TFAWS Active Thermal Paper Session

Mini-Membrane Evaporator for Contingency Spacesuit Cooling

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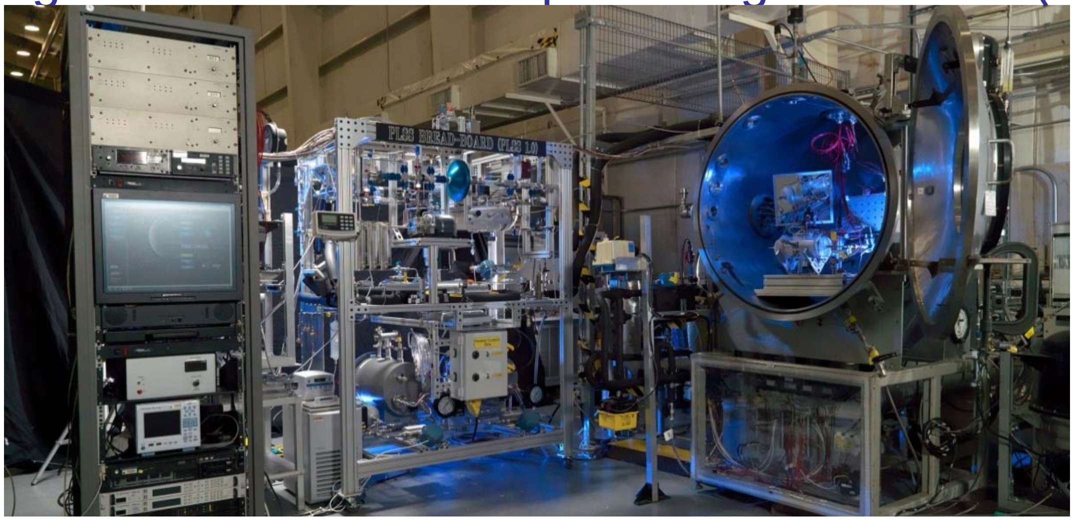
Introduction-Advanced PLSS

- A new Portable Life Support System is being developed at NASA JSC.
- Includes new technology development hardware;
  - Spacesuit Water Membrane Evaporator for heat rejection
  - High-speed ventilation fan
  - Primary and Secondary oxygen regulators
  - Rapid-Cycle Amine (CO2 removal)
- Integrated PLSS testing completed at a breadboard level in 2011 (PLSS 1.0)
- Packaging the PLSS into 'backpack' began in 2013 (PLSS 2.0)



PLSS 1.0 Testing

Introduction

- The current Extravehicular Mobility Unit (EMU) utilizes a secondary oxygen vessel (SOV) for contingency breathing oxygen and cooling of the crewmember during an EVA anomaly.
  - Sublimator failure
  - Power failure
- The SOV flows high pressure oxygen through the LCVG to cool the crewmember.
- Some drawbacks of the SOV include:
  - Very high pressure charge: 6000 psi
    - Primary oxygen vessel (POV) is charged only to 3000 psi and is smaller
  - Cannot be recharged on orbit after use—must be returned for service
  - Provides only 30 minutes of get-back time

Introduction-PLSS 2.0

- During packaging analyses for PLSS 2.0, it became clear that more space was needed to package all of the components
- A proposed solution was to eliminate the SOV and replace it with a smaller tank, identical to the POV.
  - Rely on new, smaller SOV for contingency breathing oxygen only
  - Create an Auxiliary Cooling Loop (ACL), which relies on a small membrane evaporator for heat rejection.
- Advantages to identical Primary and Secondary oxygen tanks include;
  - More available volume inside of PLSS package
  - Component similarity
  - Rechargeable on-orbit

