TFAWS Active Thermal Paper Session

Thermal-Fluid Analysis of a Liquid-Cooled Battery Module for Electrified Aircraft

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Agenda

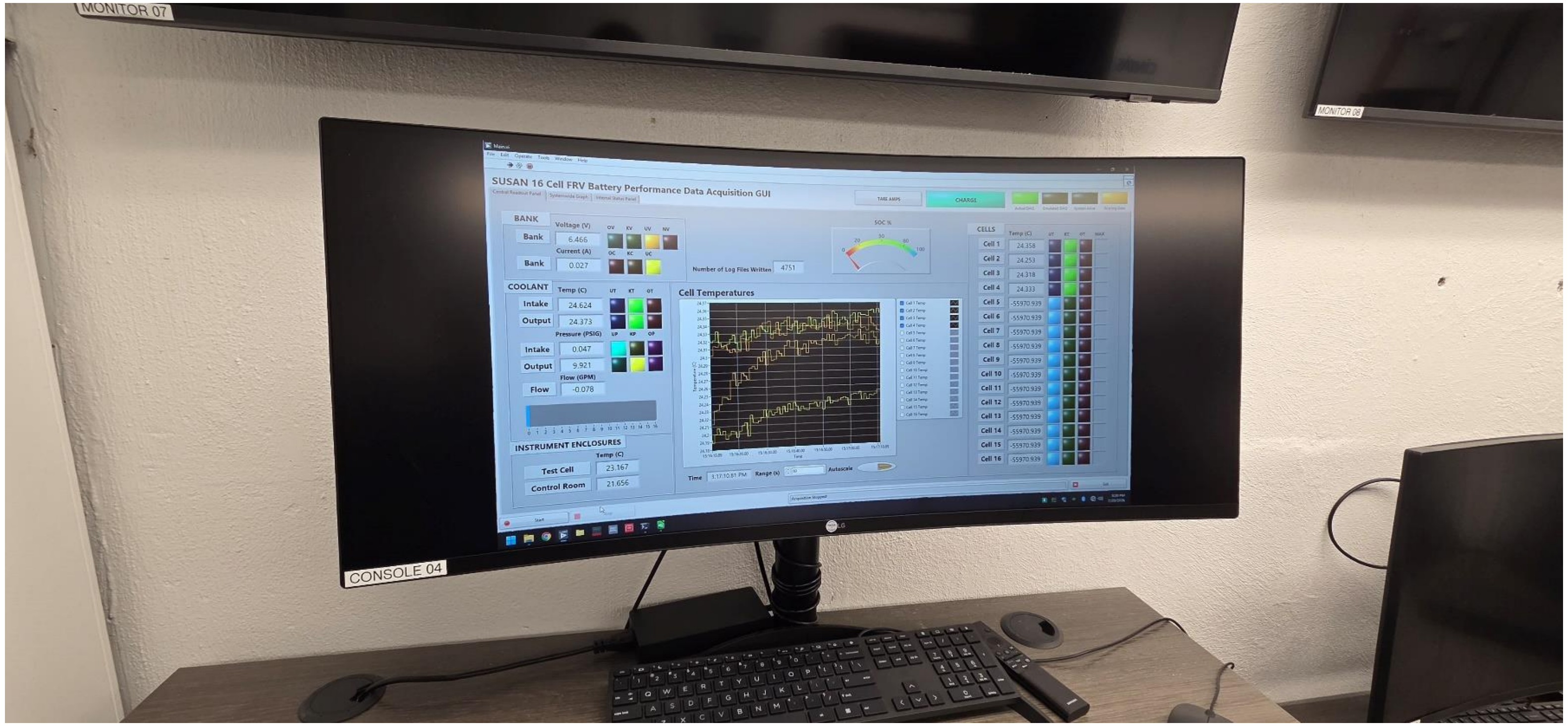
- Introduction
- Test Setup
  - Hardware & Facility
- Results
  - Experiment & Analysis
- Conclusions

Motivation

- Objective: to research, develop, and test batteries for hybrid and electrified aircraft.
  - Focus → safe, energy-dense batteries for commercial aviation
- Battery research and testing to
  - Increase the benefits of hybrid-electric or fully electrified aircraft.
  - Enable new configurations and missions for electrified aircraft and drones.
- Approach
  - Use the best available battery cells from U.S. industry to build integrated battery modules.
  - Conduct research on battery chemistries with very high performance and safety potential.
  - Gain the ability to test industry and NASA battery systems for performance and safety.

Performance Testing

- Cycling of battery module, charge/discharge rates (C-Rates) defined in the test plan
  - Testing of key components within newly-designed battery module
  - Passive and active thermal management techniques
  - Innovative packaging concepts and electrical components



