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M3Or4A-05: [Invited] Superconducting Electric Machine with Cryogenically Cooled Stator for CHEETA

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Superconducting electrical machines are emerging as transformative technologies for electric propulsion, with several ongoing efforts focused on advancing their development. This paper highlights significant progress in developing a superconducting electric machine with a cryogenically cooled stator under the Center for High-Efficiency Electrical Technologies for Aircraft (CHEETA) project. An extensive experimental campaign is underway to mitigate risks in critical subsystems and ensure the successful demonstration of the prototype motor.

CHEETA envisions a groundbreaking approach to electric aviation, utilizing a hydrogen-powered system featuring a 2.5 MW fully superconducting electric machine for a full-scale aircraft. In this system, hydrogen serves as both fuel for fuel cells and coolant for the electrical system. By leveraging cryogenic cooling without incurring weight or efficiency penalties, the motor achieves an impressive efficiency of over 99.9% and a specific power exceeding 25 kW/kg.
The conceptual design of the 2.5 MW fully superconducting electric machine poses significant challenges, including superconducting winding manufacturing, thermal management, and handling AC losses. To address these, the CHEETA project is developing a cryogenically cooled superconducting motor that employs aluminum litz wires in the stator instead of superconductors. This approach eliminates the need to operate the stator at 20K, allowing the use of liquid nitrogen (LN2) for stator cooling. To further mitigate technological challenges and reduce risks, Hinetics is developing a 750-kW cryogenically cooled electric machine with innovative cooling solutions for both the stator and rotor.

Key advancements in the CHEETA motor demonstrator include:
• Rotor-mounted Stirling-cycle cryocooler: Integration of a commercial off-the-shelf (COTS) Stirling-cycle cryocooler into a rotationally compatible configuration for closed-loop conduction cooling.

• Cryogenic thermal management system (TMS): A novel coil suspension system that transfers torque between the cold field winding assembly and the warm rotor shaft while minimizing conduction heat loads to the cryocooler, along with innovative methods to reduce radiation heat leakage to less than 10 W.

• Quench-tolerant HTS magnets: Passive quench tolerance of conduction-cooled, no-insulation (NI), double-pancake (DP) high-temperature superconducting (HTS) magnets.

• Lightweight slotless air-core armature: Designed to handle high dB/dt levels generated by the superconducting rotor field, with effective cryogenic cooling using LN2.

To mitigate risks associated with the motor, Hinetics has conducted several risk-reduction experiments. A rotor-mounted cryocooler has been tested for up to 100 hours of operation under load, including vibration and shock tests following military standards. The full-scale rotor has been cooled using an integrated cryocooler with advanced radiation management. A rotational multilayer insulation (MLI) system has been developed and validated for mechanical performance during rotation. Spokes have been tested for rated tension, and the full rotor assembly has been validated for the motor's rated torque. No-insulation (NI) coils have been manufactured and tested for quench performance. Aluminum litz wire resistance has been measured at liquid nitrogen temperatures to validate its residual resistivity ratio (RRR). Stator samples have been manufactured and cooled with LN2 to evaluate thermal expansion mismatch and other thermal properties.

Hinetics is currently prototyping the motor, with testing planned for late 2025. This paper provides a comprehensive overview of the CHEETA demonstration motor, alongside updates on risk-reduction efforts, including electromagnetic (EM) design, thermal and mechanical design, risk-reduction experiments, and detailed test plans. The entire drivetrain is scheduled for testing at the POETS test facility in Champaign, Illinois, in 2026. These efforts contribute to advancing the field of superconducting electric propulsion, paving the way for cleaner and more efficient air transportation.

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