

A Testbed for Electrified Aircraft Propulsion Control Systems Verification

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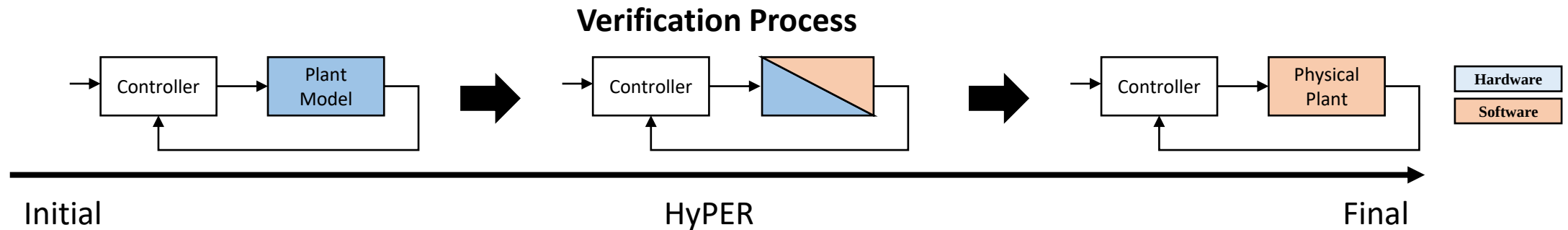
General Electric Global Research

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10/11-12/2023

Introduction

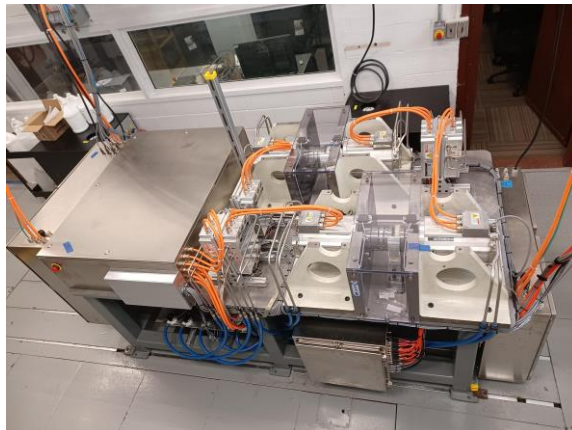
- Control systems algorithm verification involves incrementally performing tests where subsystems of a plant model are replaced with hardware.



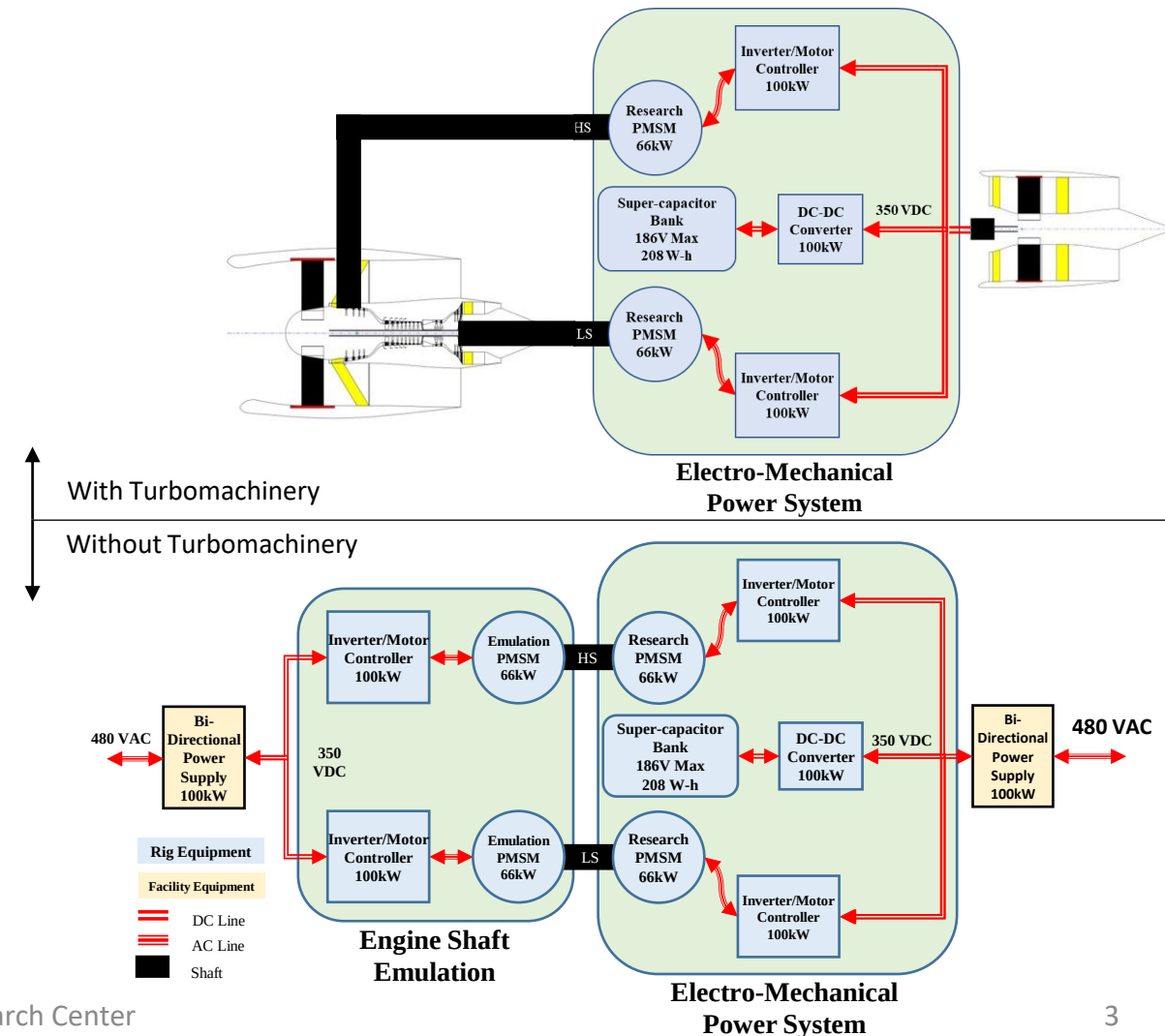
- High power electrical systems will be a large contributing subsystem to the performance of the engine/aircraft.
- Ensuring electrified aircraft propulsion control algorithms can leverage electrical hardware to provide benefits to turbomachinery/aircraft is the subject of ongoing research.
- Operating turbomachinery comes with several financial and safety risks.

