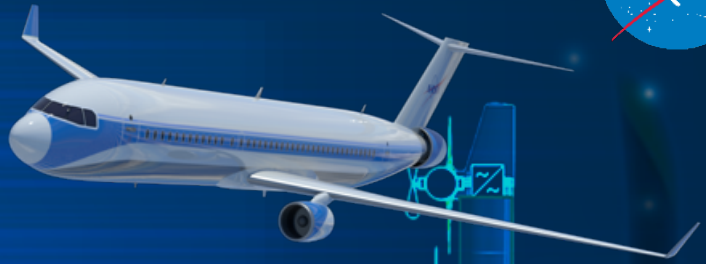
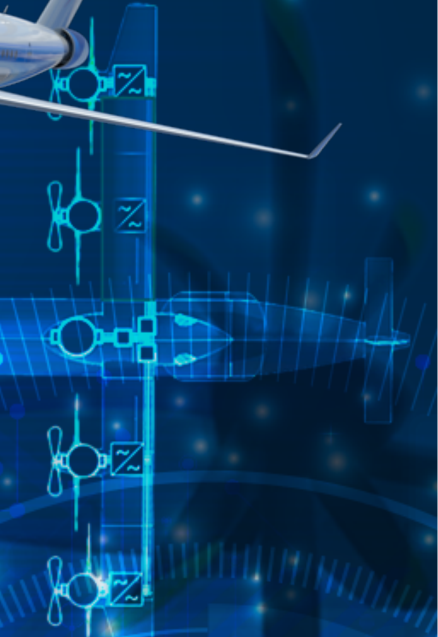


HEATheR

High-efficiency Electric Aircraft Thermal Research



Problem Statement:

Megawatt Electrical Aircraft Propulsion (EAP) systems:

- Produce large amounts of low-grade (<200C) waste heat
- Require large, heavy thermal management systems that cause drag

PI: Ralph Jansen (GRC) / Co-PI: Kevin Antcliff (LaRC), Aircraft Modeling Lead: Sydney Schnulo (GRC), Hardware Lead: David Avanesian (GRC)

Product / Market Applicability

Air vehicle applications that utilize Electric Aircraft Propulsion (EAP) systems with:

- Megawatt level power systems
- Electric, hybrid, or turboelectric EAP Systems
- Fixed wing or vertical takeoff and landing (VTOL) aircraft

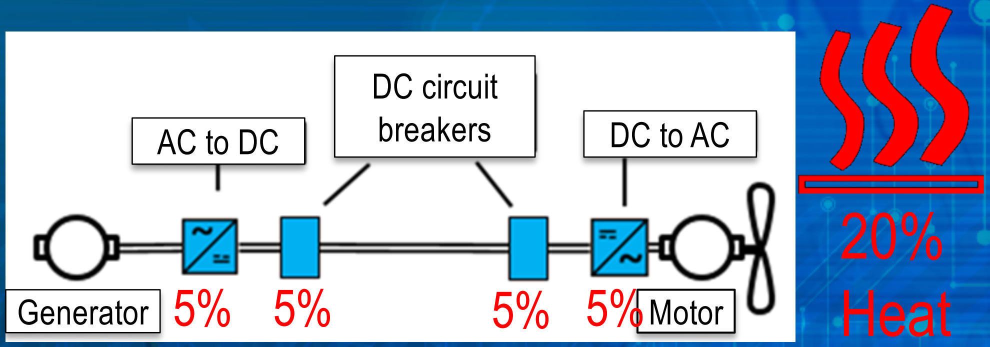

Market	Urban Air Mobility	Regional Air Mobility	Regional Turboprops & Turbofans	Single Aisle
Passengers	1-19	1-19	20-150	150-more
Speed	≈50-200 mph	≈150-250 mph	≈300-400 mph	≈500-700 mph
Range	≈25-200 miles	≈100-500 miles	500-1500 miles	1500-3500 miles
Power	≈1MW	≈1MW	1 to 5 MW	3 to 30MW
Heat	**≈200 kW heat**	**≈200 kW heat**	**200kw to 1MW heat**	**600kW to 6MW heat**