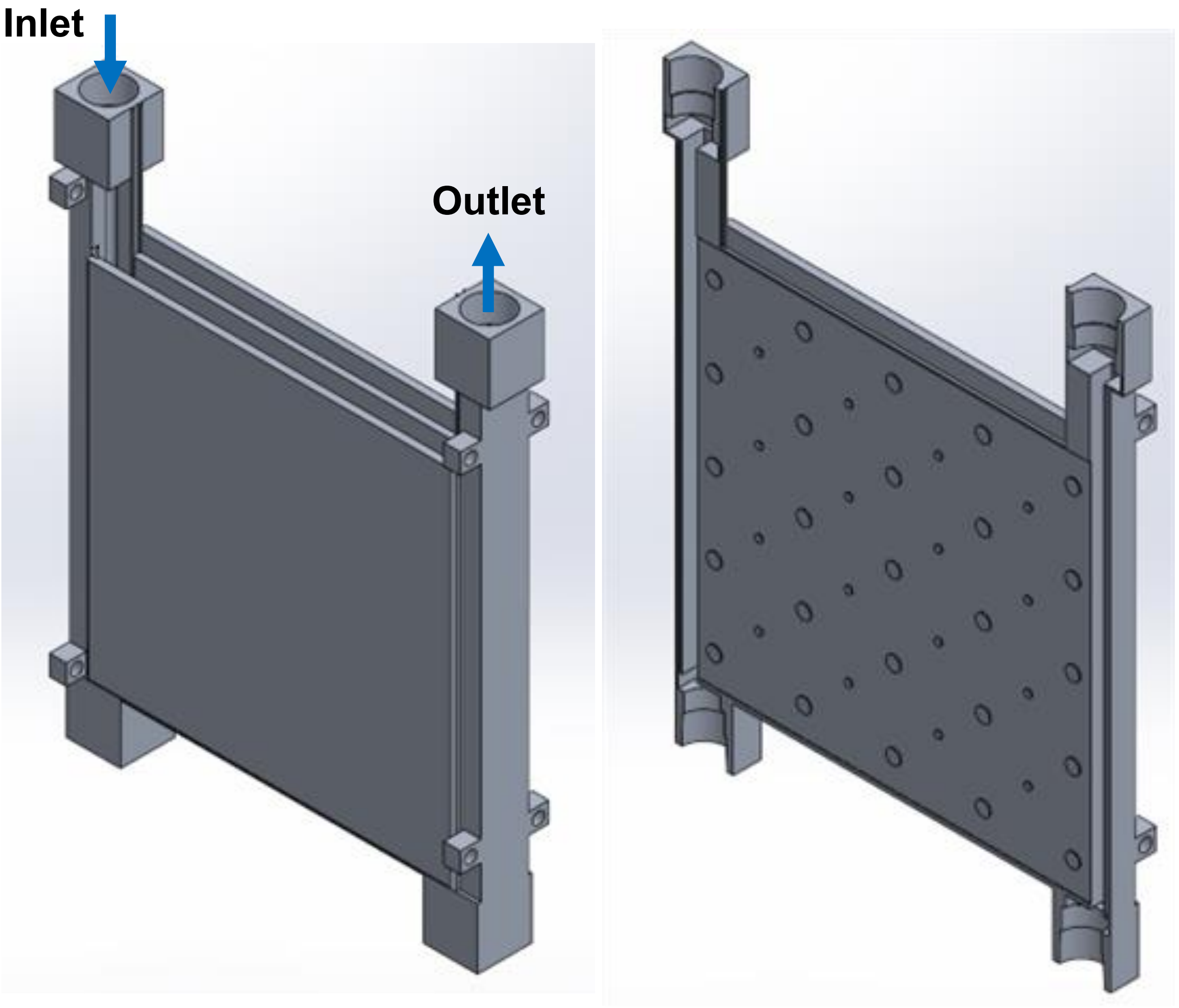
Battery Enclosure

- Built using Direct Metal Laser Sintering (DMLS) additive manufacturing (AM) to incorporate advanced cooling methods utilizing complex geometries.

- Material
  - 6061 Aluminum

- Comparison:
  - DMLS offers the benefit of the ability to be printed watertight unlike FDM.
  - SLA can be watertight but does not offer the thermal transfer characteristics due to the materials used.

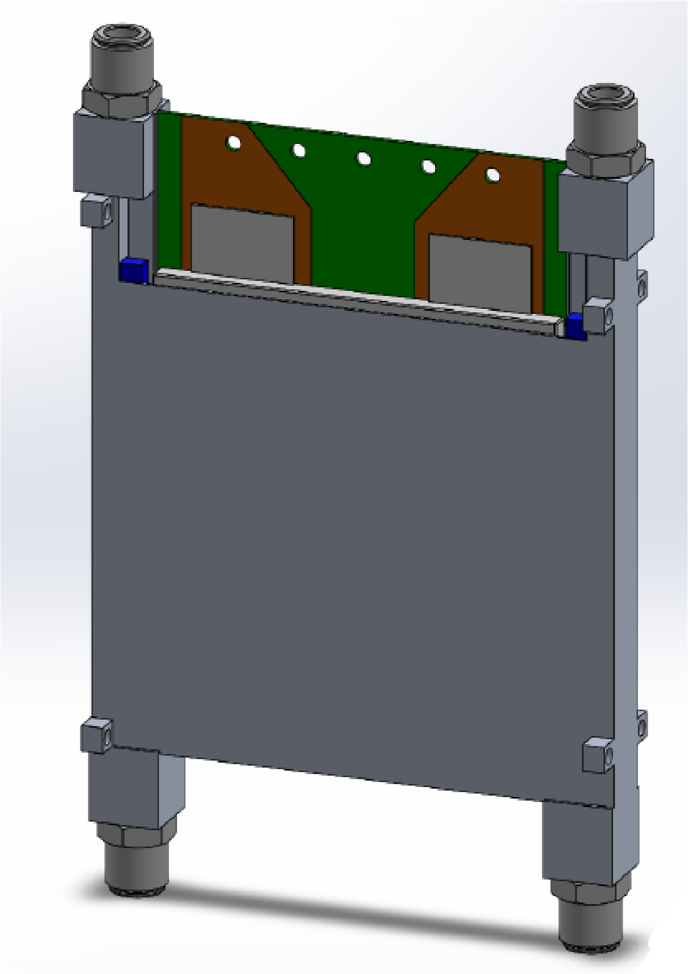
- Designed by Shay Ellafrits (GRC)



Battery Cells

- **Material**: Silicon-doped lithium-ion
- **Capacity**: 18.5 Ah
- **Voltage**: 3.6 V
- **Max Voltage**: 4.2 V
- **Max discharge current**: 40 A
- **Specific energy**: 335 Wh/kg
- **Energy density**: 600 Wh/L

Higher specific energy offers a battery system that can offer better performance with a decreased weight penalty compared to SOA Li-ion cells.



[2] D-Site Delta ORR

D-Site Test Facility

- Located at NASA's Neil Armstrong Test Facility in Sandusky, OH
  - Sub-MW testbed enabling advanced electrical powertrain ground testing for aerospace applications across industry, government, and academia.
  - Test cell chamber capable of pack-level performance testing to meet R&D and certification requirements in the industry.

Overview

Chamber Layout

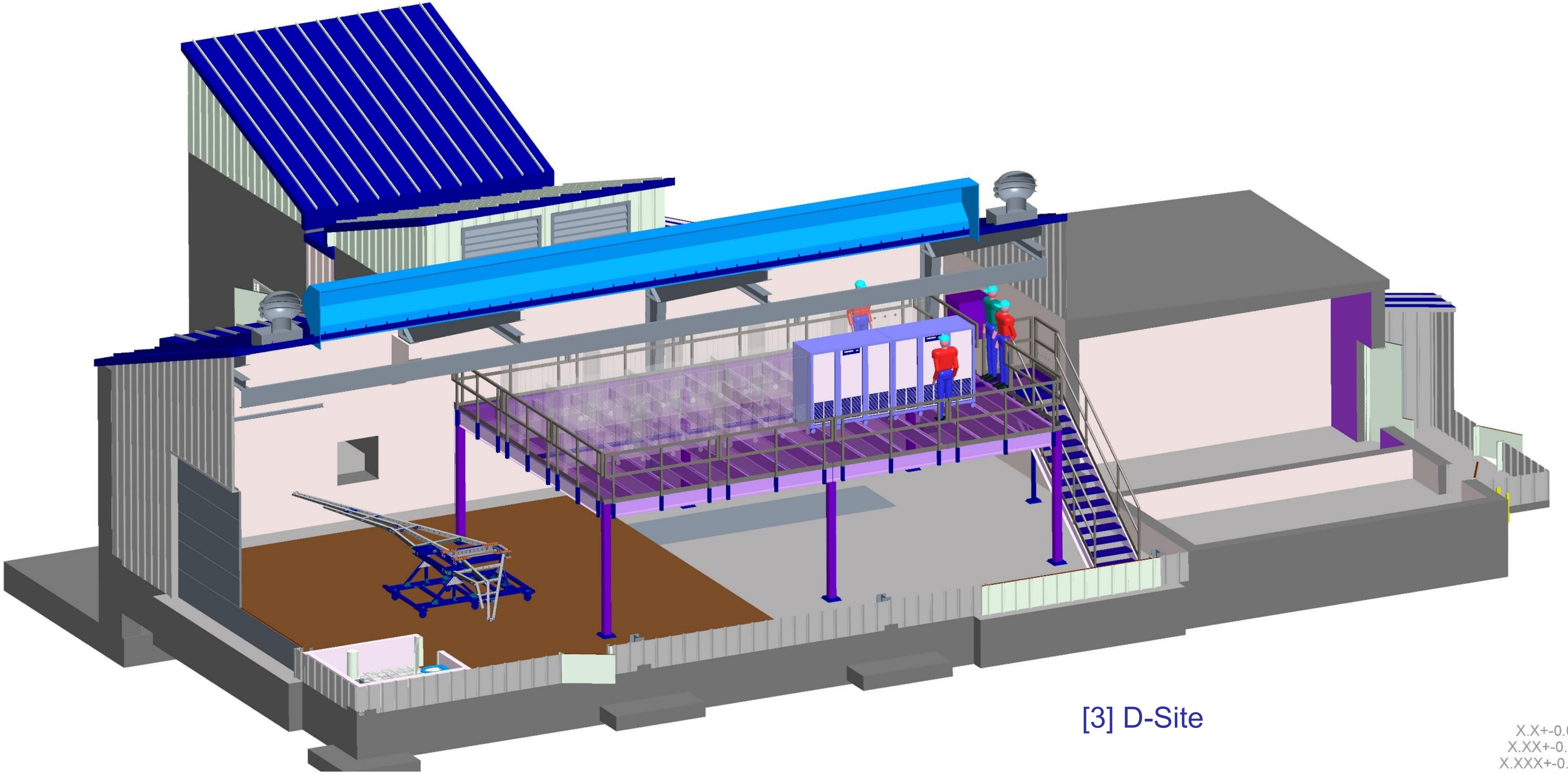
- 13'x13'x18', 169 sq ft
- 26" thick concrete reinforced walls
- Dedicated inlet/outlet ventilation system with 14' exhaust stack
- Maximum battery size: 16,000 Ah

