National Aeronautics and
Space Administration

Decarbonizing Aviation with Electric Propulsion

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Introduction

- NASA is investing in research to enable Electrified Aircraft Propulsion (EAP).
  - NASA is working across a range of markets
  - The overarching strategy is to create enabling technology, demonstrate this technology in flight-test vehicles, and transfer the knowledge to industry for future products
  - Electrified aircraft propulsion has varying impact on air vehicle design depending on the key requirements of the market that the vehicle is intended to serve

Market: National/International

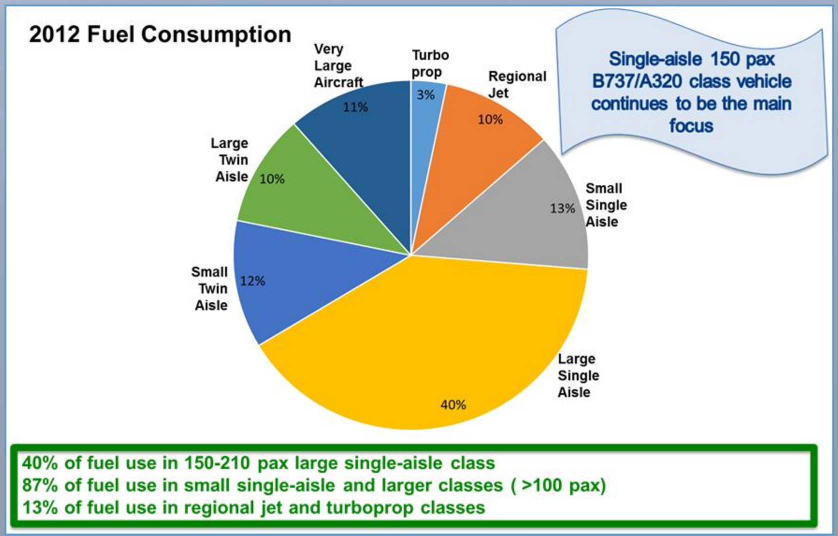
Impact: Fuel Burn/Emission Reduction

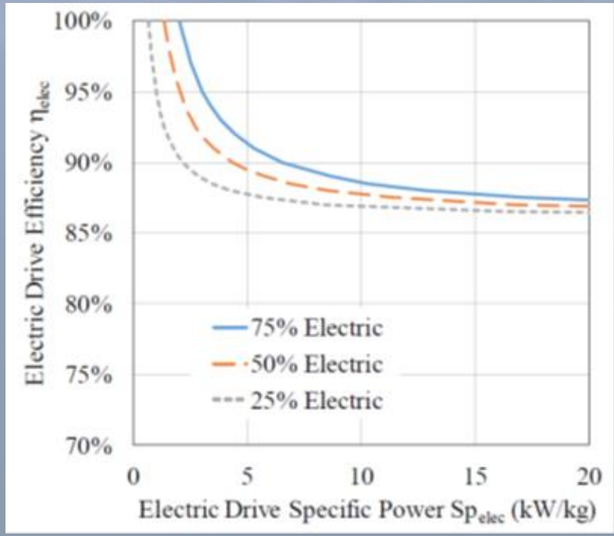
Market: On demand mobility

Impact: New mobility capability

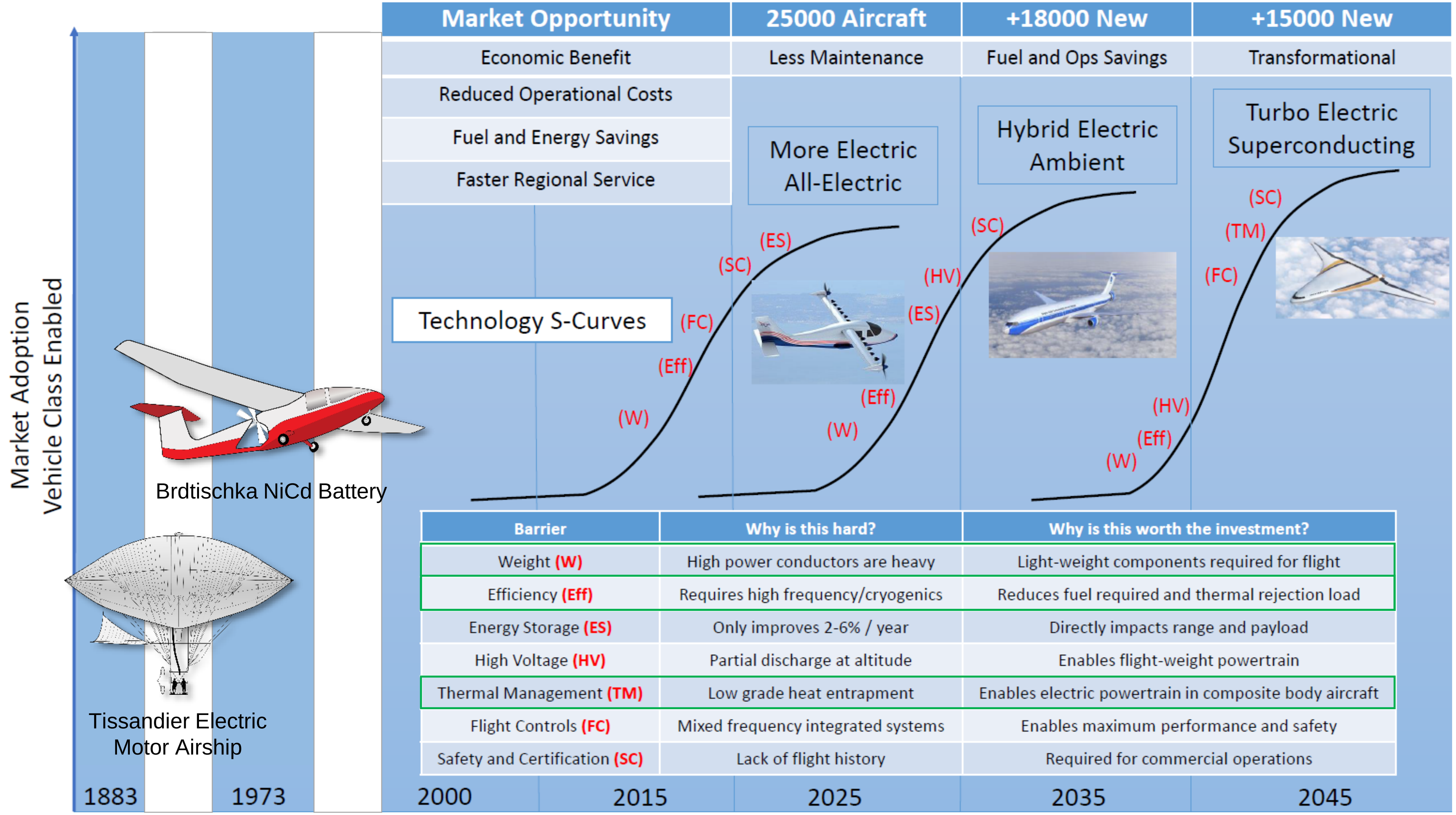