HEATheR's Two-Part Solution

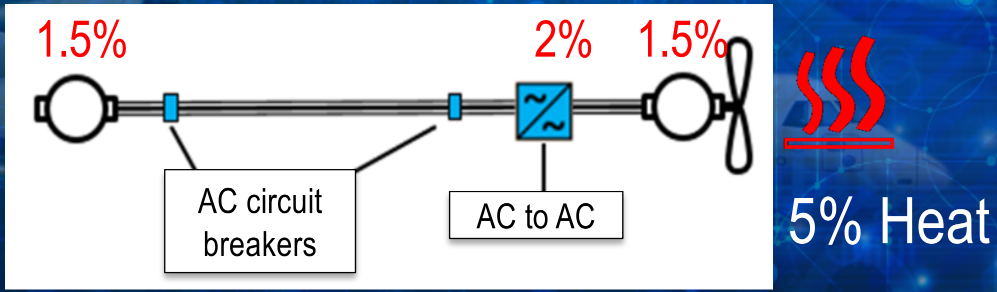
1. MINIMIZE THERMAL LOAD

- Reduce electric machine and converter losses by a factor of two or more relative to state of the art (SOA)
- Reduce the number of conversion steps

State of the art

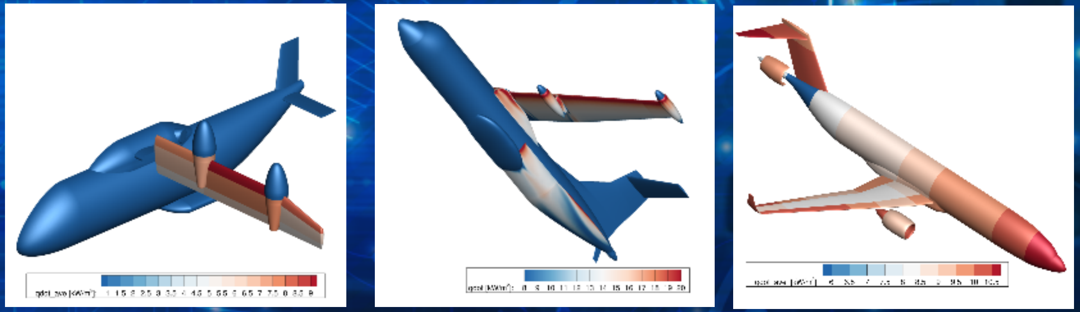


HEATheR



2. PROVIDE LOCAL, PASSIVE THERMAL MANAGEMENT

- Reject heat from electric machines and converters through the Outer Mold Line (OML) skin of the aircraft to reduce drag and power penalties.
- Transfer heat from the electrical components to the OML using passive heat transfer methods



