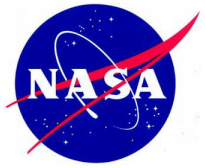


High Efficiency Megawatt Motor Stator Thermal Performance

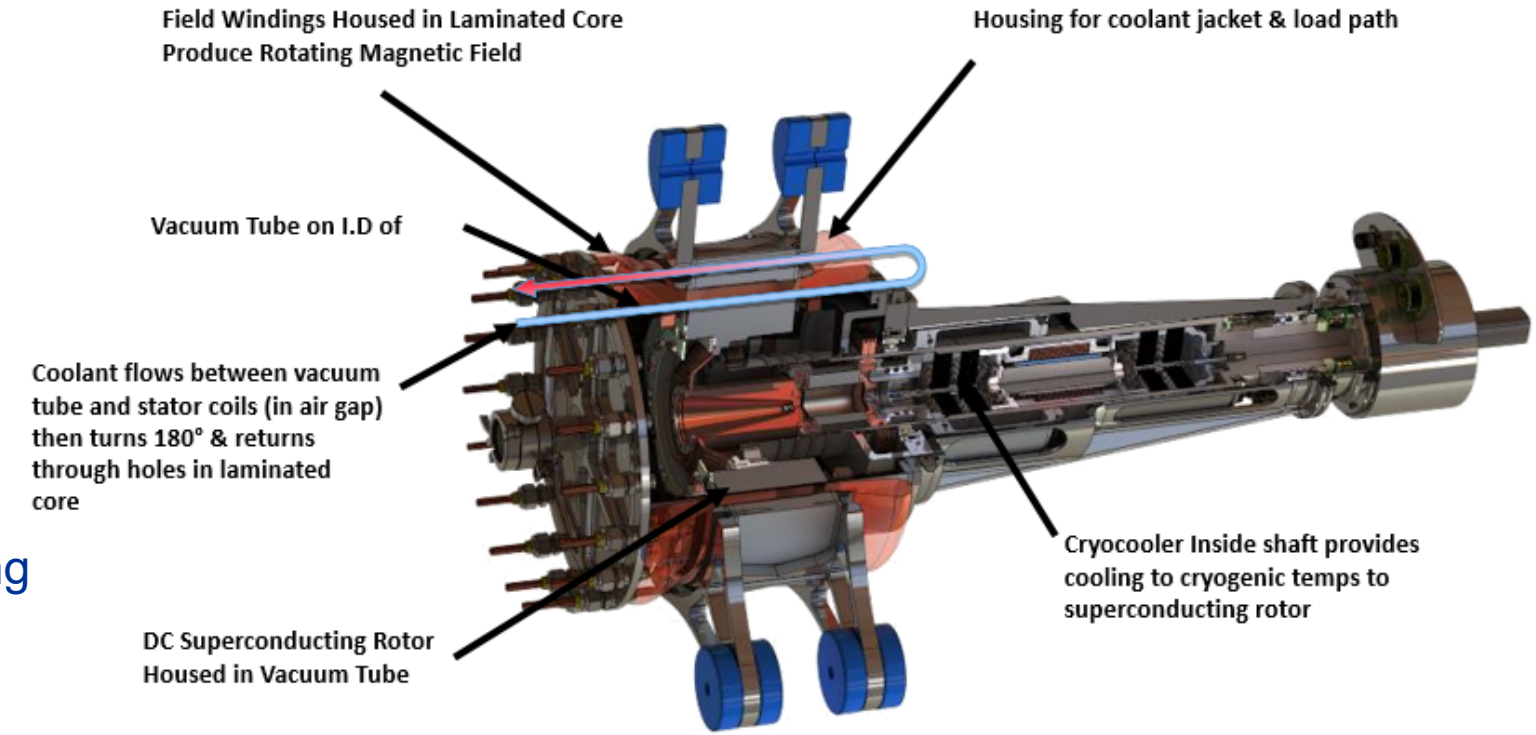
Andrew A. Woodworth, William R. Sixel, and Ralph H. Jansen
NASA Glenn Research Center, Cleveland, Ohio 44135 USA

Gerald Szpak
HX5, *LLC Brook Park Ohio 44142 USA*

Electric Aircraft Technology Symposium
July 29-31, 2024
Las Vegas, NV, USA

High Efficiency Megawatt Motor (HEMM)