Market: Regional

Impact: Revitalization of smaller routes





Decarbonizing Electric Aircraft Propulsion Technology Adoption

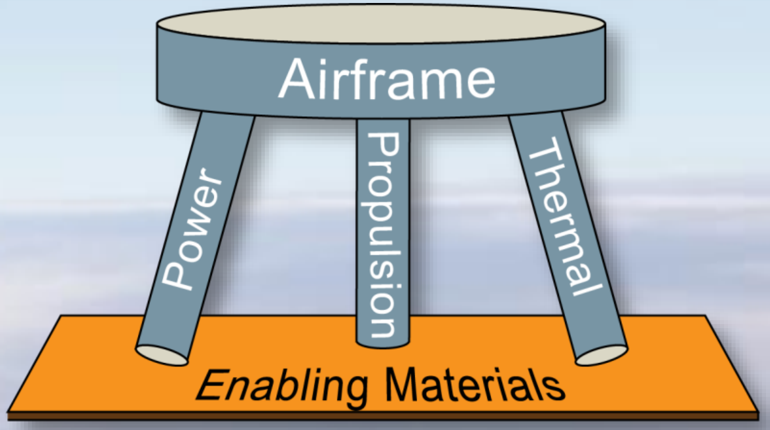


Barrier	Why is this hard?	Why is this worth the investment?
Weight **(W)**	High power conductors are heavy	Light-weight components required for flight
Efficiency **(Eff)**	Requires high frequency/cryogenics	Reduces fuel required and thermal rejection load
Energy Storage **(ES)**	Only improves 2-6% / year	Directly impacts range and payload
High Voltage **(HV)**	Partial discharge at altitude	Enables flight-weight powertrain
Thermal Management **(TM)**	Low grade heat entrapment	Enables electric powertrain in composite body aircraft
Flight Controls **(FC)**	Mixed frequency integrated systems	Enables maximum performance and safety
Safety and Certification **(SC)**	Lack of flight history	Required for commercial operations