Hybrid Propulsion Emulation Rig (HyPER)

- Location: NASA Glenn Research Center, Cleveland, Ohio
- Power Level: 100 kW
- Key Abilities:
 - Reconfigurable
 - Bi-directional Power Flow
 - Torque Load Emulation
 - Supercapacitor

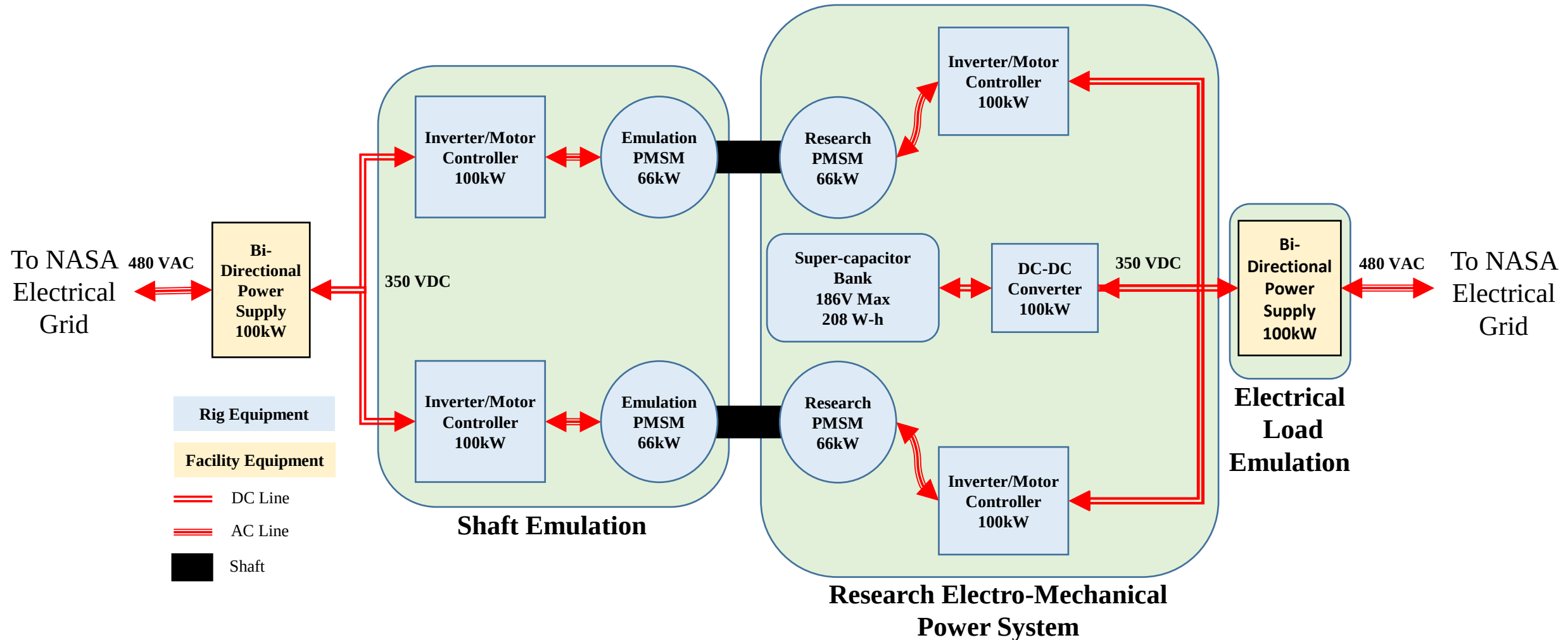


Representation of Dual Spool Series/Parallel Partial Hybrid Electric Propulsion System In HyPER



[1] Buescher, H. E., et al., "Hybrid-Electric Aero-Propulsion Controls Laboratory: Overview and Capability," *SciTech Forum*, National Harbor, MD, 2023.