Safety Features

- Fire detection & suppression systems
- Gas/flame detection system (methane, ethylene, CO, CO2, hydrogen, hydrogen sulfide, oxygen, combustibles)
- FLIR thermal camera and network video system
- E-Stop (power supply / battery disconnect)
- Independent/redundant battery temperature monitoring system

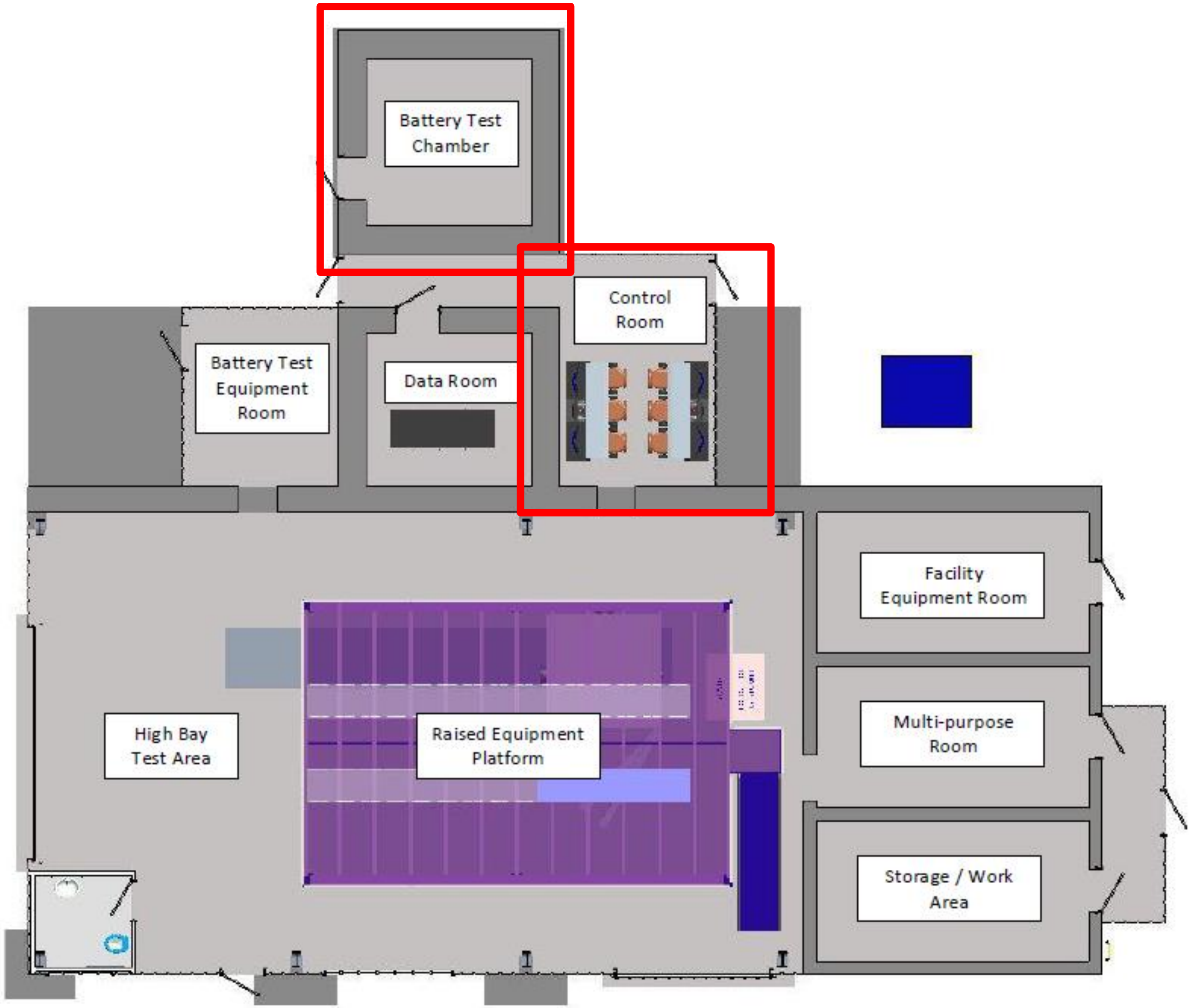
Keysight – RP7982A Bi-Directional Power Supply	National Instruments – cDAQ-9179 – Compact DAQ
Performance Test: Charge & Discharge	Performance Test: Data Acquisition
UI: Benchvue Software – Laptop	UI: LabVIEW Software GUI – Laptop
• 0-1000V / 0-45A • 15kW • Accuracy: .03% ± 75 mV / 0.03% ± 9 mA	• 14 Slot – C-Series Modules • USB 3.0 • 127 Samples per slot • 50 ppm of sample rate
Checkout performed with COTS electronic load/power supply. Part of test card 0	Checkout performed with COTS electronic load/power supply. Part of test card 0

D-Site Test Facility (cont.)