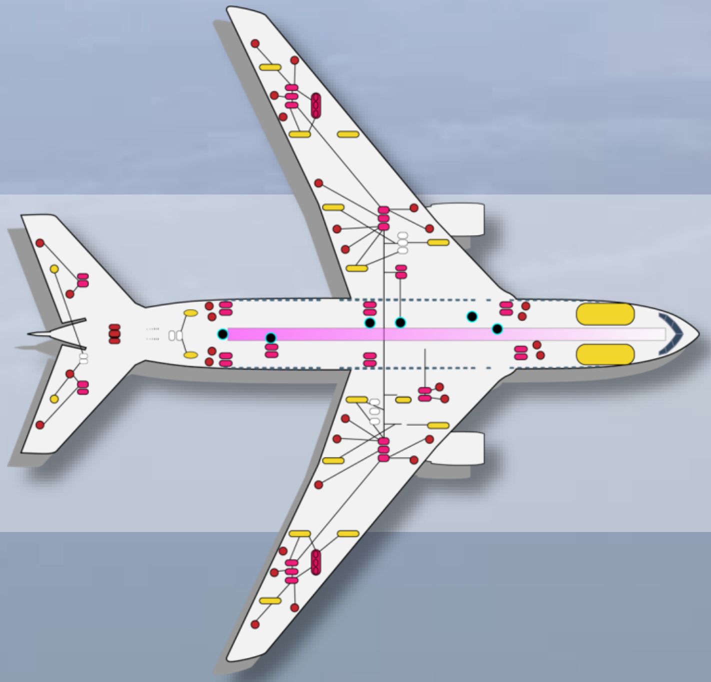
Research addresses weight, efficiency, thermal, and fault management technology barriers.

Power, Propulsion, Thermal, and Airframe Integration Challenge

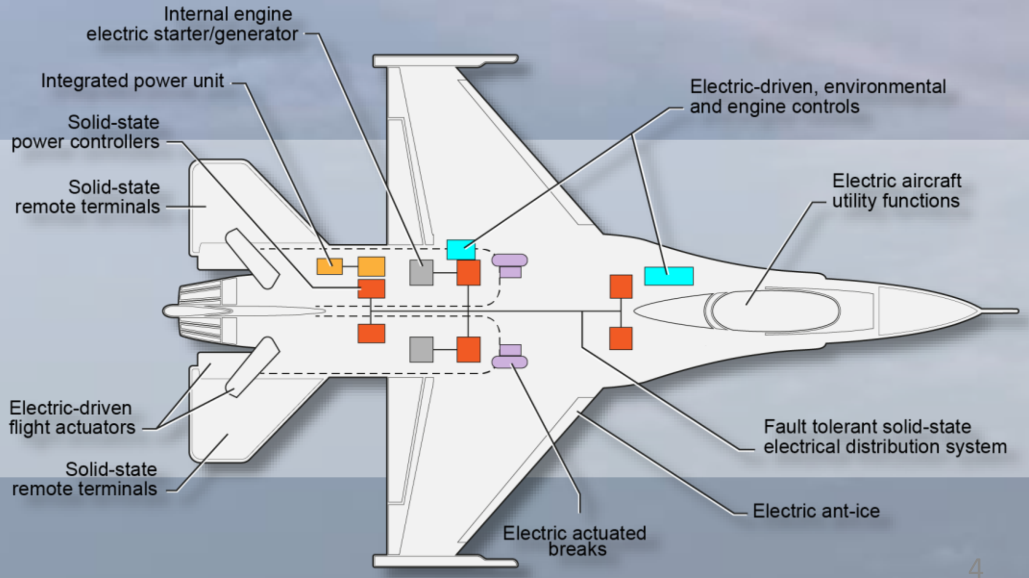
- **Challenge is to highly integrate all systems:**
  - improves fuel efficiency
  - reduces emissions
  - reduces low grade waste heat
  - reduces vehicle mass