OML Heat Transfer Limits Estimated

Aircraft Level Feasibility and Benefit

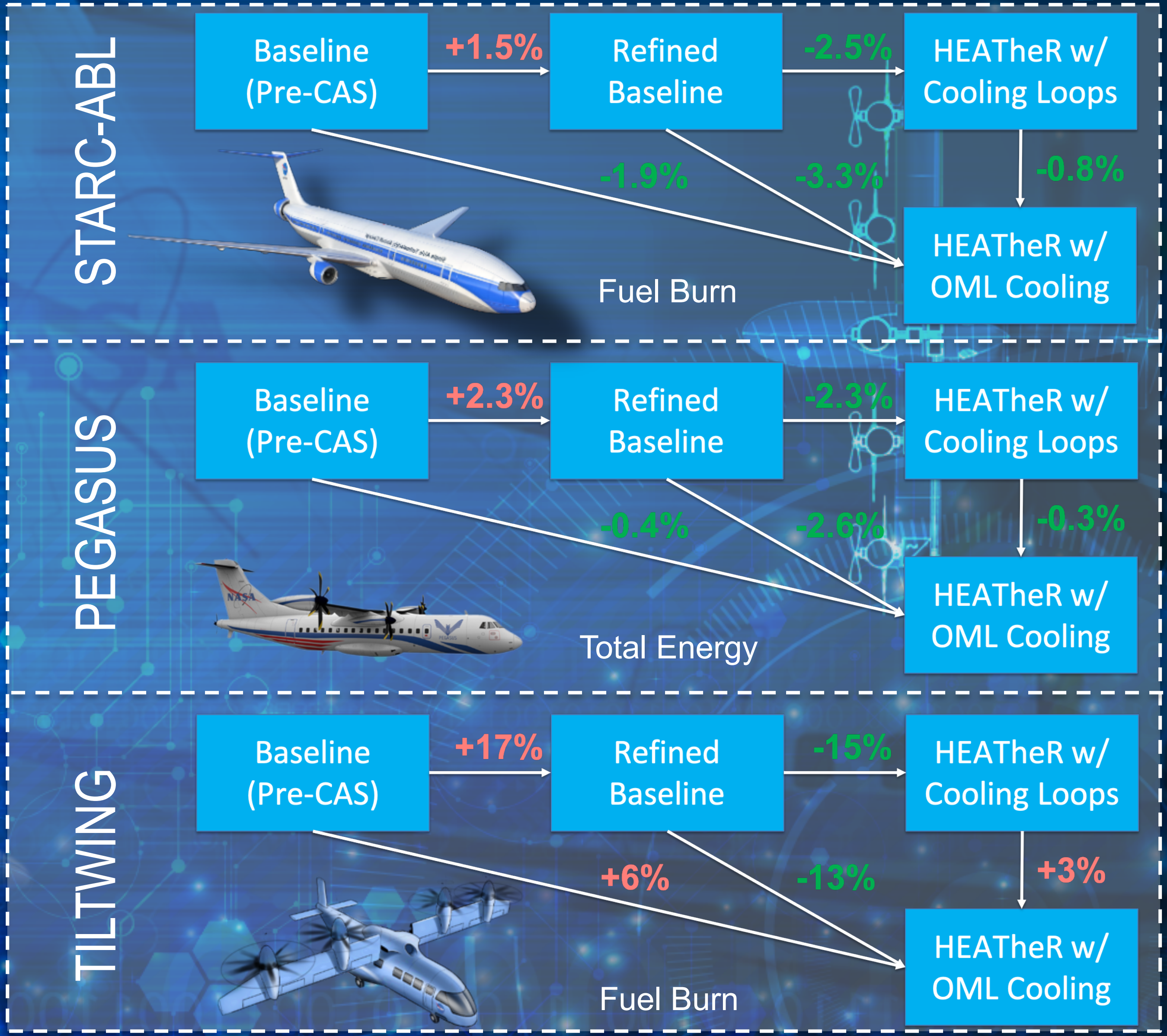
Analytical Aircraft Modeling was used to:

- Show the feasibility of the Outer Mold Line cooling approach
- The mission energy reduction benefits for three NASA conceptual aircraft.

	Baseline (pre-CAS)	Refined Baseline	HEATheR w/ Conv. Cooling	HEATheR w/ OML Cooling
Electric	Simplified DC	DC	AC	AC
Thermal	Simplified Thermal	Cooling Loop	Cooling loop	OML Cooling

Maximum Benefit:

- Single-Aisle: 3.3% fuel burn benefit
- Regional: 2.6% total energy benefit
- UAM: 15% fuel burn benefit



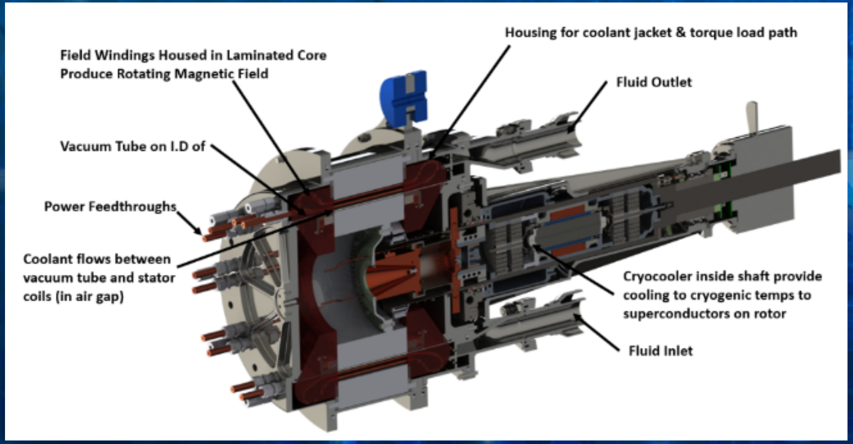
Electrical Component Feasibility

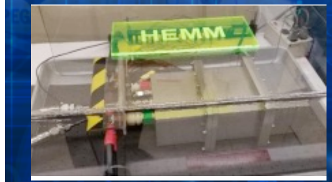
High Efficiency Megawatt Motor

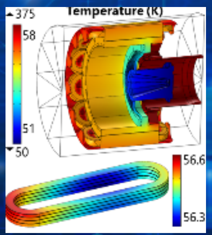
- Partially superconducting, synchronous, wound field machine
- Can operate as a motor or generator
- Combines a self-cooled, superconducting rotor with a slotless stator
- Exceptional specific power (>16kW/kg) and efficiency (>98%)
- No external cooling weight penalty