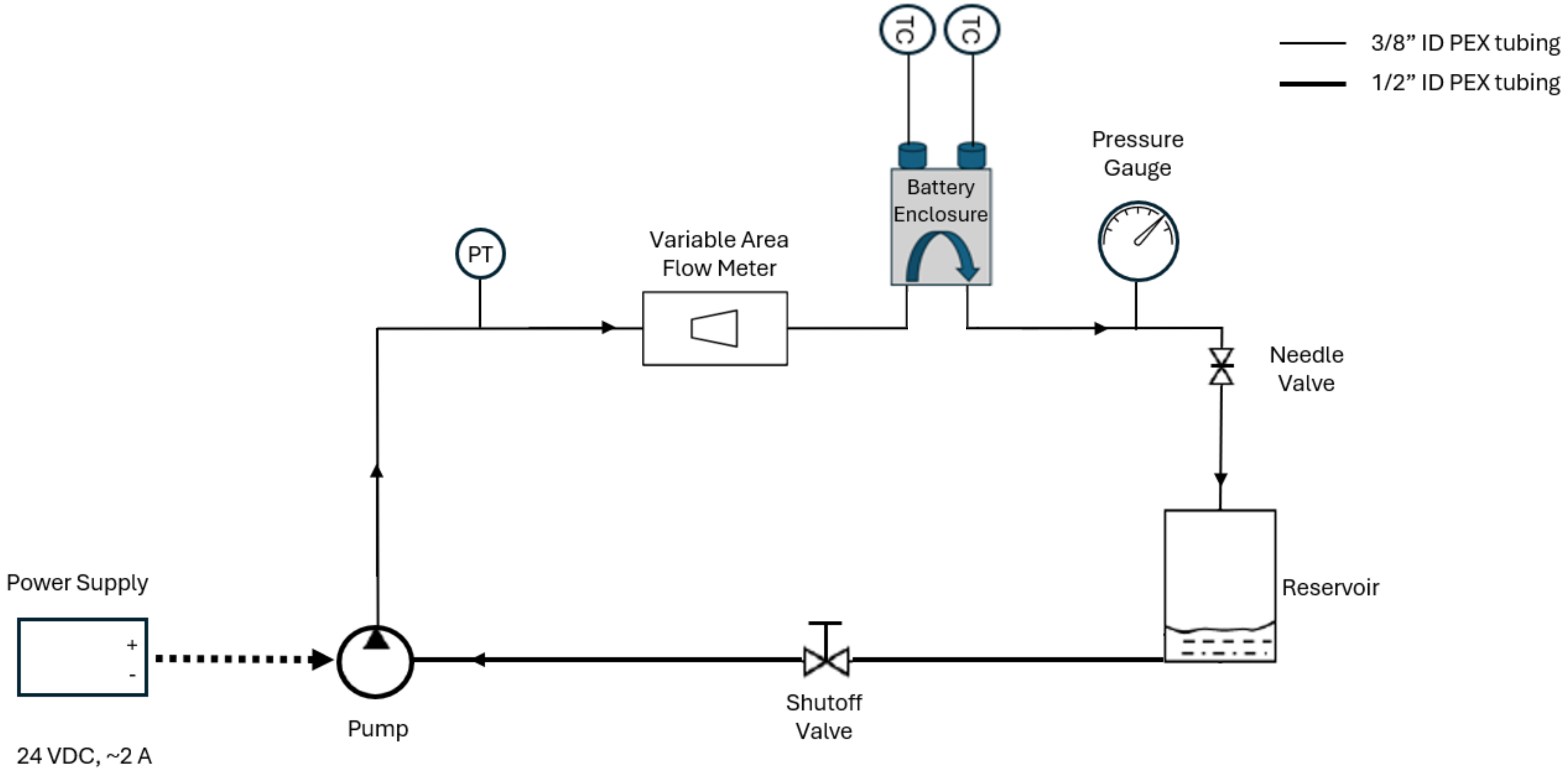
[3] D-Site

D-Site Test Facility (cont.)