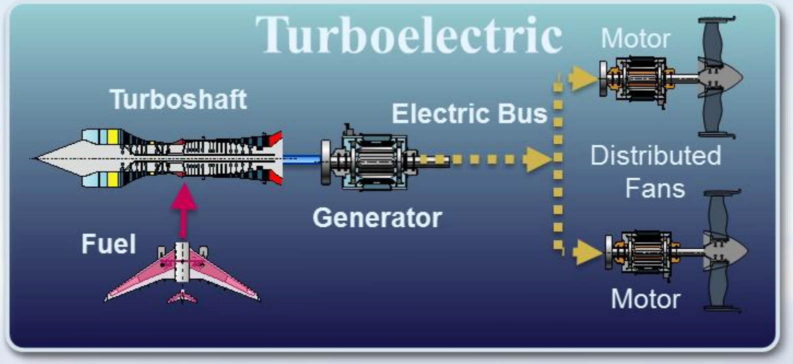
All components must integrate



PM and Induction Machine is a Near-term Technology

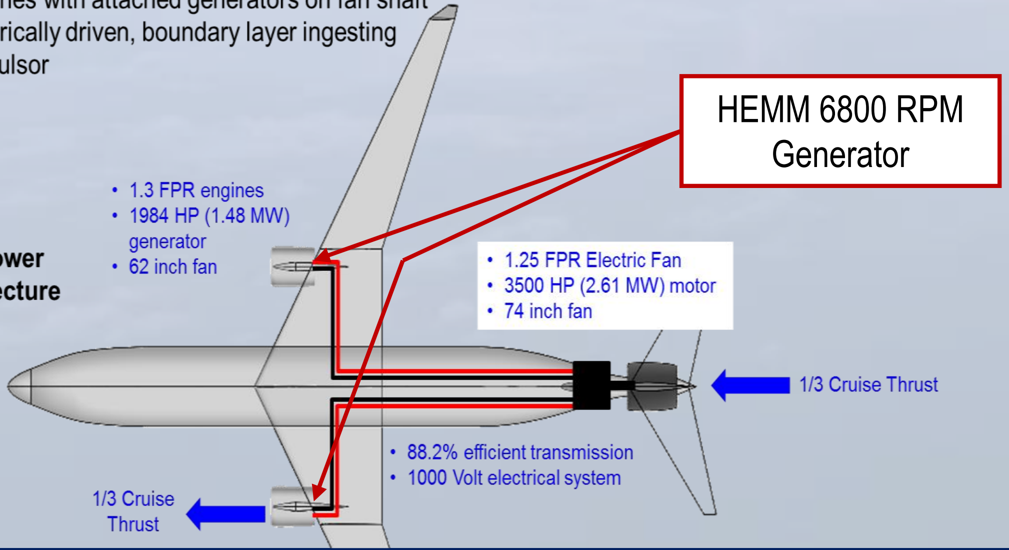


Electric Propulsion and Controls Integration Challenge

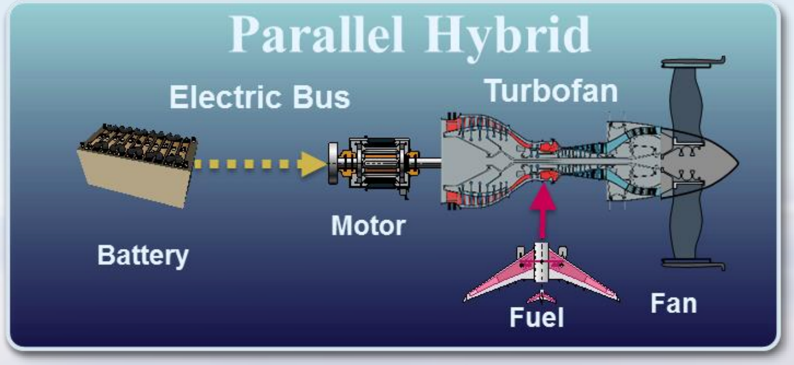


Single-aisle **T**urboelectric **A**i**RC**raft with **A**ft **B**oundary **L**ayer propulsion (STARC-ABL)

- Conventional single aisle tube-and-wing configuration
- Twin underwing mounted N+3 (Far-term) geared turbofan engines with attached generators on fan shaft
- Ducted, electrically driven, boundary layer ingesting tailcone propulsor