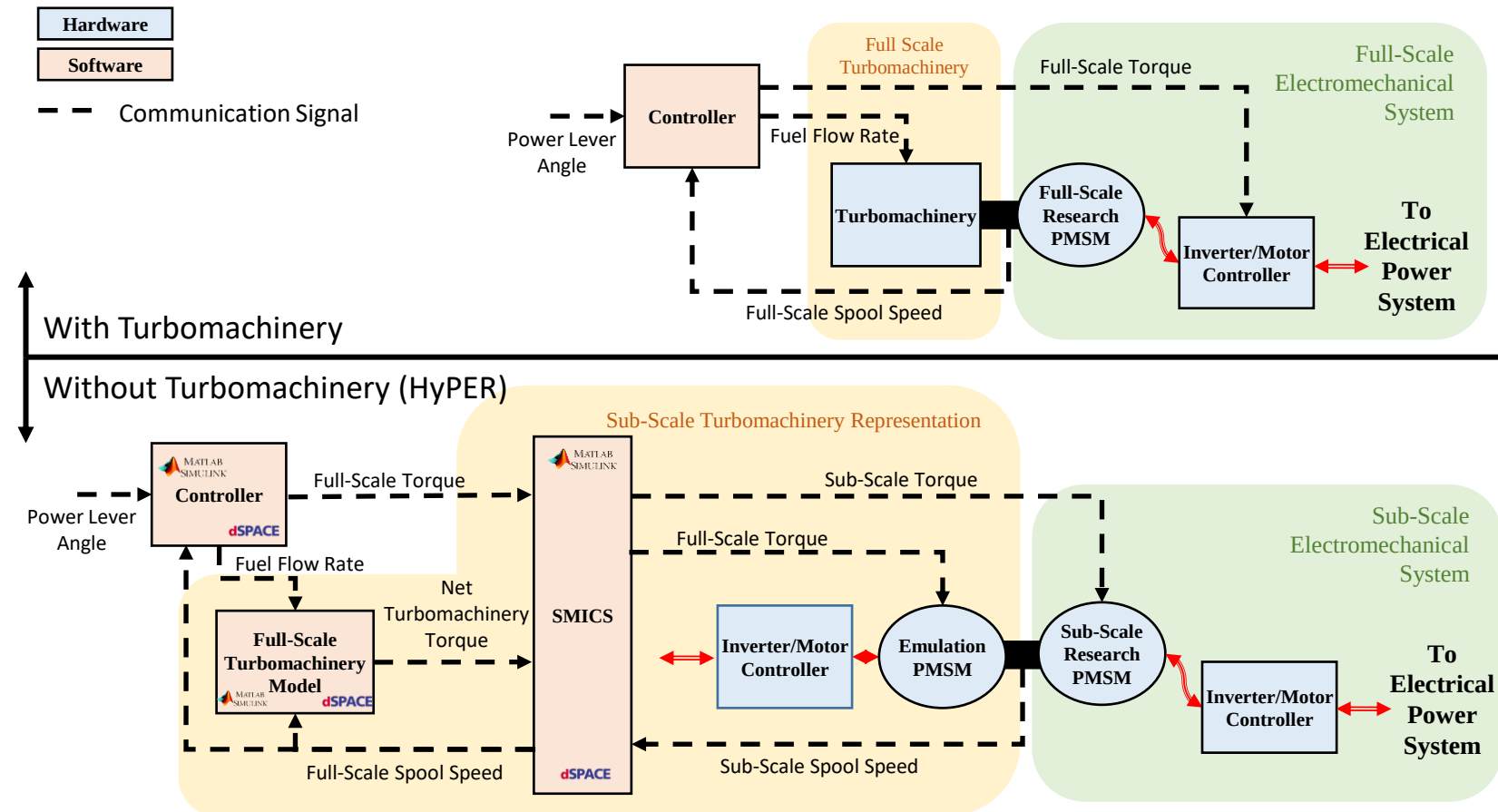
HyPER Architecture



Emulation Control

- Sliding Mode Impedance Controller with Scaling (SMICS) [2]
- Enables the replacement of turbomachinery while preserving shaft dynamical characteristics.
- Mimics dynamic sub-scale torque load of turbomachinery/rotors.
- Scalable to facilities of differing power levels and architectures.
- Real-time

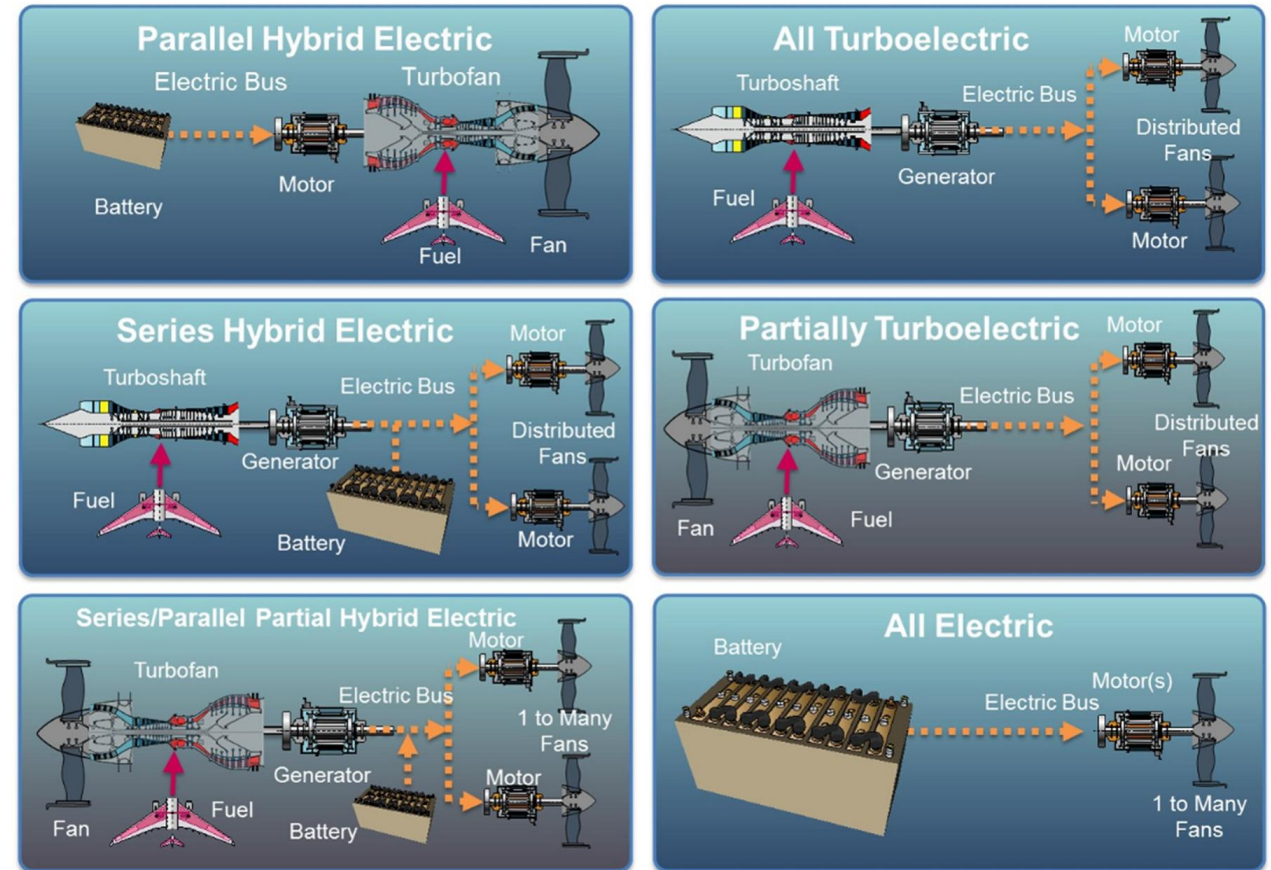
Control System Implementation Example on Single Spool Turbomachinery



[2] Bianco, S. J., Simon, D. L., "Control and Scaling Approach for the Emulation of Dynamic Subscale Torque Loads," *AIAA Electric Aircraft Technologies Symposium (EATS)*, San Diego, CA, 2023.