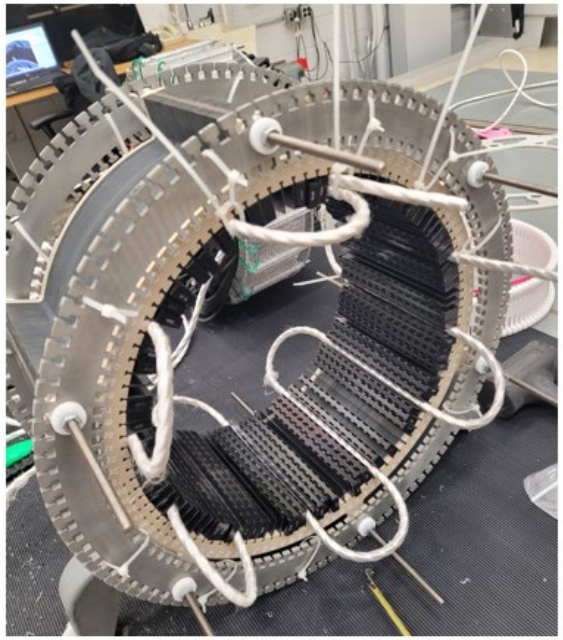
- 1.4 MW
- > 98% efficient
- 16 kW/kg active components
- Superconducting rotor
  - Cryocooler
- Cu Litz wire stator
  - 9 phases (108 slots)
  - 420 A AC operation
  - PAO (Polyalphaolefin) direct cooling
  - 60 °C oil temperature
  - 200 °C max operation

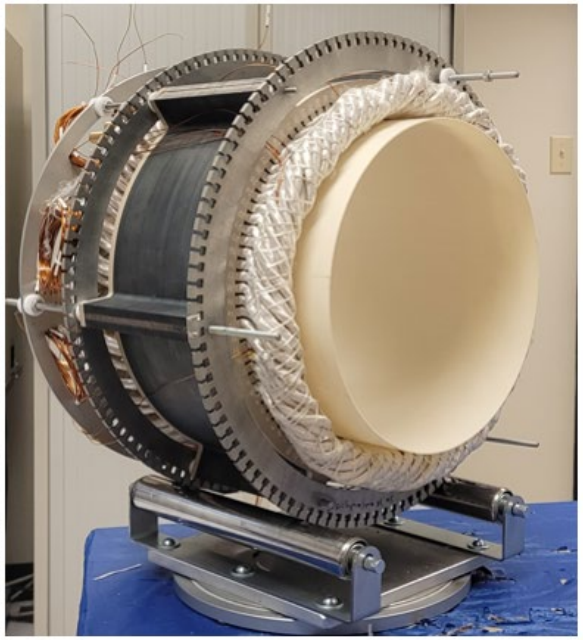


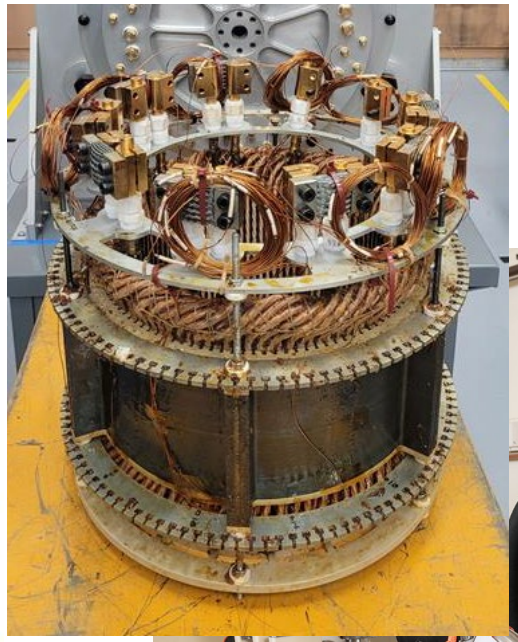
[1] Jansen, R., et al., "High Efficiency Megawatt Motor Risk Reduction Activities," *2020 AIAA/IEEE Electric Aircraft Technologies Symposium*, 2020.
[2] Woodworth, A., *et al.*, "Thermal Analysis of Potted Litz Wire for High Power Density Aerospace Electric Machines," *AIAA Propulsion and Energy 2019*
[3] Szpak, G., *et al.*, "High Efficiency Megawatt Motor Thermal Stator Preliminary Design," *2020 AIAA/IEEE EATS*, 2020.
[4] Woodworth, A., *et. al.*, "Select Variables Affecting Thermal System Design of a Liquid-Cooled Stator," *AIAA/IEEE EATS*, 2020.
[5] Chapman, J. W., *et al.*, "Update on SUSAN Concept Vehicle Power and Propulsion System," *AIAA Science and Technology Forum*, 2023.
[6] Tallerico, T. T., *et al.*, "Electromagnetic redesign of NASA's high efficiency megawatt motor," *AIAA/IEEE EATS*, 2020.