Current Status

- Preliminary design is complete
- Hardware demonstration of super conducting coil, statorette, and parts of the cryocooler of the motor was completed (TRL1-2)
- HEMM development continues under the AATT/Power & Propulsion Project (TRL3-4)





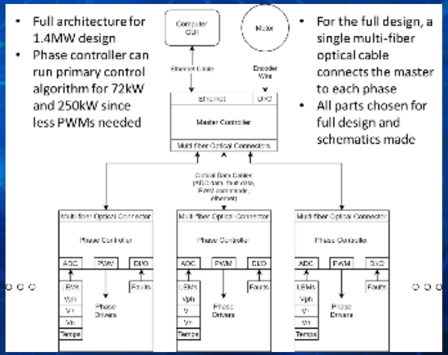


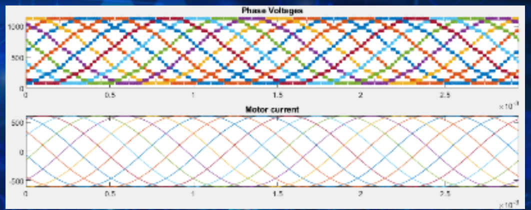
HEATheR Converter

- Bidirectional AC to AC converter
- Specific power goal of >10kW/kg
- Efficiency goal of 99%

Current Status

- Concept design is complete
- Hardware demonstration was completed for some control and power features (72kW prototype, TRL1-2)
- 250kW HEATheR converter development continues under the AATT/Power & Propulsion Project (TRL3-4)





Further Information

HEATheR IP and Publications

Patent IP Filed or under consideration for future filing	Status
"Wound Field Synchronous Machine"	Patent Application
"Novel Motor Drive Technology"	Abandonded
"Single Engine Transport Class Aircraft"	Provisional Patent
"Enabling Cable Technology for Megawatt Electrified Aircraft Propulsion"	New Technology Disclosure
"Waste Heat Anti-Ice System for Aircraft"	New Technology Disclosure

HEATheR Aircraft Modeling Publications	Document ID
"Outer Mold Line Cooled Electric Motors for Electric Aircraft"	AIAA-2020-3573
"Heat Flux Requirements for Electrified Aircraft Wing Anti-Ice Systems "	
"Development of a Thermal Management System for Electrified Aircraft"	AIAA–2020–0545 NASA/TM—2020-220473
"Computational Evaluation of an OML-based Heat Exchanger Concept for HEATheR"	AIAA 2020-3575
"Assessment of the Impact of an Advanced Power System on a Turboelectric Single-Aisle Concept Aircraft'	AIAA 2020-3548
"Thermal Management System Design for Electrified Aircraft Propulsion Concepts"	AIAA 2020-3571

HEMM Publications	Document ID
"High Efficiency Megawatt Motor Preliminary Design"	AIAA 2019-4513
"Thermal Analysis of Potted Litz Wire for High-Power-Density Aerospace Electric Machines"	AIAA 2019-4509
"Progress Toward the Critical Design of the Superconducting Rotor for NASA's 1.4 MW High-Efficiency Electric Machine"	AIAA 2019-4496
High Efficiency Megawatt Machine Rotating Cryocooler Conceptual Design"	AIAA 2019-4515
"High Efficiency Megawatt Motor Risk Reduction Activities"	AIAA-2020-3559
"Electromagnetic Redesign of NASA's High Efficiency Megawatt Motor"	AIAA-2020-3600
"High Efficiency Megawatt Motor Thermal Stator Preliminary Design"	AIAA-2020-3602
"Design, Analysis, and Testing of the HEMM Cryocooler Linear Motor"	AIAA-2020-3601
"Select Variables Affecting Thermal System Design of a Liquid-Cooled Stator"	

For further information or inquiries please contact the Convergent Aeronautics Solutions Transition Manager: Jessica Reinert
jessica.m.reinert@nasa.gov