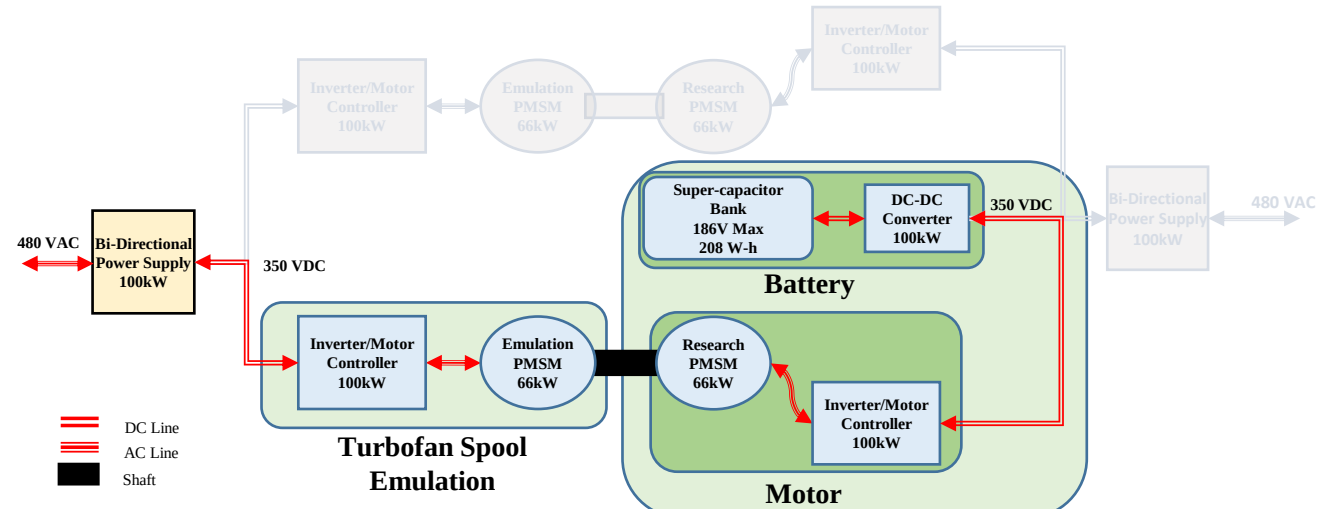
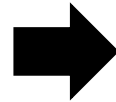
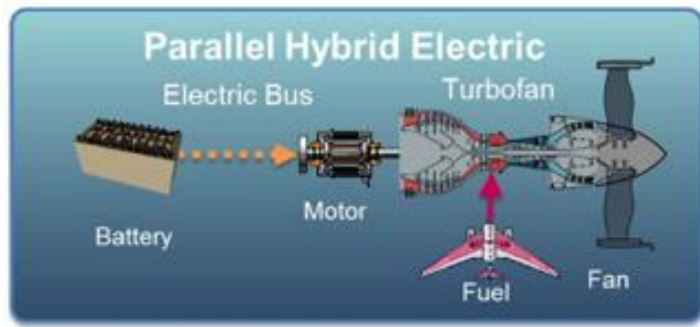
Representable Architectures

- Capable of representing all 6 electrified aircraft propulsion architectures outlined by NASA [3].
- Accomplished through the software reconfiguration of the rig.

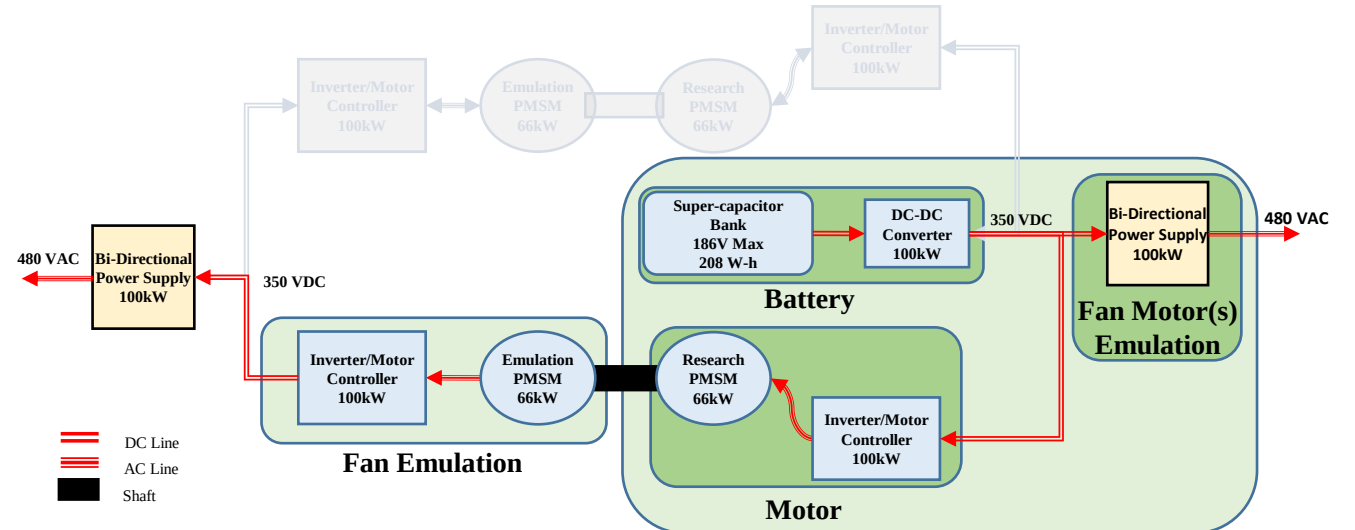
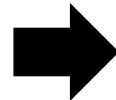
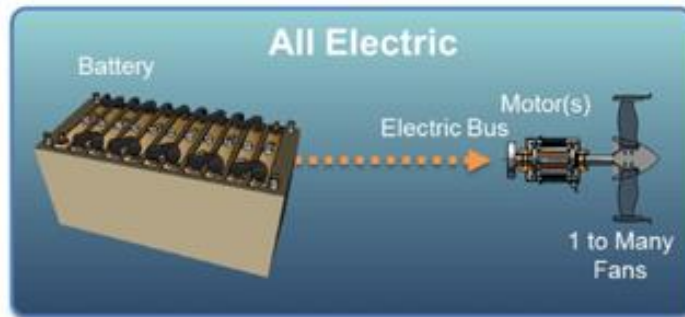


[3] Bowman, C. L., Felder, J. L., Marien, T. V., "Turbo- and Electrified Aircraft Propulsion Concepts for Commercial Transport," *AIAA/IEEE Electric Aircraft Technologies Symposium (EATS)*, Cincinnati, OH, 2018.