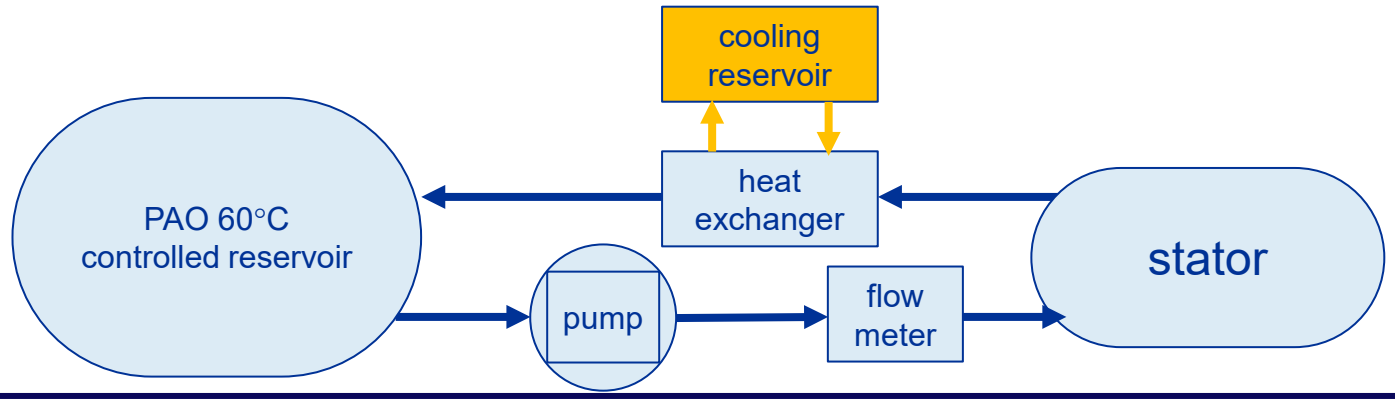
EATS = Electric Aircraft Technologies Symposium

