New Aero Efficiencies

High Efficiency Power Distribution

Power Rich Optimization

Non-flight Critical First Application

Energy & Cost Efficient, Transport Aviation

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)

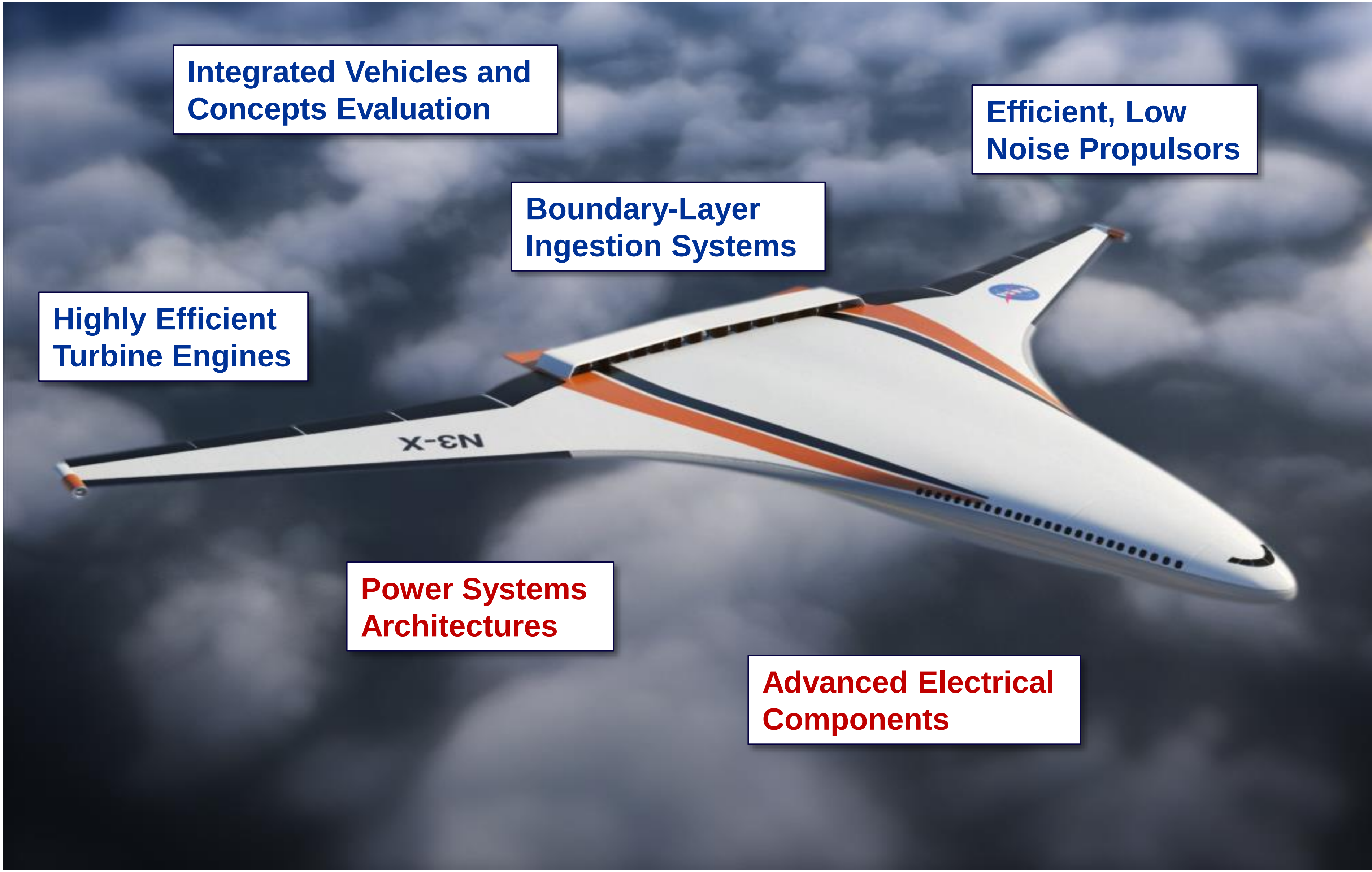
NASA SCEPTOR Derivative Objectives

- ~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.

Adv. Air Transport Technology Project Investment



Adv. Air Transport Technology Project Investment

<u>Objective</u>

Key performance parameters and threshold level requirements for gas turbine aircraft augmented with electrical powertrain