Partial Turbo-electric Benefits From Efficient Generator



Parallel Hybrid Performance Improves with Energy Storage

Electric Aircraft Fault Management Challenge

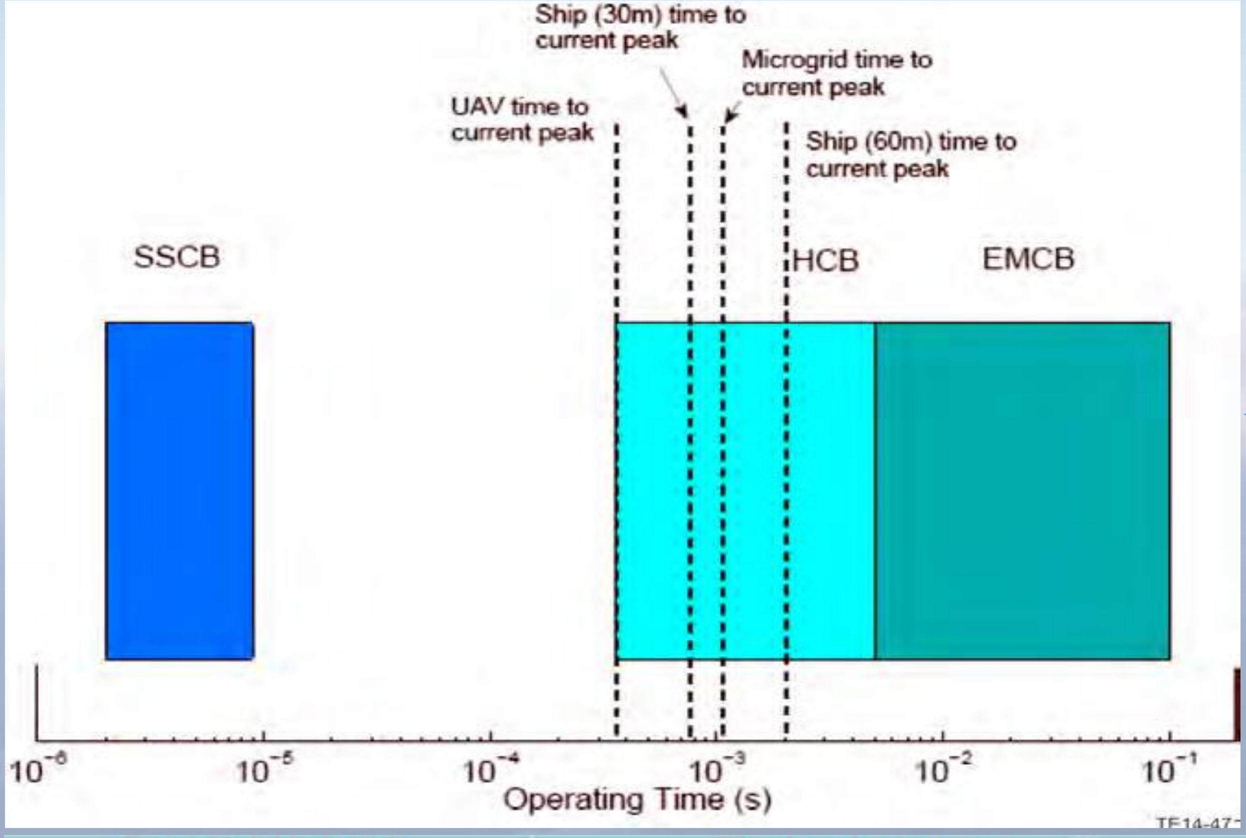
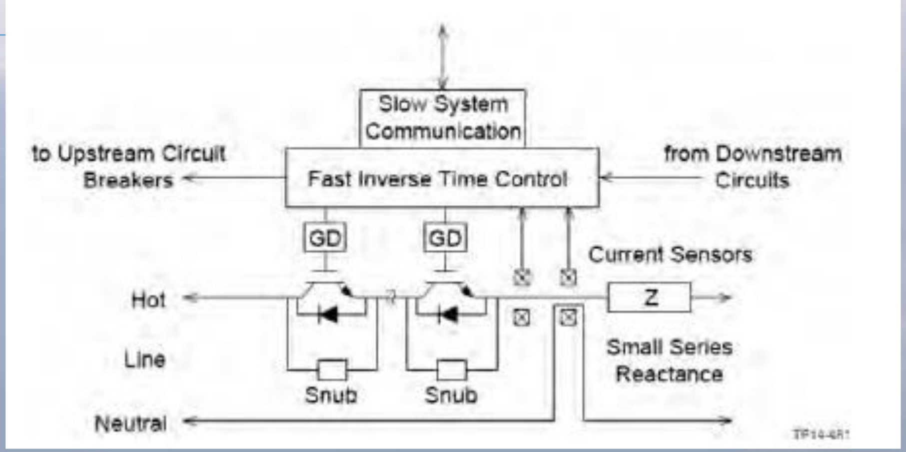
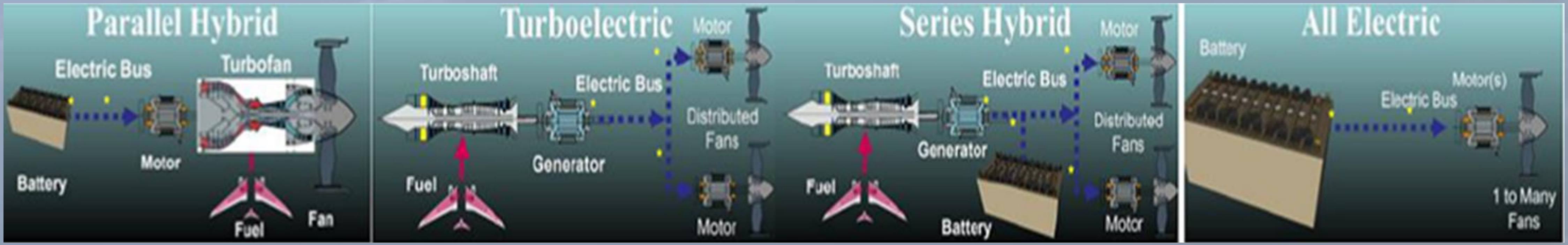