Stator build and test setup

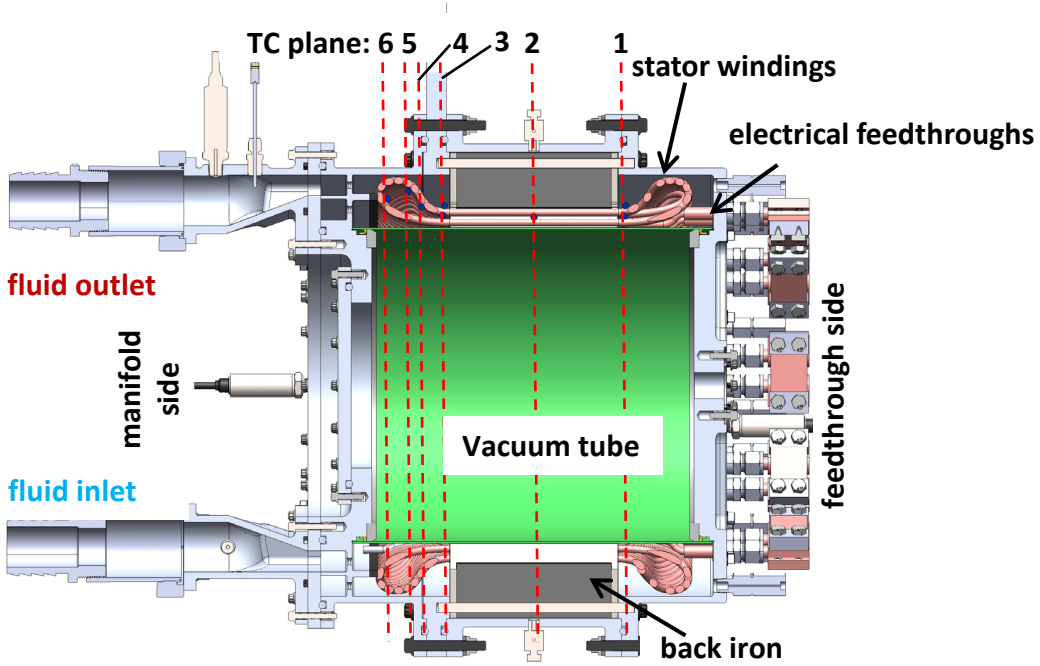


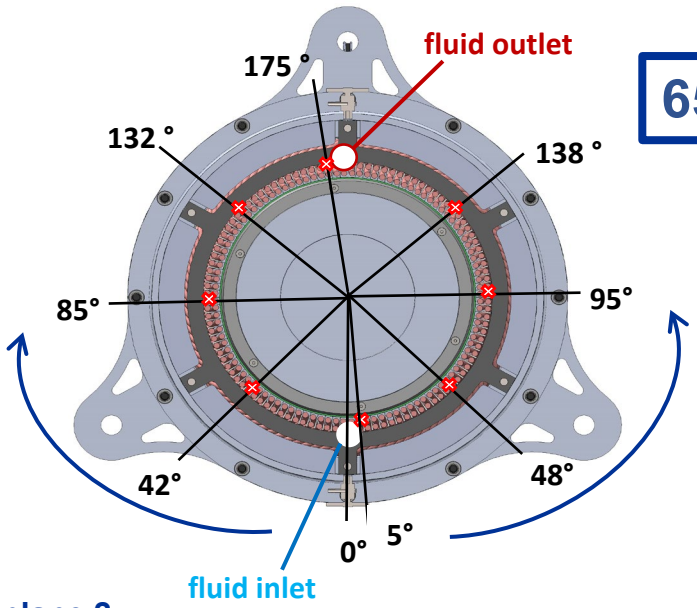




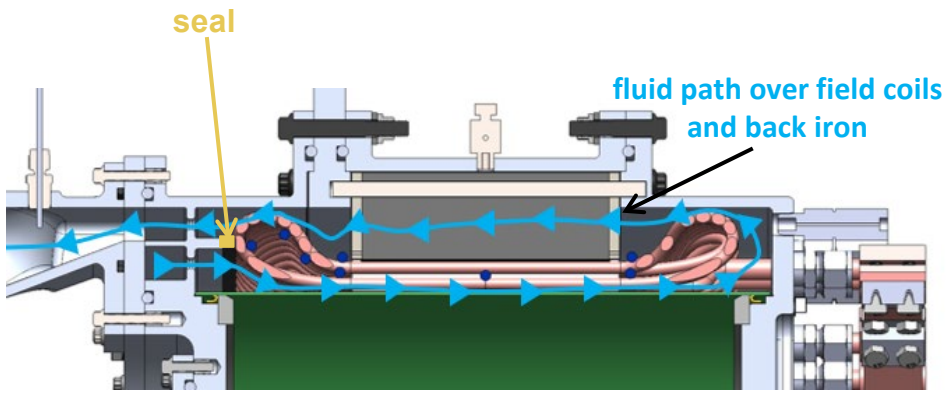


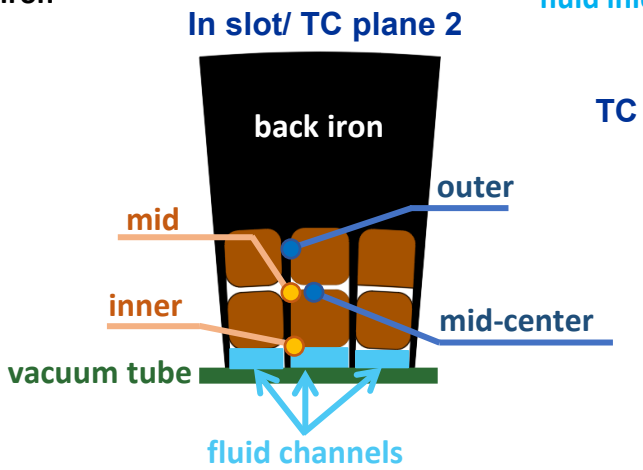
Design & Instrumentation

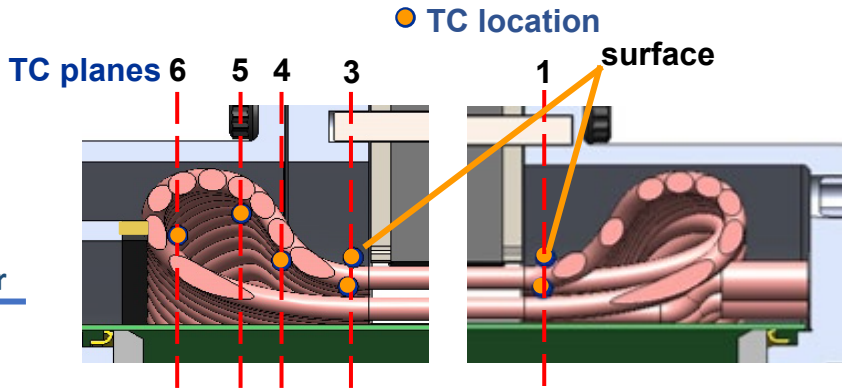




65 imbedded TCs

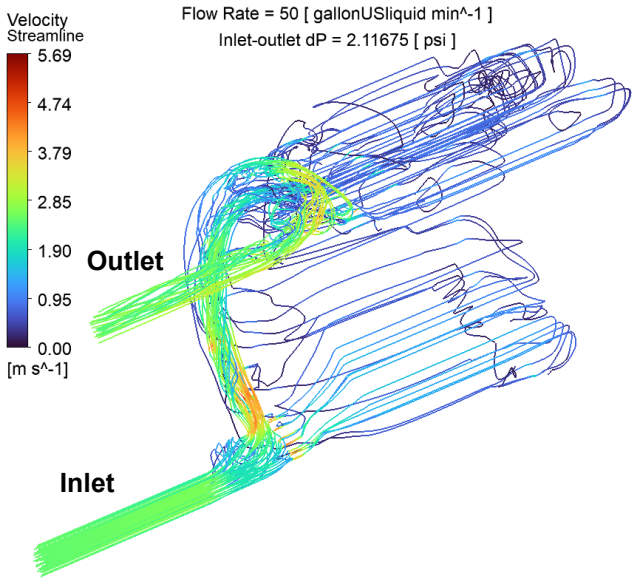