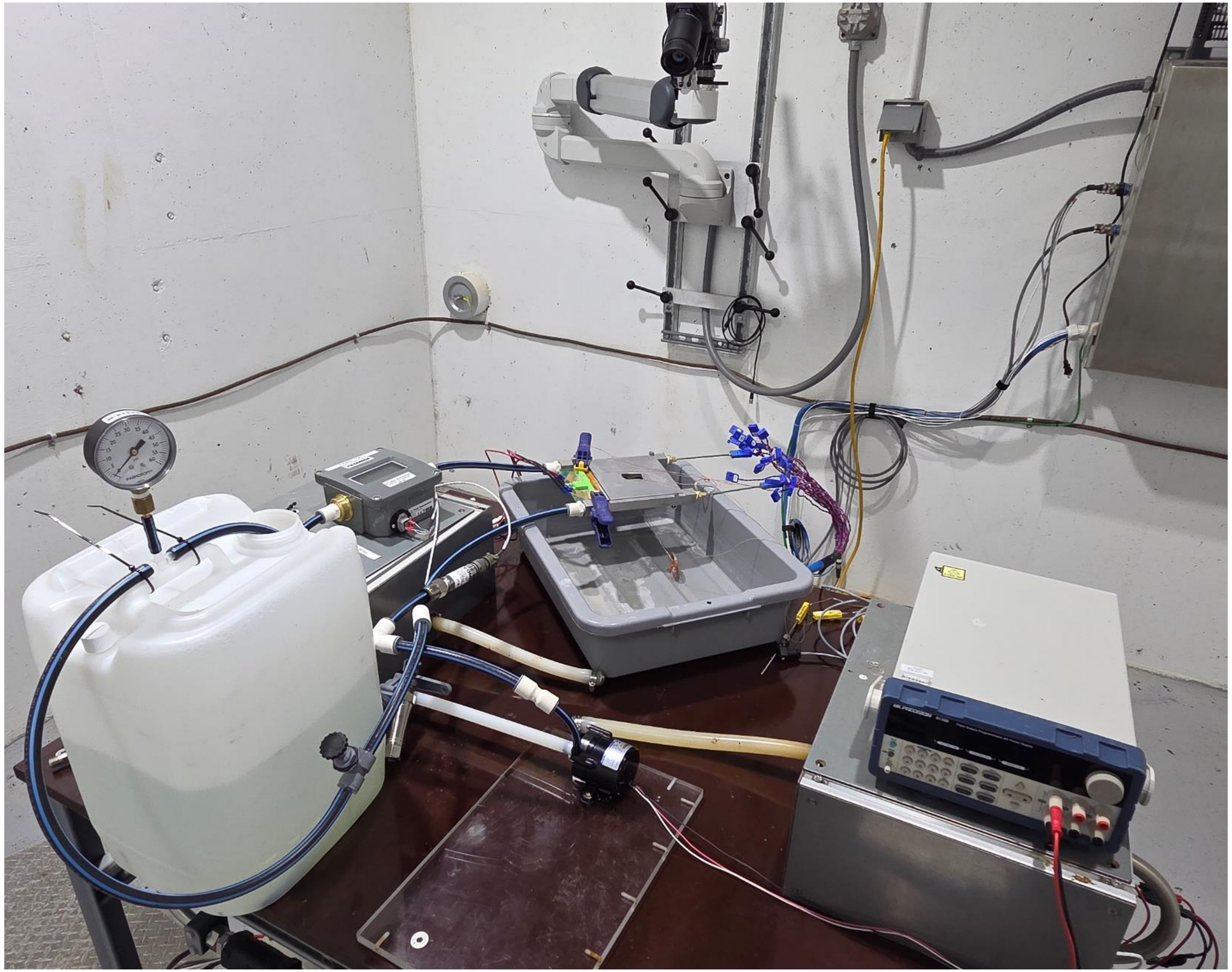
[] D-Site

Thermal Loop

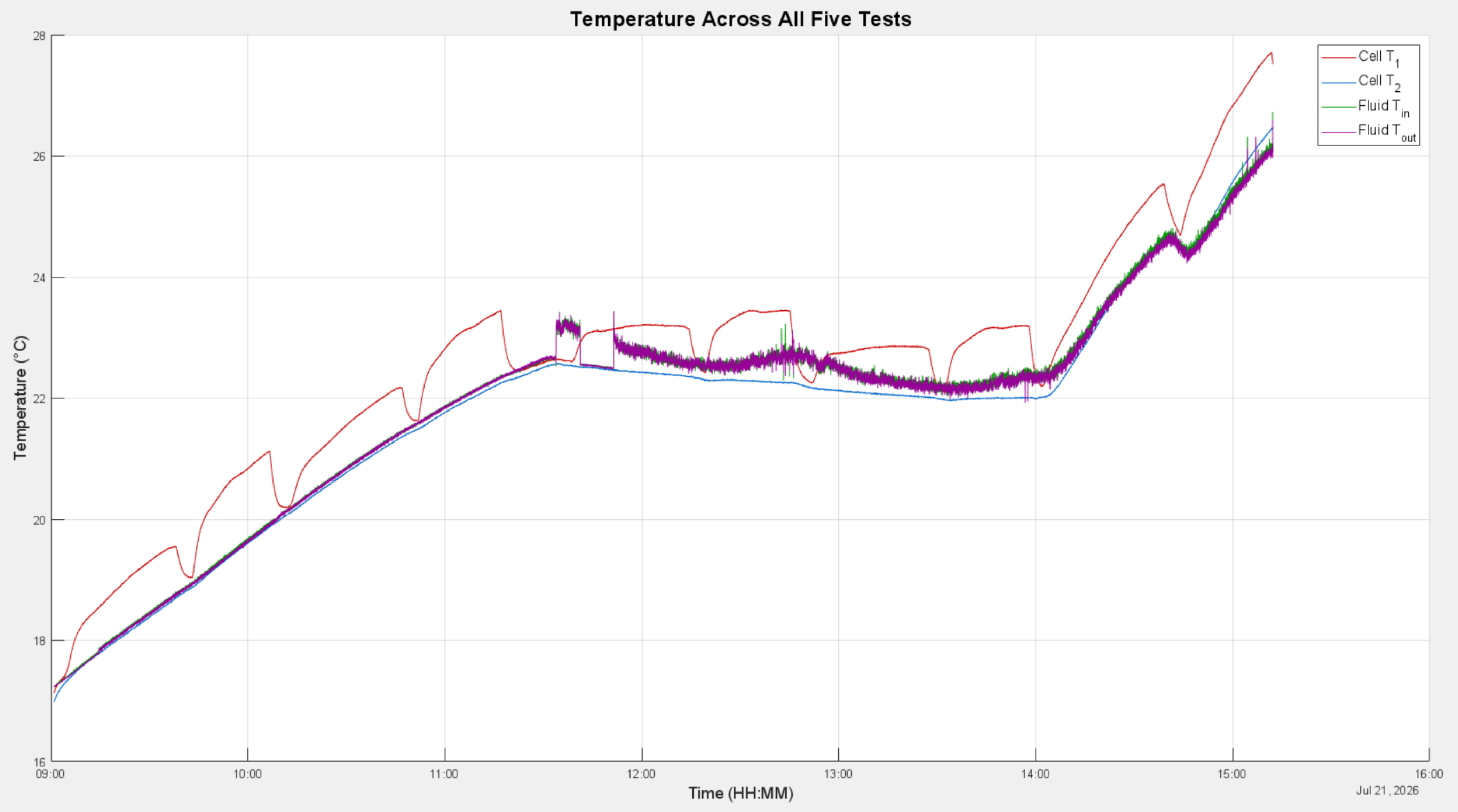


Test Conditions

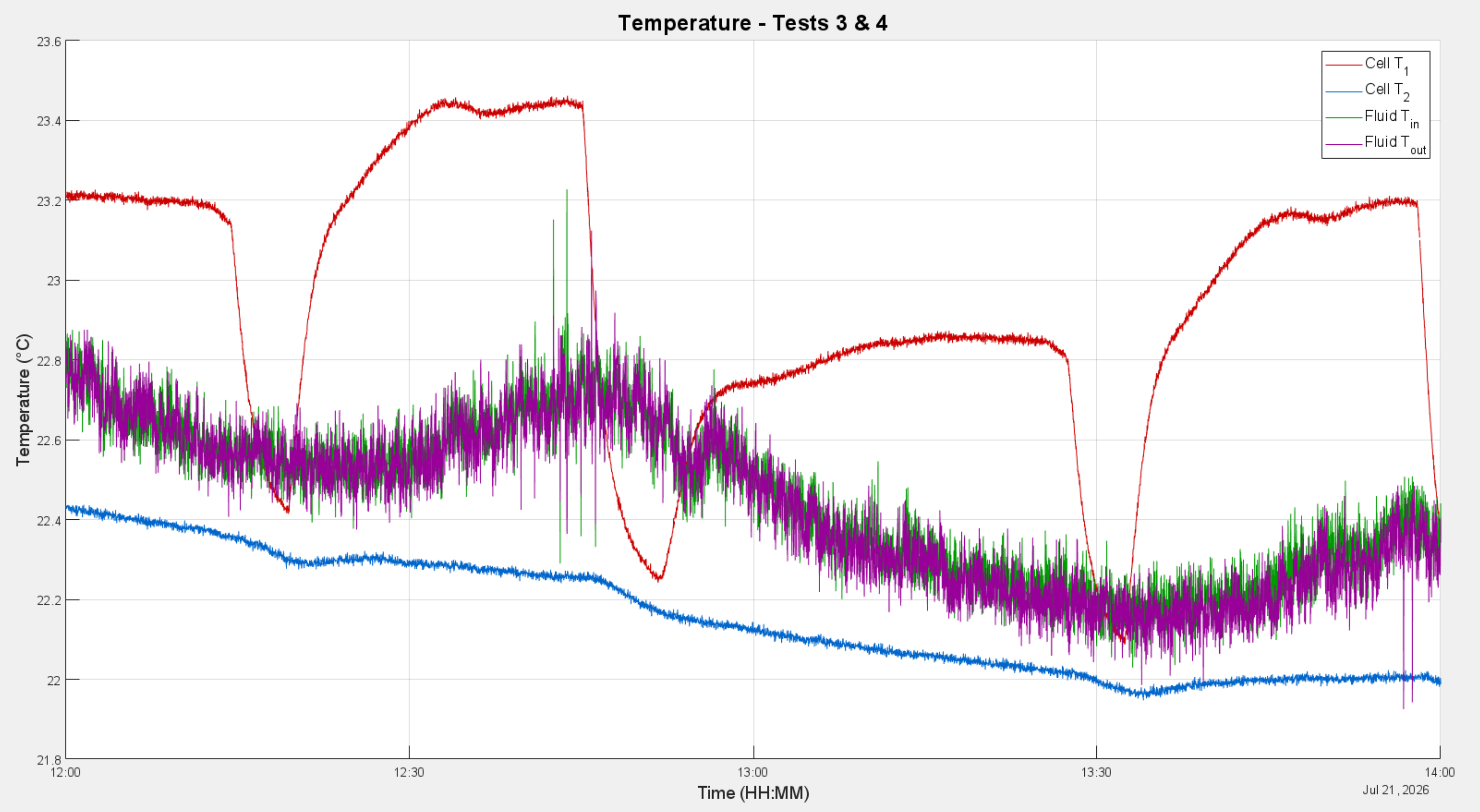
- Battery
  - Charge: 0.7C, ~4.2 V
  - Discharge: 1C, ~3.0 V
- Flow parameters
  - Working fluid: water
  - Test #1: 1.6 gpm
  - Test #2: 1.2 gpm
  - Test #3: 0.8 gpm
  - Test #4: 0.4 gpm
  - Test #5: 0 gpm (pump off)
- Flow measurements
  - Inlet/outlet fluid pressure and temperature
- Battery measurements
  - Temperature, voltage, current, capacity