Representable Architectures – 1

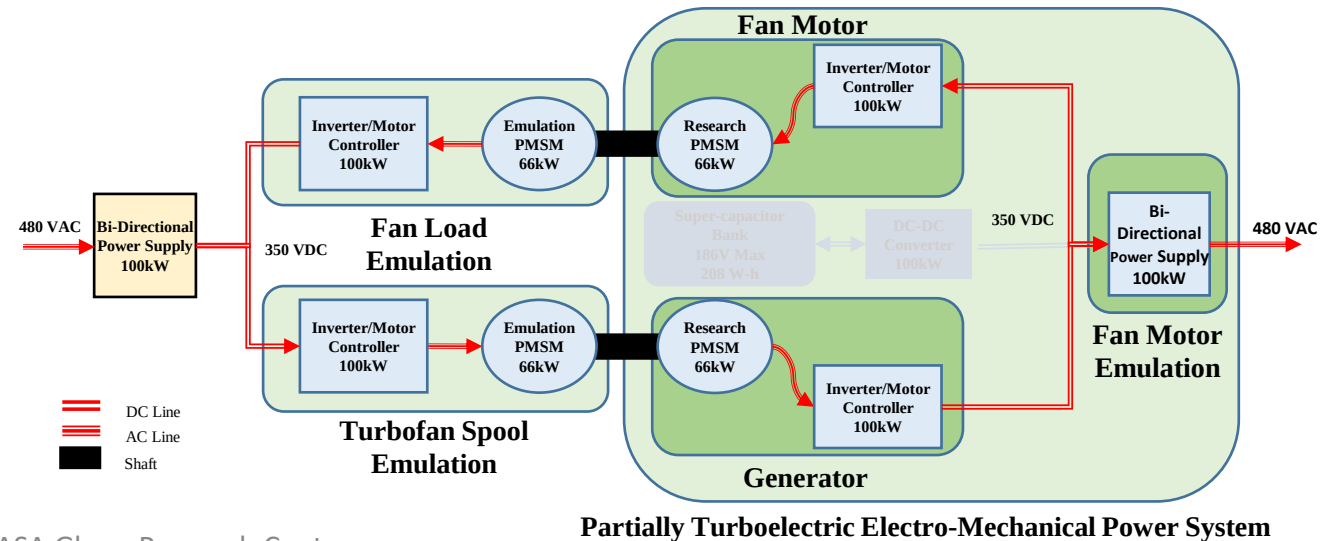
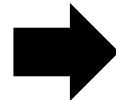
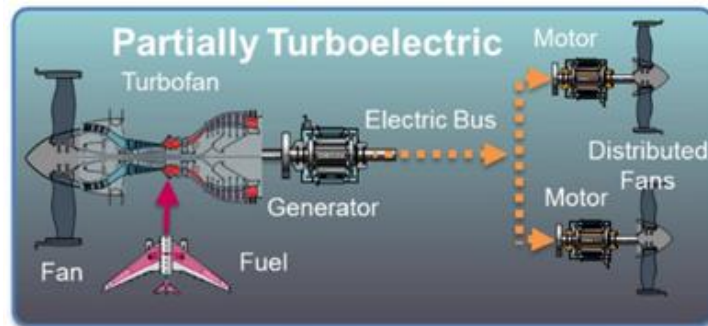
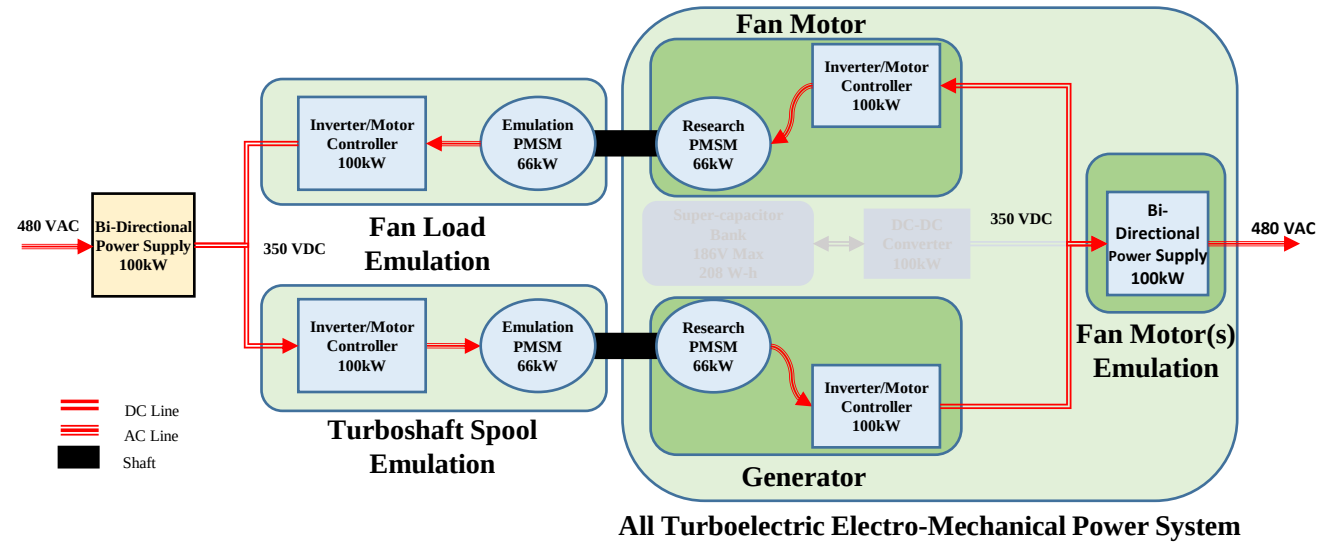
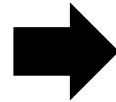
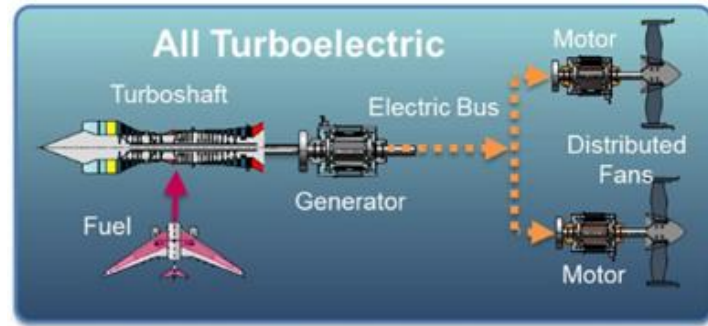