TABLE 12.—DC PROTECTION DEVICE SUMMARY

Characteristic/Device	EMCB	HCB	SSCB
Operating time	–	o	+
Weight	–	o	+
Conduction resistance	+	o	–
Cryogenic operation	o	+	+



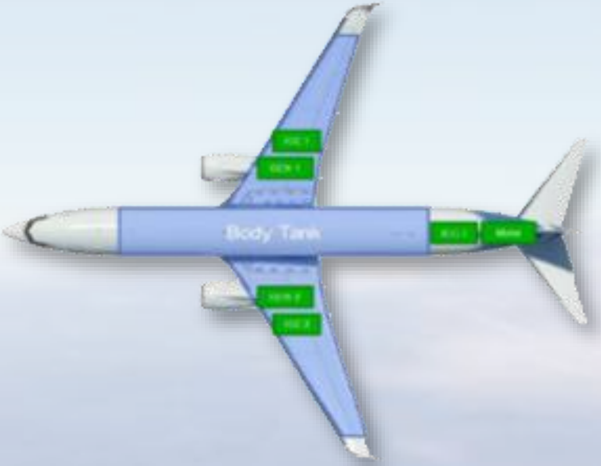


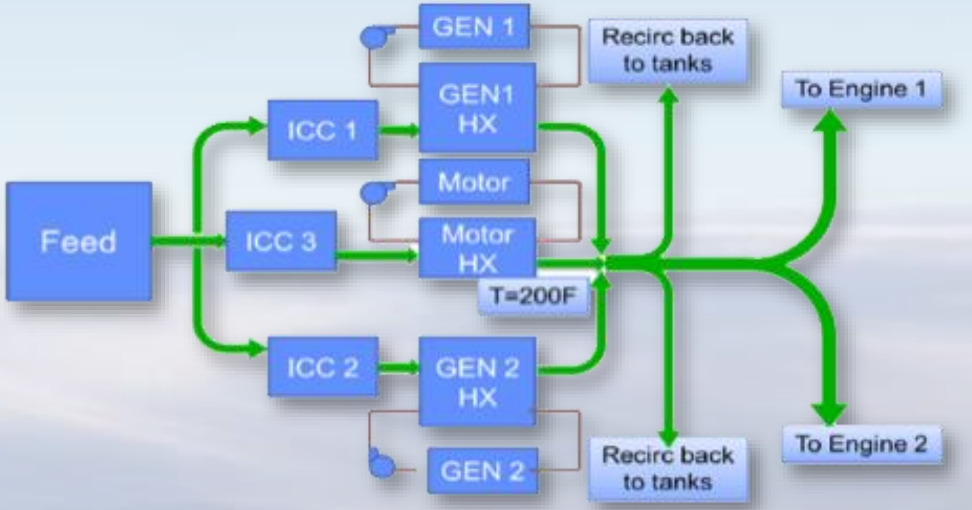
Approach: Integrate thermal and fault management for best system performance

Thermal Management Challenge

Dumping heat into:

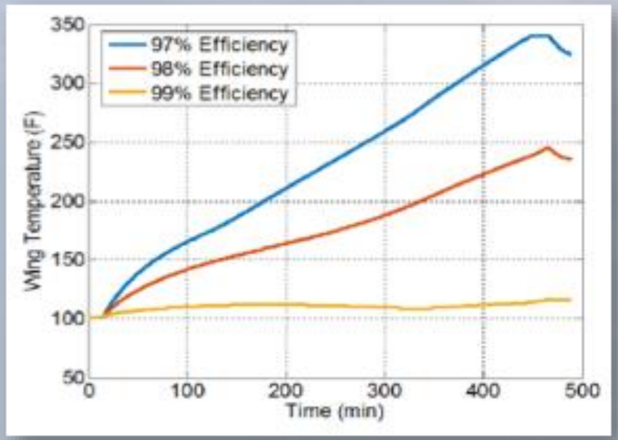
- Fuel (limited 50 kW)
- Outer mold line (limited 300 kW)
- Ram air (see below for losses)
- By-pass air (see below for losses)





	1% Hot Day		Standard Day	
	Total Penalty (zero exit Velocity)	Total Penalty (non-zero exit velocity)	Total Penalty (zero exit Velocity)	Total Penalty (non-zero exit velocity)
900NM	4.98%	3.31%	2.76%	2.36%
3500NM	5.00%	3.62%	3.01%	2.57%

Thermal Runaway with Composite Fuselage



Electric Aircraft Propulsion Thermal management technology impacts performance and safety certification