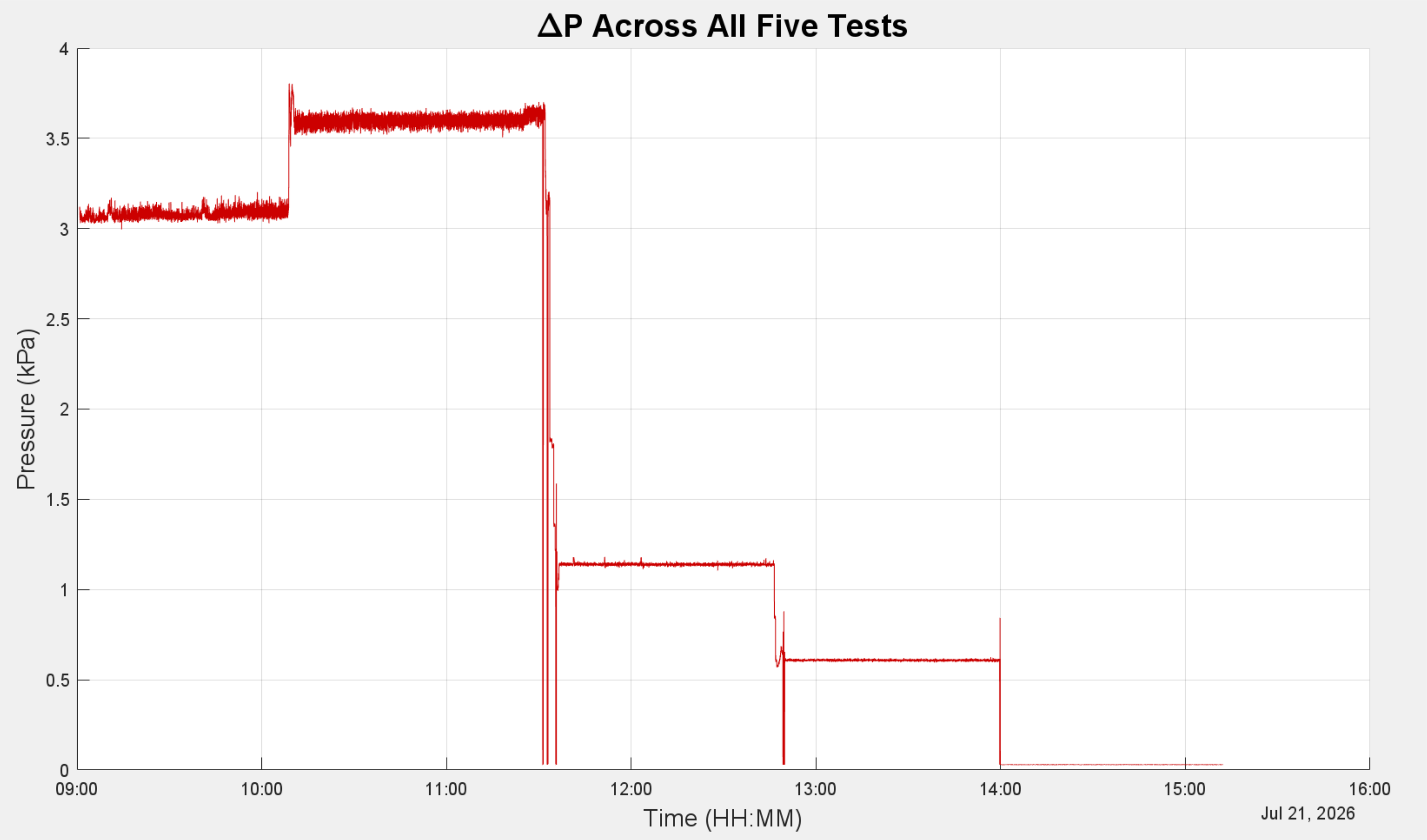
Results: Temperature



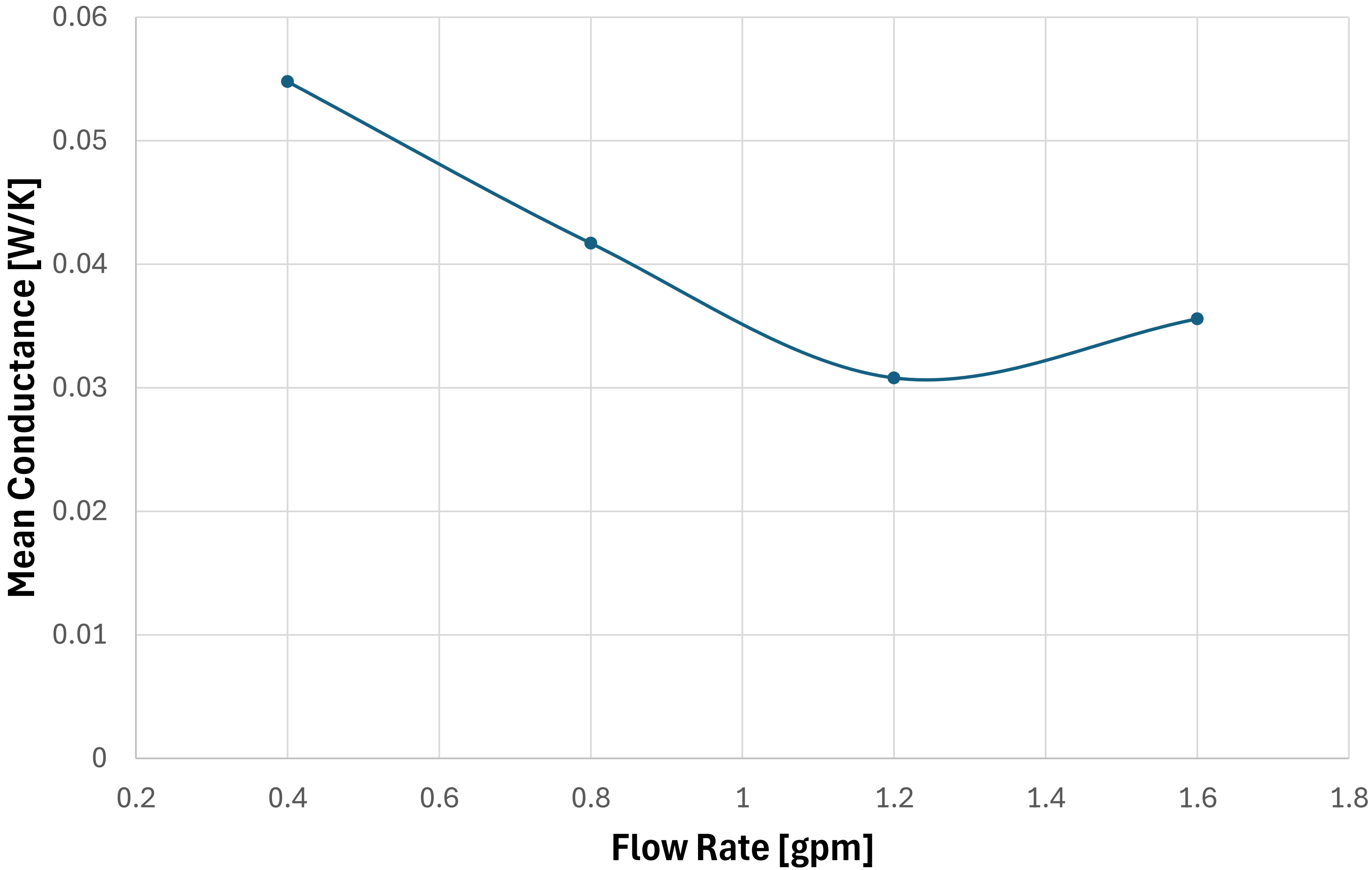
Results: Steady-State Temperature



Results: Pressure



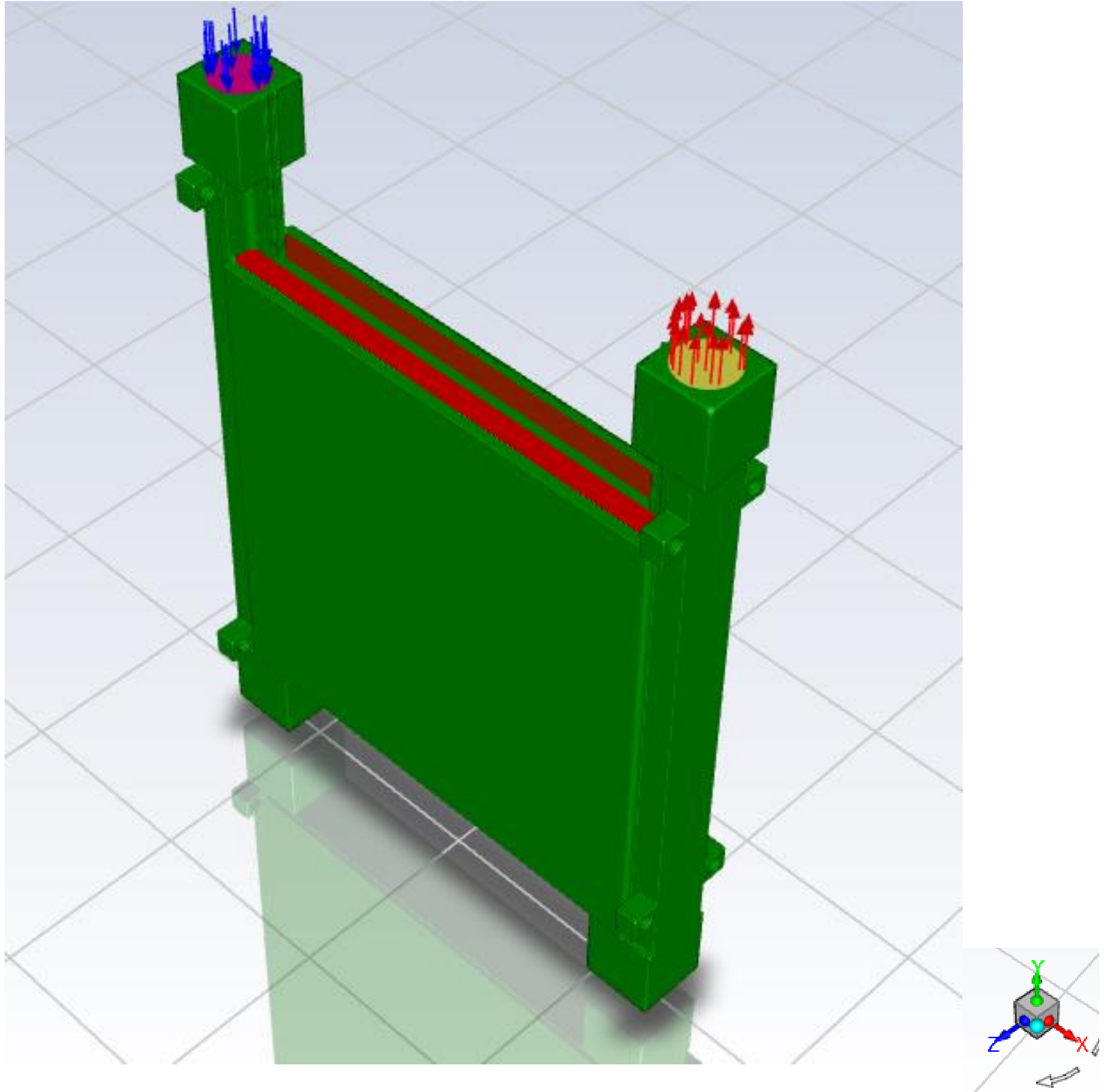
Thermal Conductance vs. Flow Rate



$$C = \frac{\dot{m}c_p\left(T_{f,out} - T_{f,in}\right)}{T_{comp} - T_{f,avg}}$$

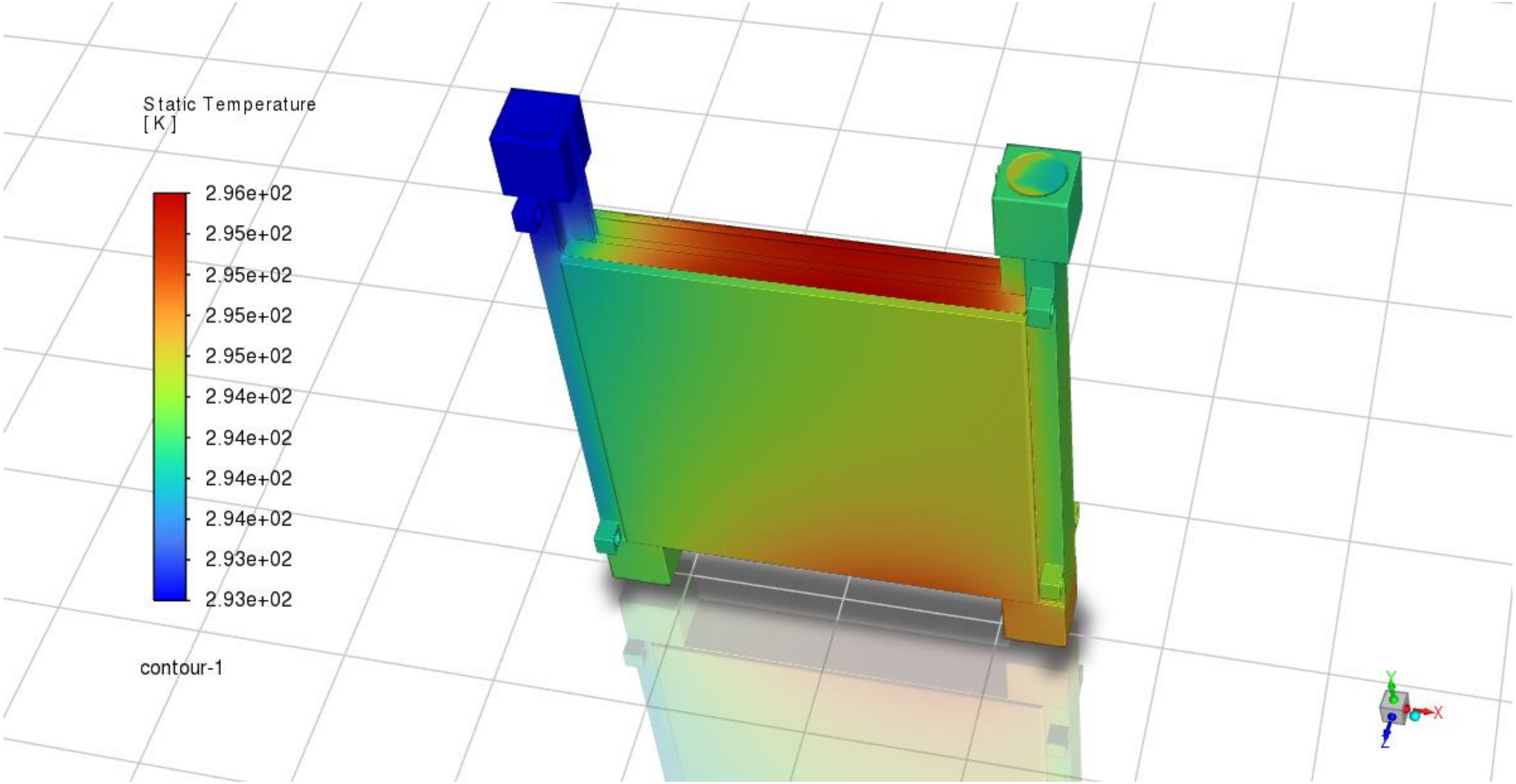
CFD Methodology

- **Objective**:
  - Develop thermal-fluid CFD model of coolant flow through battery enclosure and compare with experimental results.
- **Model**: Ansys Fluent
- **Boundary Conditions:**
  - Water inlet: 0.8 gpm, 20°C
  - Outlet: 0 Pa
  - Laminar flow
  - $\dot{Q}_{gen} = I^2 R =$ 68.9 kW/m³
    - Max discharge current, $I = 13\ A$, $\mathrm{R} = 50\ m\Omega$
- **Steady-state solution**



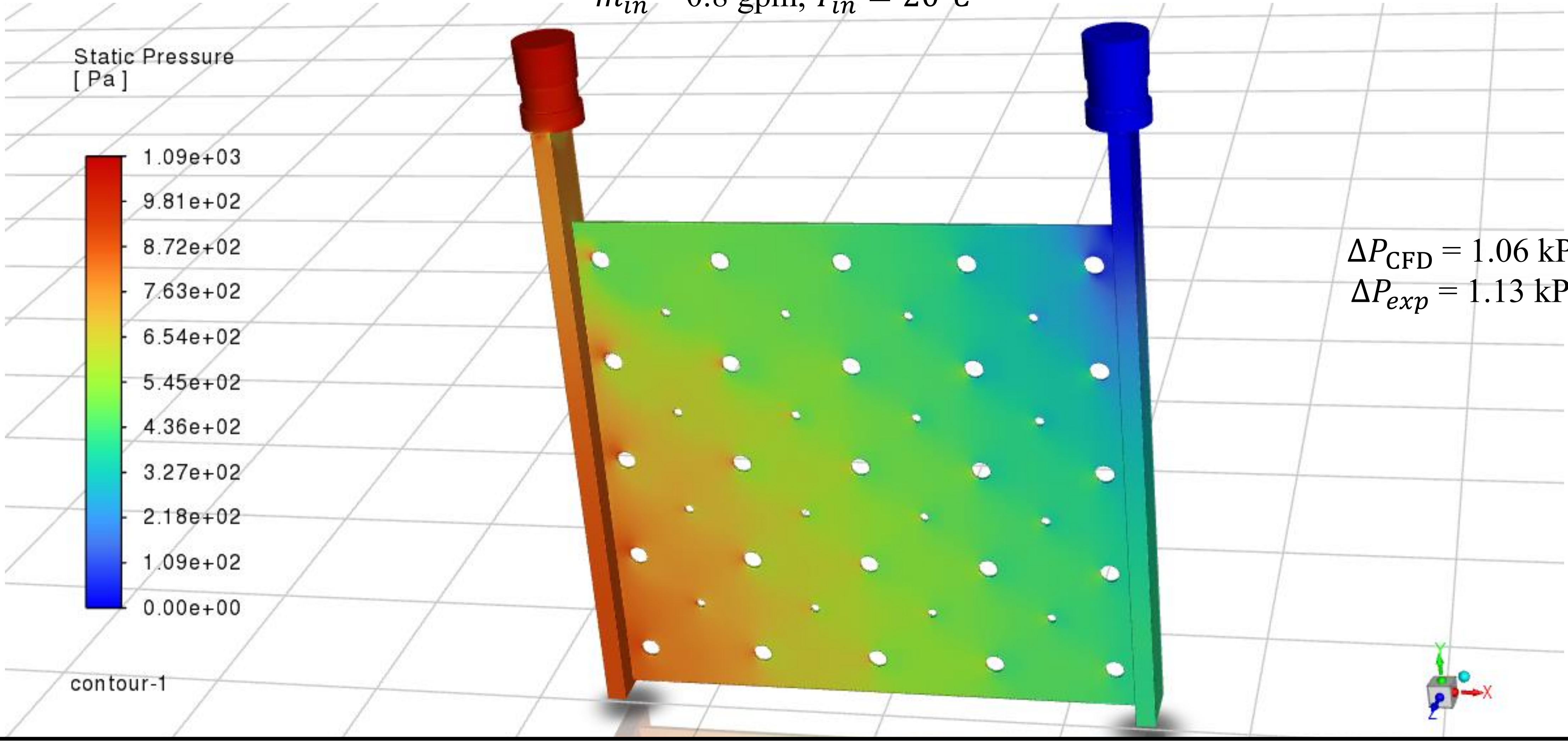