Parallel Hybrid Electro-Mechanical Power System

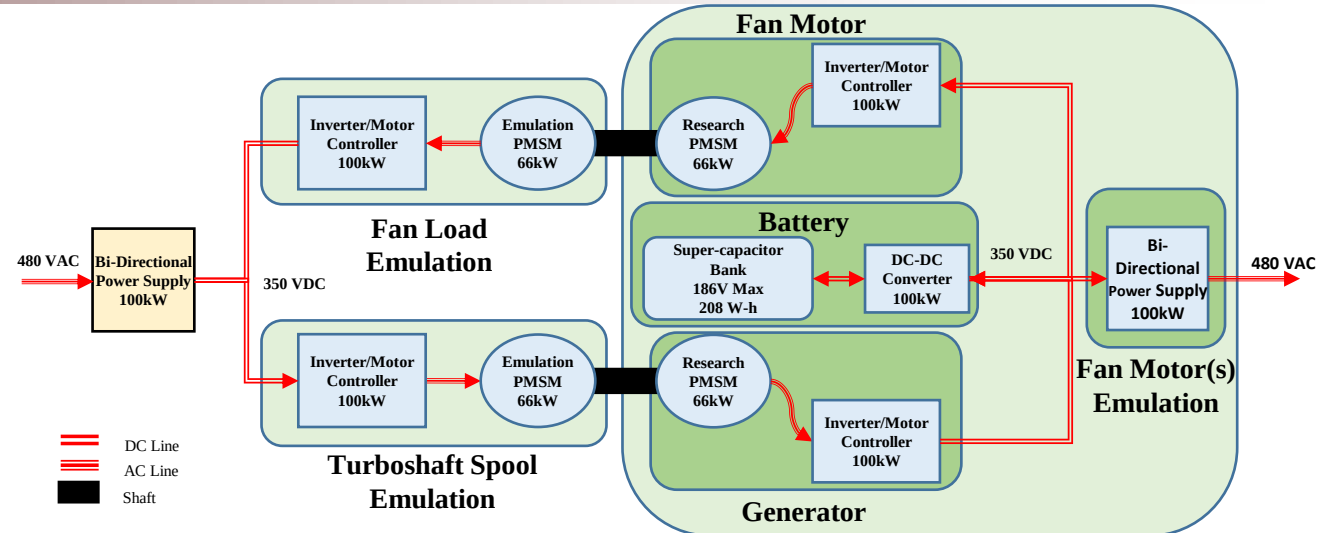
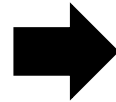
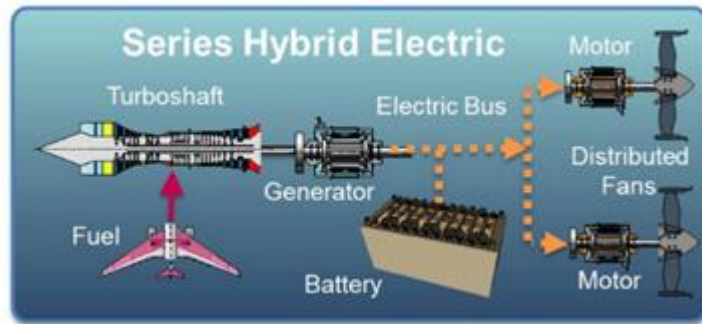


All Electric Electro-Mechanical Power System

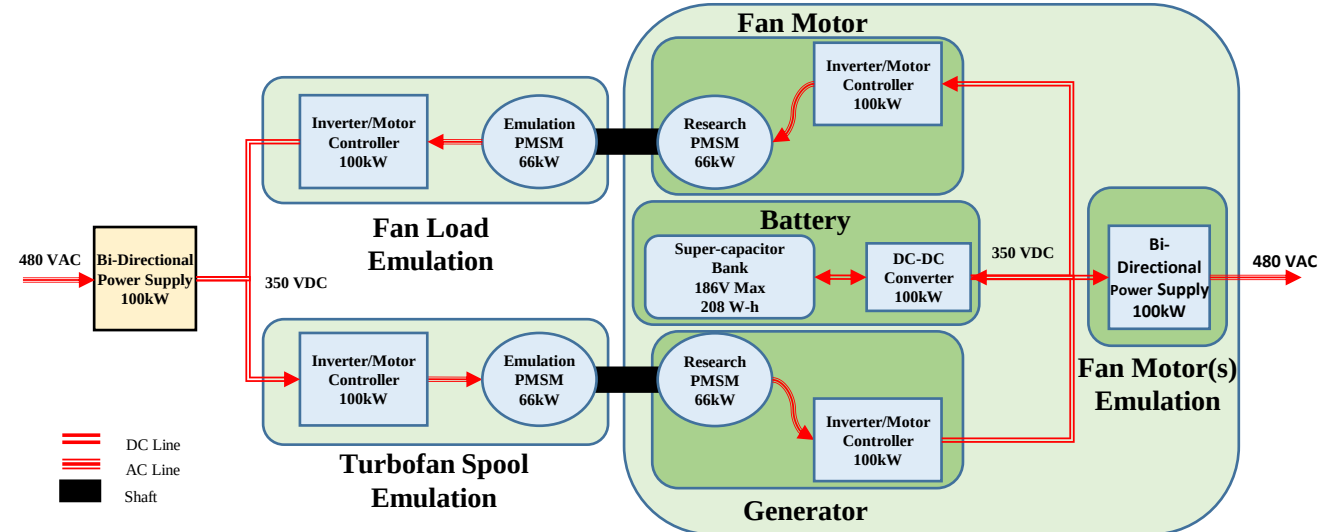
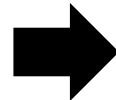
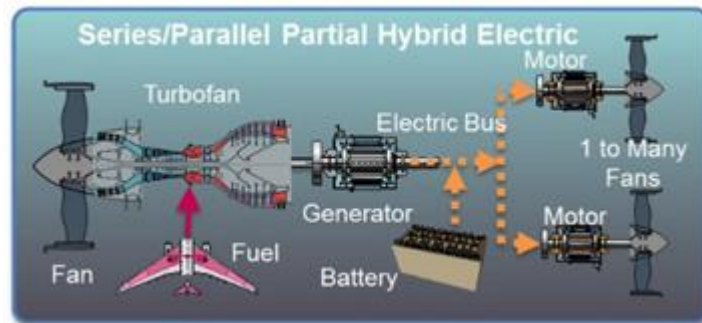
Representable Architectures - 2