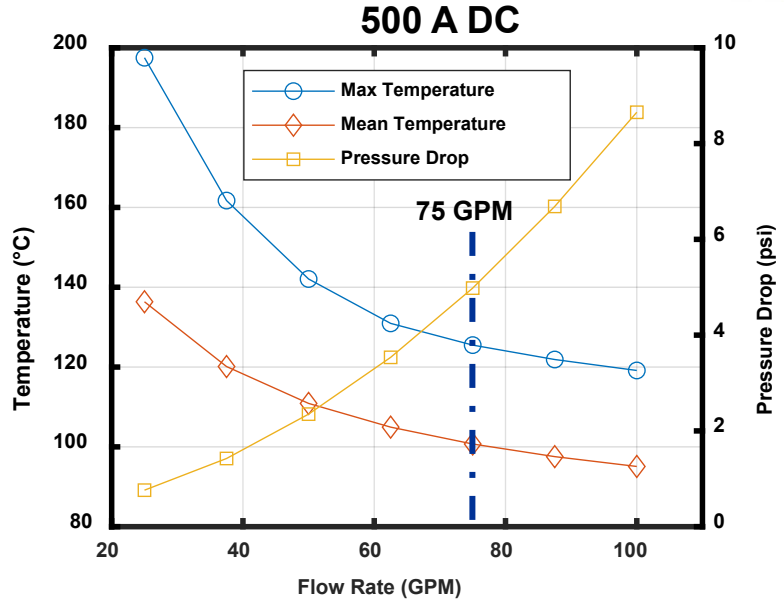


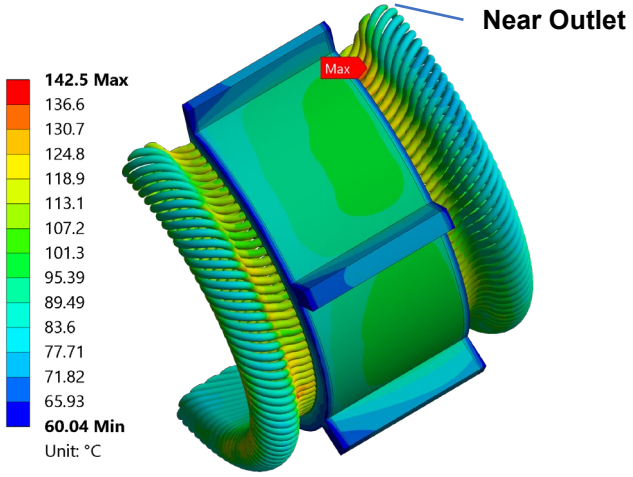


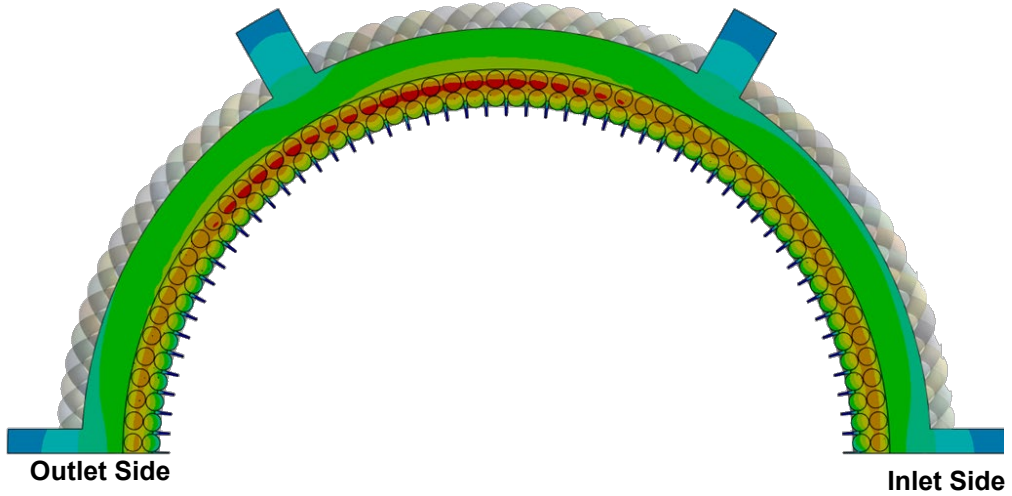
Half symmetry CFD model

- Prediction of hotspot locations
- Prediction of max and mean temperatures
- At 500 A DC, 25 GPM is the minimum flow rate
- Prediction ~75 GPM being the optimal flow