Energy Storage Challenge

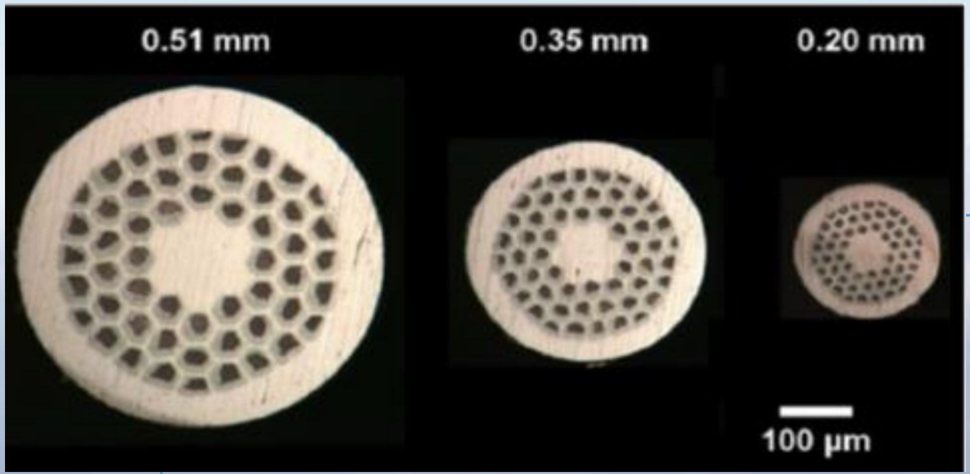
❑ 1 kg coal	8 kWh
❑ 1 kg wood	4 kWh
❑ 1 kg oil	10 - 12 kWh
❑ 1 kg natural gas	10 - 14 kWh
❑ 1 kg enriched uranium(~2% burnup)	600 000 kWh
❑ 1 kg of water - 1000 m fall	0.003 kWh
❑ 1 kg Pb battery	0.03 kWh
❑ 1 kg lithium battery	0.2 kWh

(1 kWh : kinetic energy of a 10 ton truck at 100 km/h)

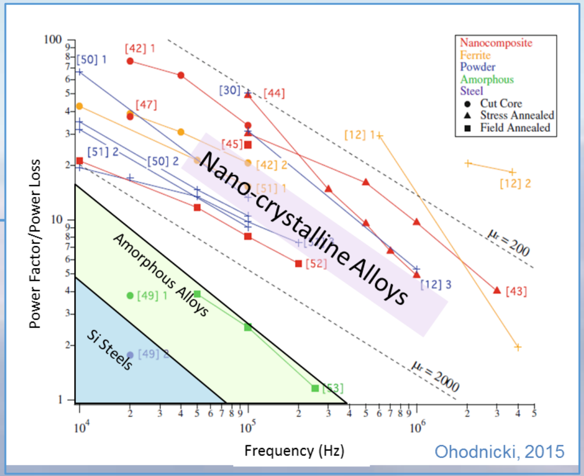
Jet Fuel is Light-Weight and Low-Cost but only carbon neutral if synthesized
Required mission power level determines energy source