Representable Architectures - 3



Series Hybrid Electric Electro-Mechanical Power System



Series/Parallel Partial Hybrid Electric Electro-Mechanical Power System

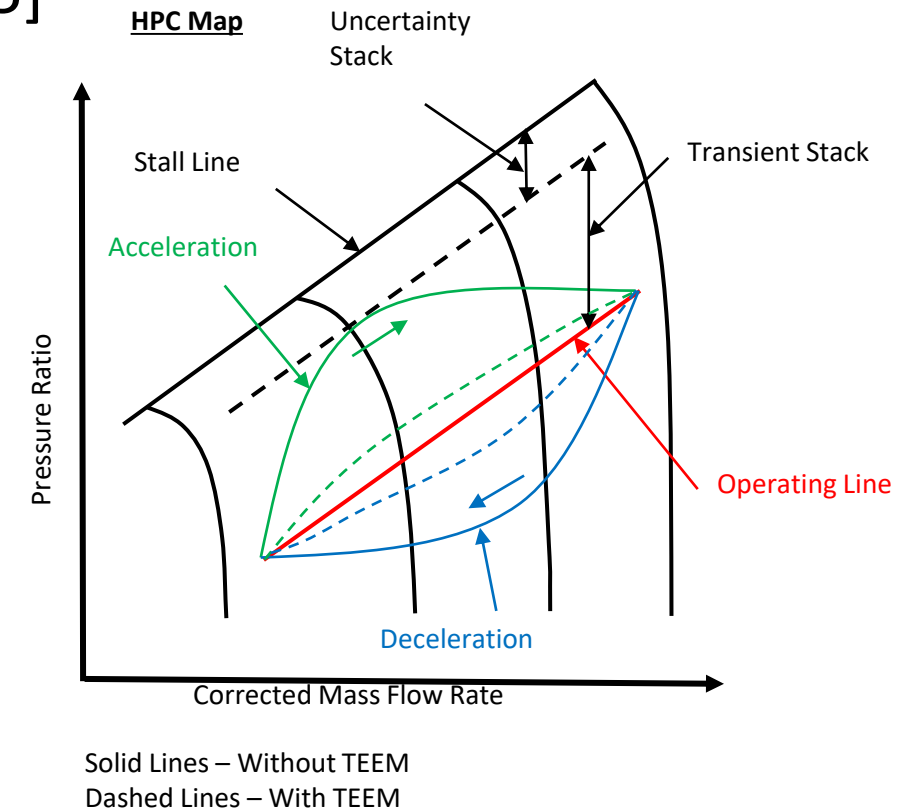
Past Research – 1 [6]

• Turbine Electrified Energy Management (TEEM) [4,5]

- Leverages an electro-mechanical system to improve operability during transients by keeping compressor operating points near/on operating line.
- Tested on:
 - Dual Spool Parallel Hybrid Turbofan [7]
 - Series/Parallel Partial Hybrid Turbofan

• Energy Extraction

- Shown ability to extract energy from emulated turbomachinery to power an emulated downstream electrical load.
- Tested on:
 - Series Parallel Partial Hybrid Turbofan



[4] Culley, D. E., Kratz, J. L., Thomas, G. L., "Turbine Electrified Energy Management (TEEM) For Enabling More Efficient Engine Designs," *AIAA Propulsion and Energy Forum*, Cincinnati, OH, 2018.

[5] Kratz, J. L., Culley, D. E., Thomas, G. L., "A Control Strategy for Turbine Electrified Energy Management," *AIAA/IEEE Electric Aircraft Technologies Symposium (EATS)*, Indianapolis, IN, 2019.

[6] Connolly, J. W., et al., "Electrified Aircraft Propulsion Controls Hardware Testing," *AIAA Aviation/Electric Aircraft Technologies Symposium (EATS)*, San Diego, CA, 2023.

[7] Bianco, S. J., et al., "Hybrid-Electric Aero-Propulsion Controls Testbed Results with Energy Storage," *AIAA Electric Aircraft Technologies Symposium (EATS)*, San Diego, CA, 2023.

Past Research – 2

- Dual Spool Parallel Hybrid with Turbine Electrified Energy Management (TEEM) control tested in HyPER. [7]
 - Engine: Advanced Geared Turbofan – 30,000 (AGTF30)
- Controller behaved as it would if full-scale engine and electrical system were present.

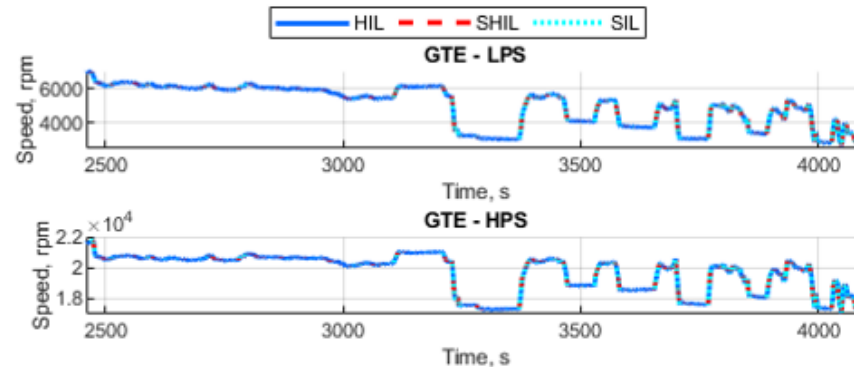


Figure 9. AGTF30 model low- and high-pressure shaft speeds during descent/landing.

[7] Bianco, S. J., et al., “Hybrid-Electric Aero-Propulsion Controls Testbed Results with Energy Storage,” *AIAA Electric Aircraft Technologies Symposium (EATS)*, San Diego, CA, 2023.