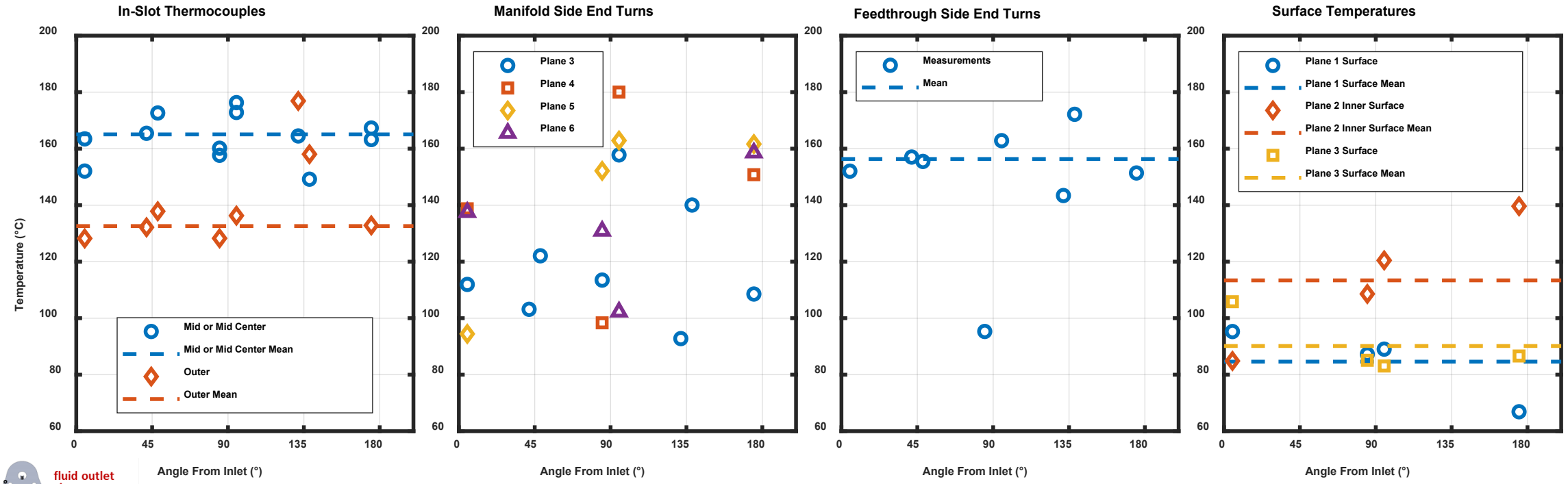


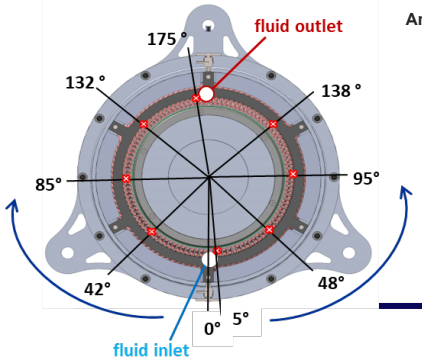




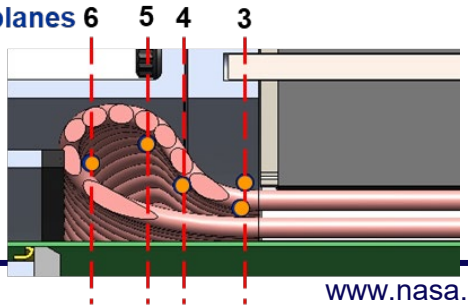
Results

- 14 test conditions run
- 25 -100 GPM
- ~400 to ~500 A DC
  - One point at ~300 A DC
- 25.1 GPM
  - 185 °C @ 449.5 A
  - 50 GPM was successful
- 75 GPM was verified as the optimal for min losses