CFD Results

$\dot{m}_{in} = 0.8$ gpm, $T_{in} = 20°C$



CFD Results (cont.)

$\dot{m}_{in} = 0.8$ gpm, $T_{in} = 20°C$



$\Delta P_{\text{CFD}} = 1.06$ kPa
$\Delta P_{exp} = 1.13$ kPa

CFD predicted ΔP within ~7% of experimental results at 0.8 gpm at max discharge current.

Conclusions/Future Work

- Experimental testing demonstrated effective thermal management of the battery cells using
  - Liquid cooling and additively-manufactured battery enclosure.
  - Maintained battery temp < 30°C
- Coolant flow rate had strong influence on battery thermal performance
  - With higher flow rates producing lower coolant and cell temperatures.
- CFD results showed good agreement with experimental trends
  - Similar ΔT (2-3°C from inlet to outlet)
  - Predicted ΔP within ~7% of experimental results at 0.8 gpm, using estimated heat load based on max discharge current.
- Future tests will include
  - Multi-cell advanced battery pack to be used in distributed propulsion research aircraft.
  - Increase TC coverage on battery cells to better monitor temperature distribution and identify hotspots across larger battery volume.

Acknowledgements

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- Ralph Jansen
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- Tim Dever
- Shawn Dellinger
- TTT APA Project

References

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- 2. D-Site: TTT APA Safe, Energy Dense Batteries, Delta ORR, Mar. 25, 2026.
- 3. Jansen, R., Litt, J. "Alternative Propulsion Architecture Focus Area Electrical Energy Storage", Apr. 15, 2026.

Questions