Electric Powertrain Materials Challenge

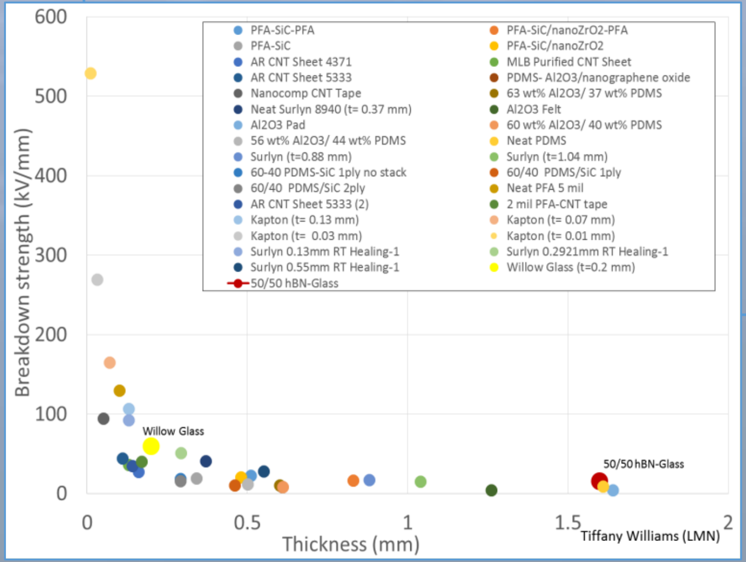
Superconducting Materials



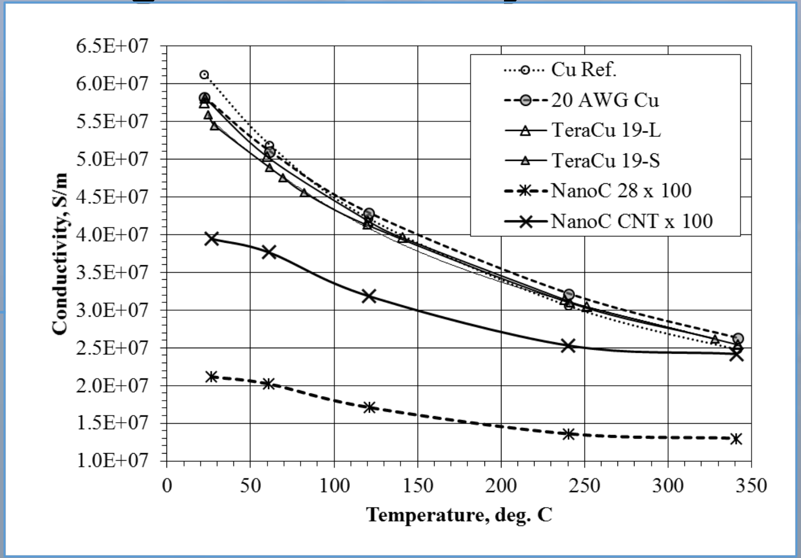
Magnetic Materials



Insulation Materials



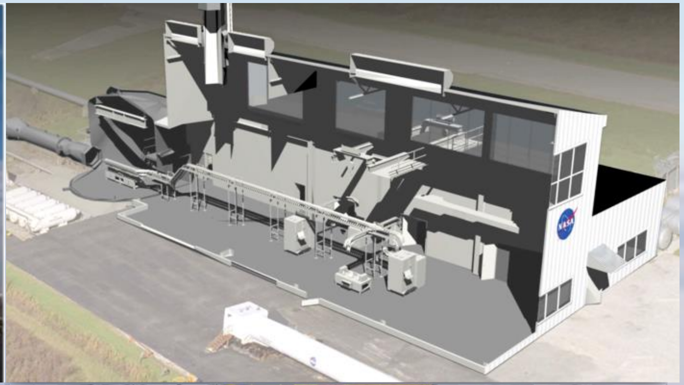
High Conductivity Materials



Integrated System Testing Challenge

Reconfigurable Powertrain Testbed

- Located at NASA Glenn Plum Brook Station in the recently refurbished Hypersonic Tunnel Facility (HTF)
- Full-scale powertrain testing under actual flight scenarios
- Can support cryogenic fuel, high voltage, large wingspan, electromagnetic interference, and high power research h/ware



Planned Testing at NEAT

- Phased approach with ~1 aircraft configuration per year (goal)
- **Initially COTS, ambient**

TRL maturation of:

High voltage bus architecture –
Insulation, geometry, 600V up to 4500V

High power MW Inverters, Rectifiers-
Commercial, In-House, NRAs

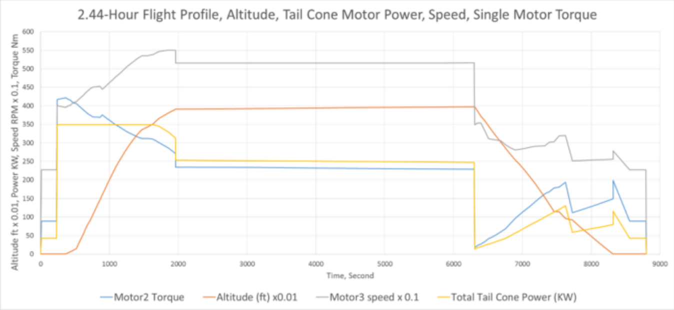
High power MW Motors, Generators-
Commercial, In-house, NRAs

System Communication –
Aircraft CAN, Ethernet, Fiber-optics

System EMI Mitigation and Standards –
Shielding, DOD-160, MIL-STD-461

System Fault Protection –
Fuse, Circuit Breaker, Current Limiter

System Thermal Management –
Active/Passive, Ambient/Cryo, Distributed/Mixed



Conclusion

- Key Power, Energy Storage and Conversion Technologies are being developed that support On Demand Mobility and Transport Class Aircraft:
  - **MW Motors and Inverters** are flight-weight and soon flight-ready
  - **Integrated Propulsion Controls, Fault, and Thermal Management** technology are the next frontier to safely support energy storage, high voltage, and low grade heat sources in a certifiable vehicle
  - Multiple government agencies and industry are collaborating in all areas
- **Hybrid Gas Electric Propulsion** technology enables:
  - Decarbonization of large transport class vehicles and medium scale on demand transport
  - New mission capability including duration and durability
- **Technology Adoption Challenges** include:
  - Developing Operational and regulatory certification requirements
  - Meeting the existing EMI and flight management standards
  - Dispatch ability and Infrastructure Integration

Decarbonizing Powertrain Technology is maturing at a fast pace!