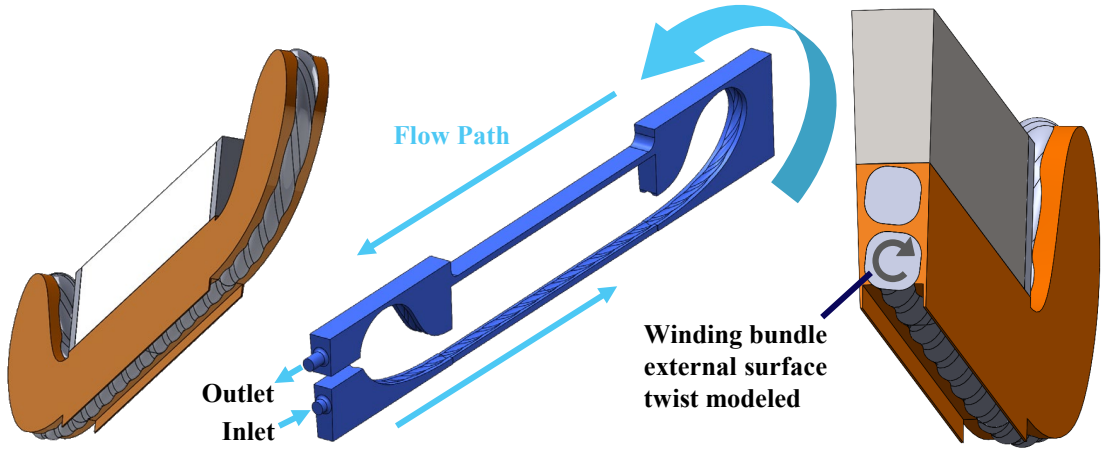
plane 1 mid

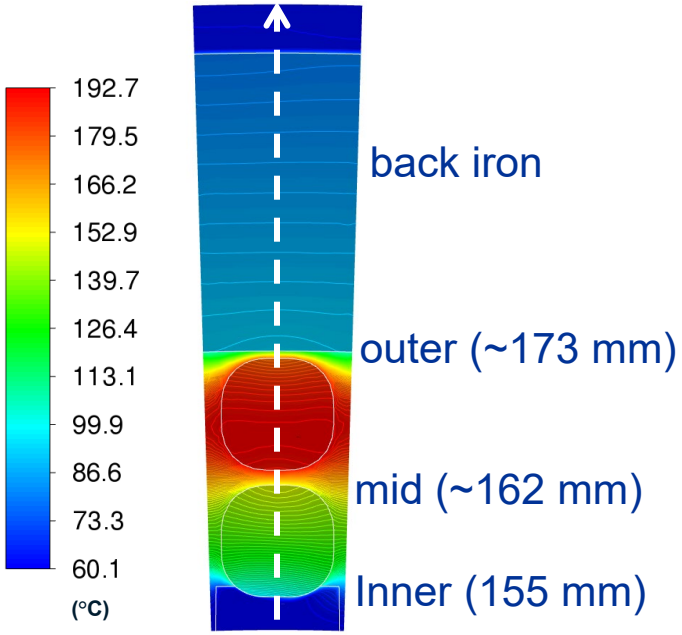


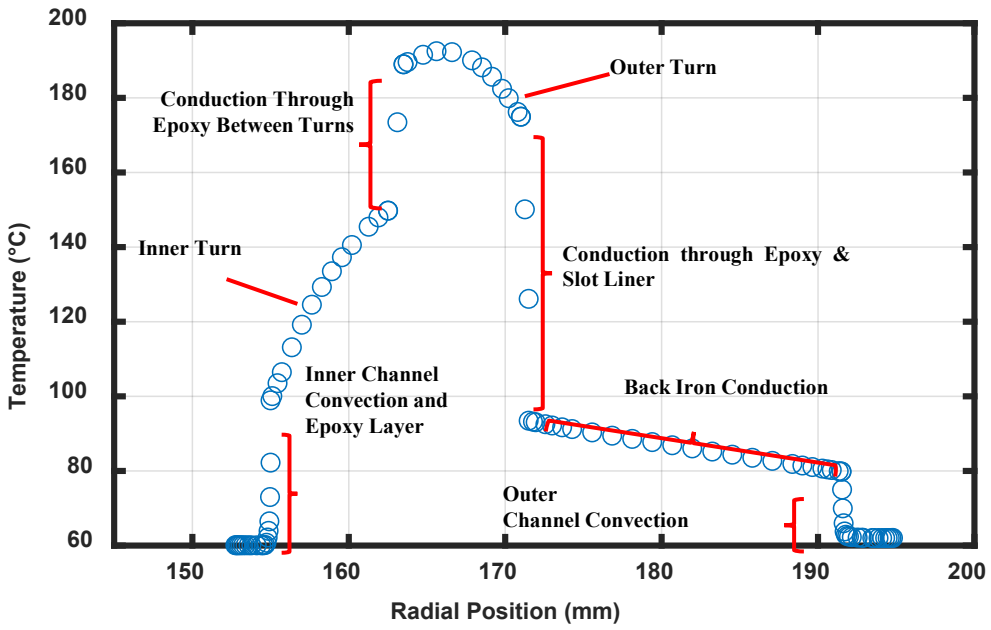
Test Condition: 499.8A, 75 GPM

Single-Slot Conjugate CFD Model

- The interface between turns was determined to be non-adiabatic
- High thermal gradients not previously predicted
- Small in-plane difference in position of TC and model location can drive large temperature differences
- Determined the transverse thermal conductivity to be 4.5 W/(m · K)