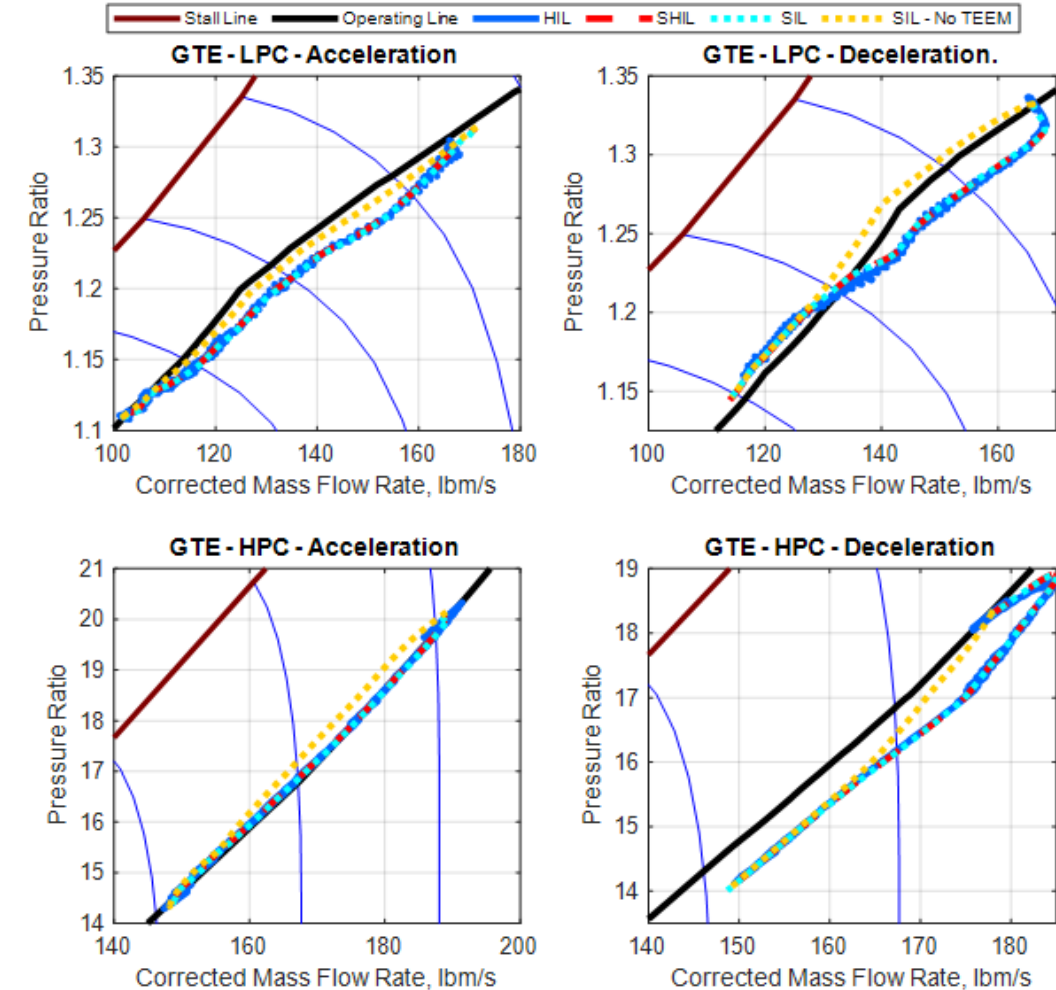
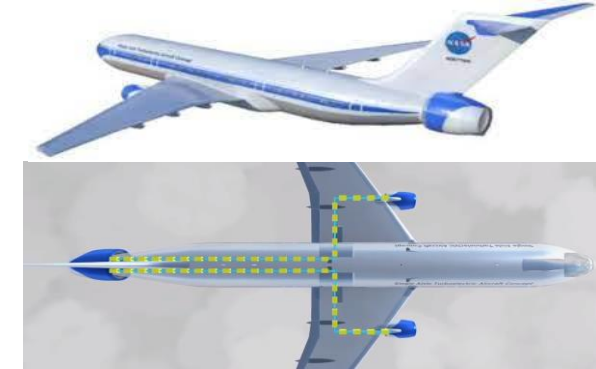


Figure 12. Compressor maps during largest acceleration and deceleration in full flight profile.

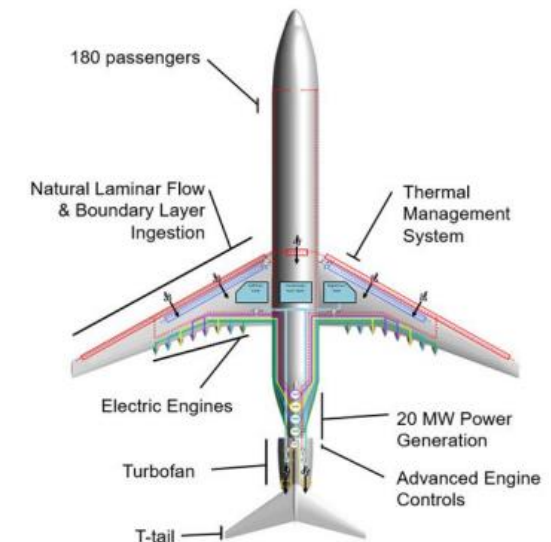
Envisioned Research

- Partial Turboelectric
 - Single-aisle Turboelectric AiRCraft with Aft Boundary Layer propulsion (STARC-ABL) [8]
- Series/Parallel Partial Hybrid
 - SUBsonic Single Aft eNgine (SUSAN) [9]
- Other electrified aircraft propulsion architectures.
- Fault Mitigation Algorithm Verification
 - Insertion of simulated faults and actual hardware faults
- Industry Partner/Customer
 - Control algorithm verification
 - Sub-scale electrical system hardware testing under realistic dynamic loading conditions.

STARC-ABL



SUSAN



[8] Connolly, J. W. et al., "Modeling and Control Design for a Turboelectric Single Aisle Aircraft Propulsion System," *AIAA Propulsion and Energy Forum/Electric Aircraft Technologies Symposium (EATS)*, Cincinnati, OH, 2018.

[9] Litt, J. S. et al., "Control Architecture for a Concept Aircraft with a Series/Parallel Partial Hybrid Powertrain and Distributed Electric Propulsion," *AIAA SciTech Forum*, National Harbor, MD, 2023.