Propulsion System Conceptual Design

– Concepts for system interaction exploration

Integrated Subsystems

– Flight control methodology for distributed propulsion

High Efficiency/Power Density Electric Machines

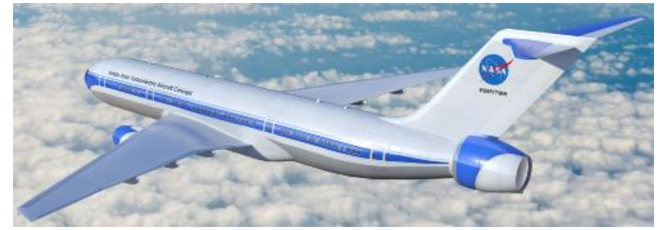
– Step change in component performance

Flight-weight Power System and Electronics

– High voltage power electronics, transmission, protection, and management

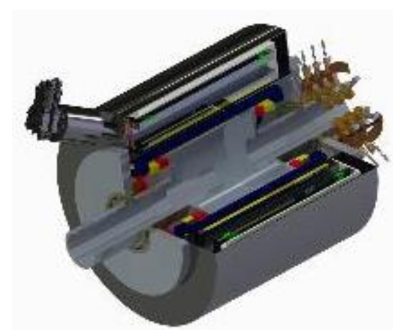
Enabling Materials

– Insulation, Conductors, Magnetic Materials

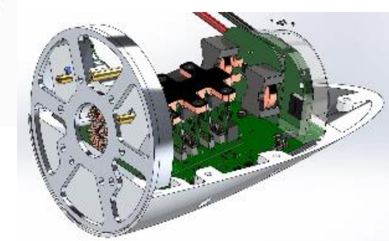


Scrutinizing tube & wing architectures

Revolutionary system testing



Superconducting and ambient machines

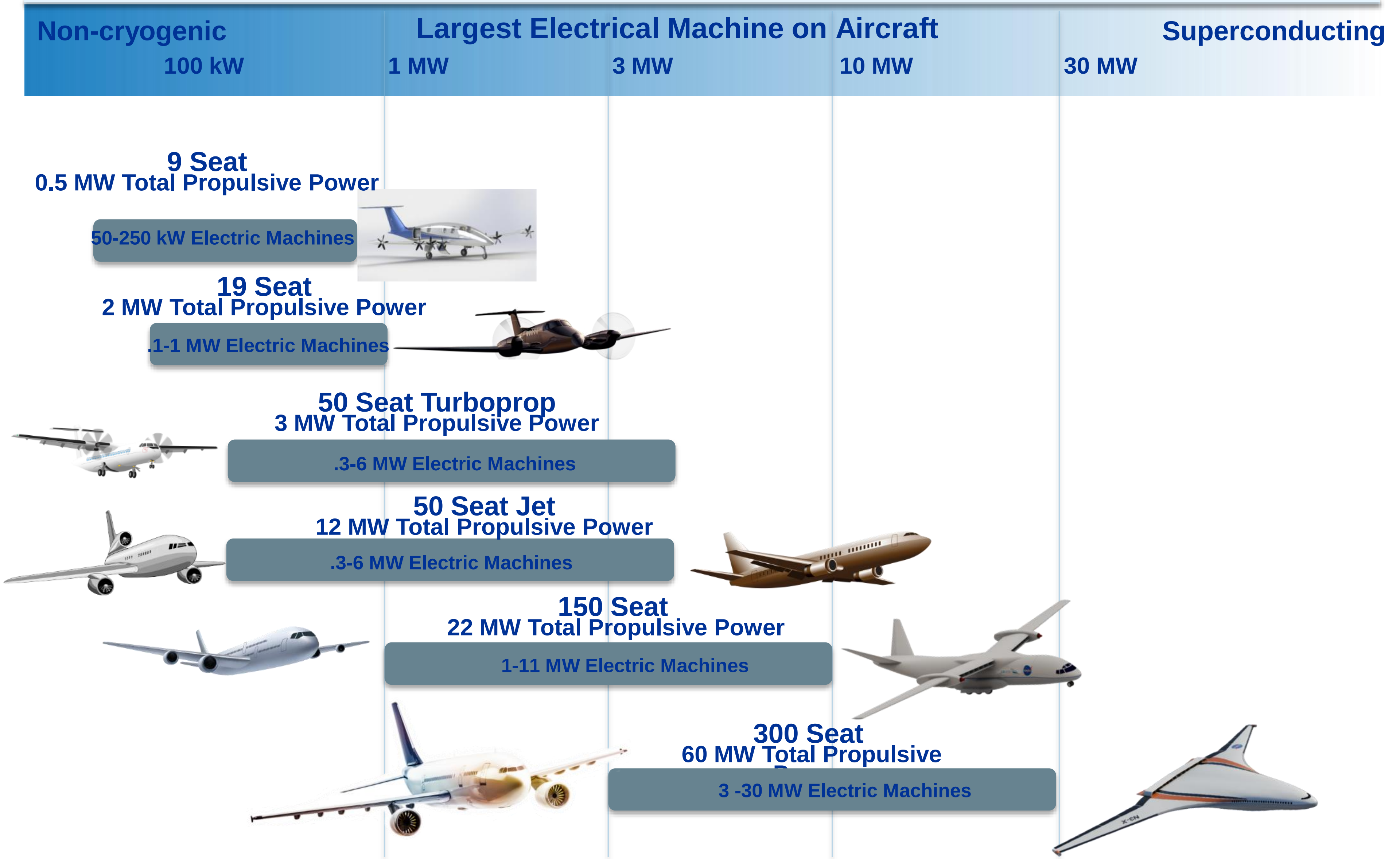


Transitioning materials from lab to component

NASA Electrified Propulsion Takeaways

- NASA Aeronautics Strategic Thrust 4 -Transition to Low-Carbon Propulsion is supporting investment in alternative aircraft propulsion including electrified aircraft propulsion
- The NASA vision includes transforming aviation via new propulsion technologies integrated with airframes to
  - increase aircraft functionality
  - reduce carbon emissions
  - improve operational efficiency and reduce noise
- There are many possible Electrified Aircraft configurations
- NASA investment includes vehicle concepts and technology to support aircraft for
  - Small to midsize aircraft to increase mobility provide a new paradigm
  - Commercial transport aircraft to impact the current large carbon producing market segment

Timeline of Machine Power Relevant to Aircraft Class



NASA