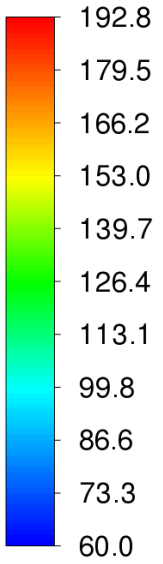


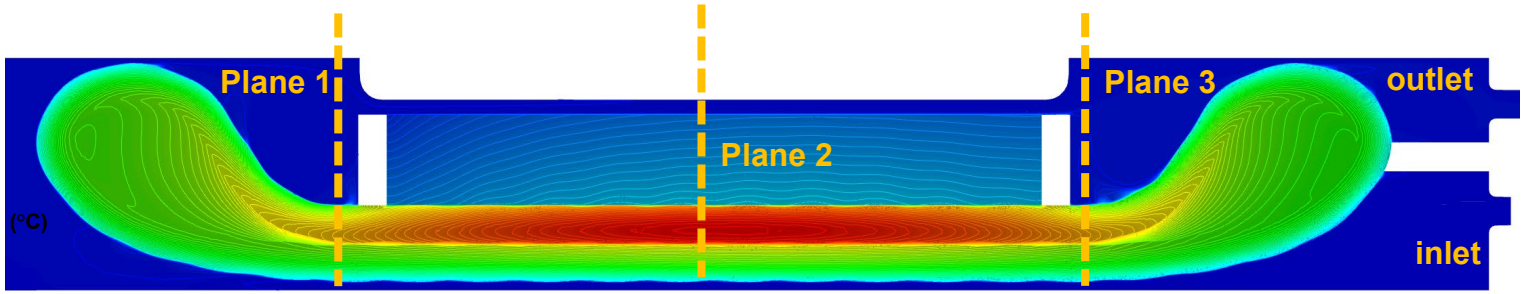


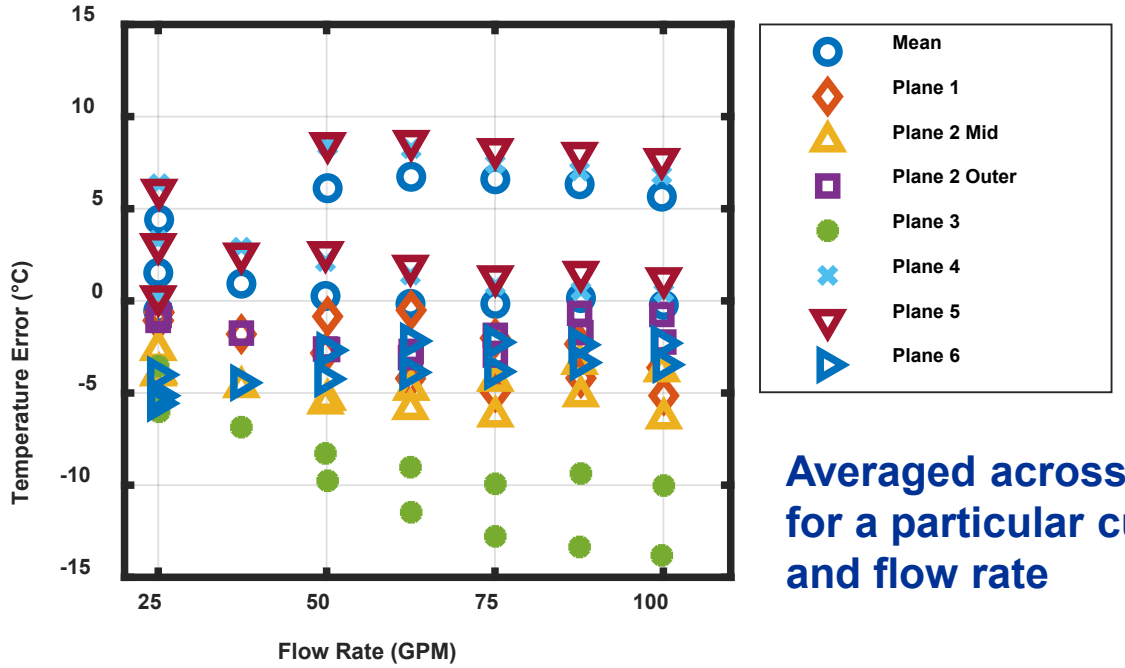


Single-Slot Conjugate CFD Model (continued)

- A slight asymmetry in the lot temperature
- Most predictions within +/- 5 °C







Averaged across slots for a particular current and flow rate

$$T_{error} = T_{measured,avg} - T_{CFD}$$

Conclusions

- A 1.4 MW full scale stator was fabricated, instrumented, and tested to validate the thermal design and further develop stator fabrication techniques.
  - Testing demonstrated operation at 500 A (> 420 A requirement)
  - Measured winding temperature below 200 °C, at a minimum flow rate of 50 GPM,
- Models did accurately predict an optimal flow rate of ~75 GPM
- An improved estimate of the winding transverse thermal conductivity was determined (4.5 W/(m•K))
- There is much room for improvement in both the design of cavity around the end turns as well as the modeling of the end turns

Acknowledgments

- This work is sponsored by:
  - NASA Advanced Air Transportation Technologies project's Aircraft Electrification subproject
    - Amy Jankovsky Project Manager
  - Convergent Aeronautics Solution HEATheR Activity performed at NASA Glenn Research Center.
- Special thanks to
  - Daniel Scheiman
  - Frank Gaspare
  - William Torres
  - Andrew Smith
  - Zach Wong
  - Don Fong
  - Casey Theman