Auxiliary Cooling Loop Overview

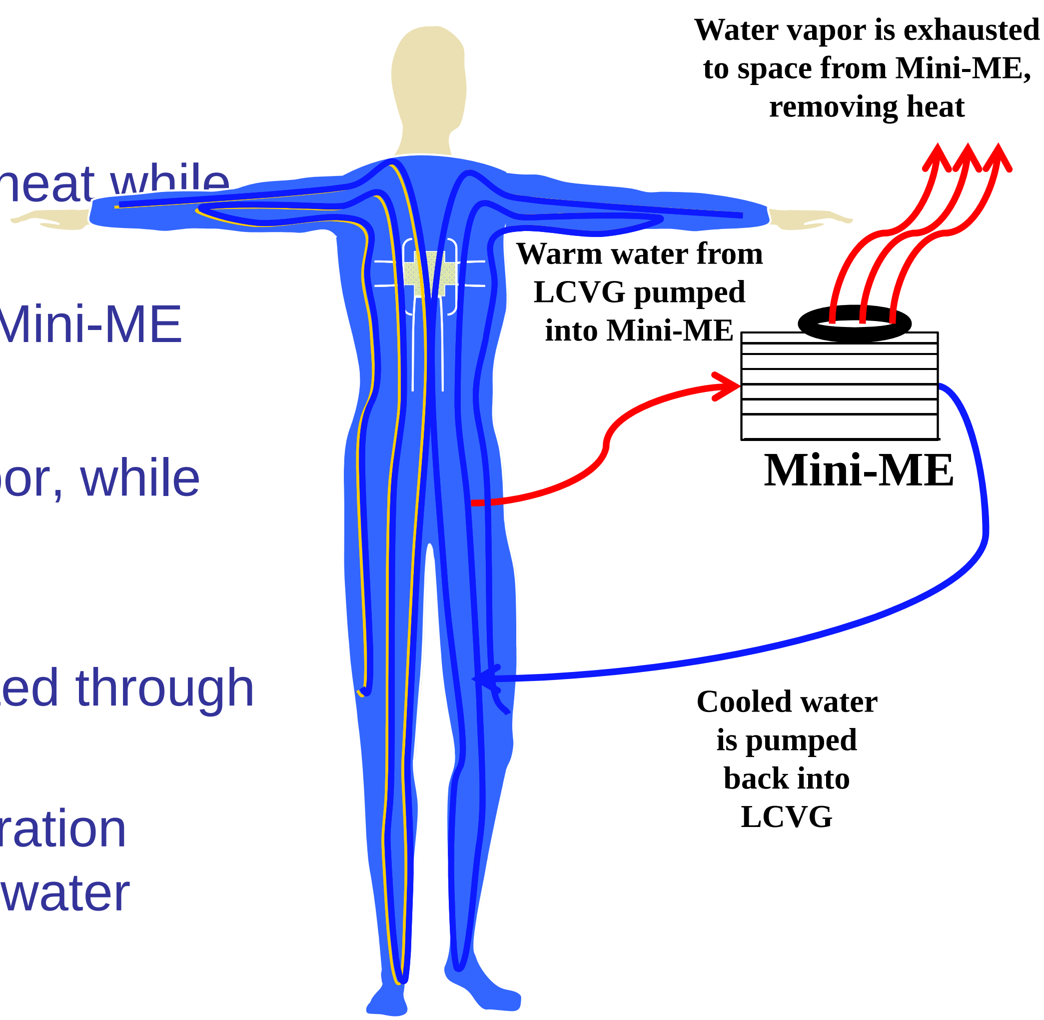
- Auxiliary Cooling Loop consists of;
  - Small Membrane Evaporator, Mini-ME, utilizing same technology as the primary heat rejection device for the PLSS, the Spacesuit Water Membrane Evaporator (SWME)
  - Independent pump
  - Independent power supply
  - Independent LCVG tubing in the vest area only
  - Independent feedwater assembly
  - Independent controller
- Advantages of the ACL
  - Can be recharged on orbit
  - Can provide more get-back time
  - Completely independent system

Auxiliary Cooling Loop Overview

- Mini-ME is an evaporative cooler
  - 8000 porous microfibers
    - 300 microns in diameter

<u>Process</u>

- Water in LCVG absorbs body heat while circulating
- Warm water pumped through Mini-ME
- Valve is opened
- Mini-ME evaporates water vapor, while maintaining liquid water
  - Cools water
- Cooled water is then recirculated through LCVG.
- LCVG water lost due to evaporation (cooling) is replaced from feedwater



ACL & Mini-ME

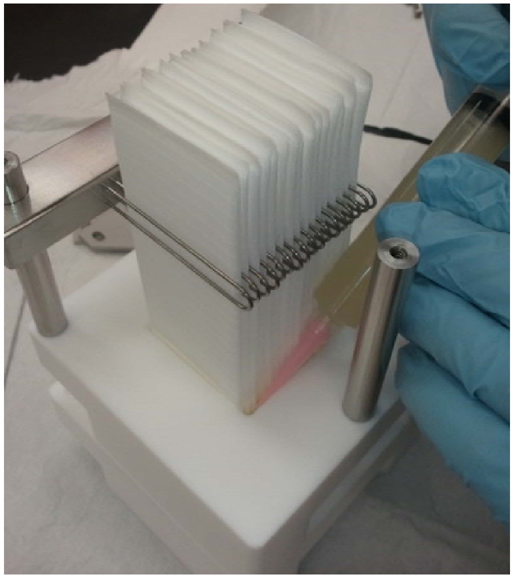
- Proposed operation of ACL
  - During a contingency event, the crewmember will turn-on the ACL via a switch on the Display Control Module (DCM)
  - The switch will turn on the independent controller
  - The pump will start
  - The valve will fully open, exposing fibers to vacuum, rejecting heat

- Goals for first generation of hardware:
  - Accommodate a 1200 BTU/hr crewmember metabolic rate
  - Provide 60 minutes of heat rejection
  - Package into PLSS 2.0—rectangular cross section preferred

- The dimensions for the first Mini-ME were dictated by available volume in the PLSS.

First Generation Mini-ME

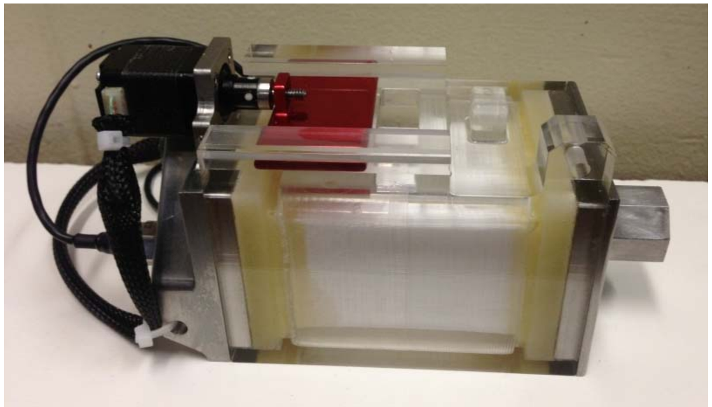
- A rectangular membrane evaporator was designed and constructed in-house.
- A clear, acrylic housing was chosen in order to evaluate membrane integrity
- The fiber cartridge was constructed with 8000 fibers, utilizing a new, layered technique
- Gate valve with small stepper motor
  - Gate valve chosen due to volumetric constraints within the PLSS volume.



Mini-ME Fabrication

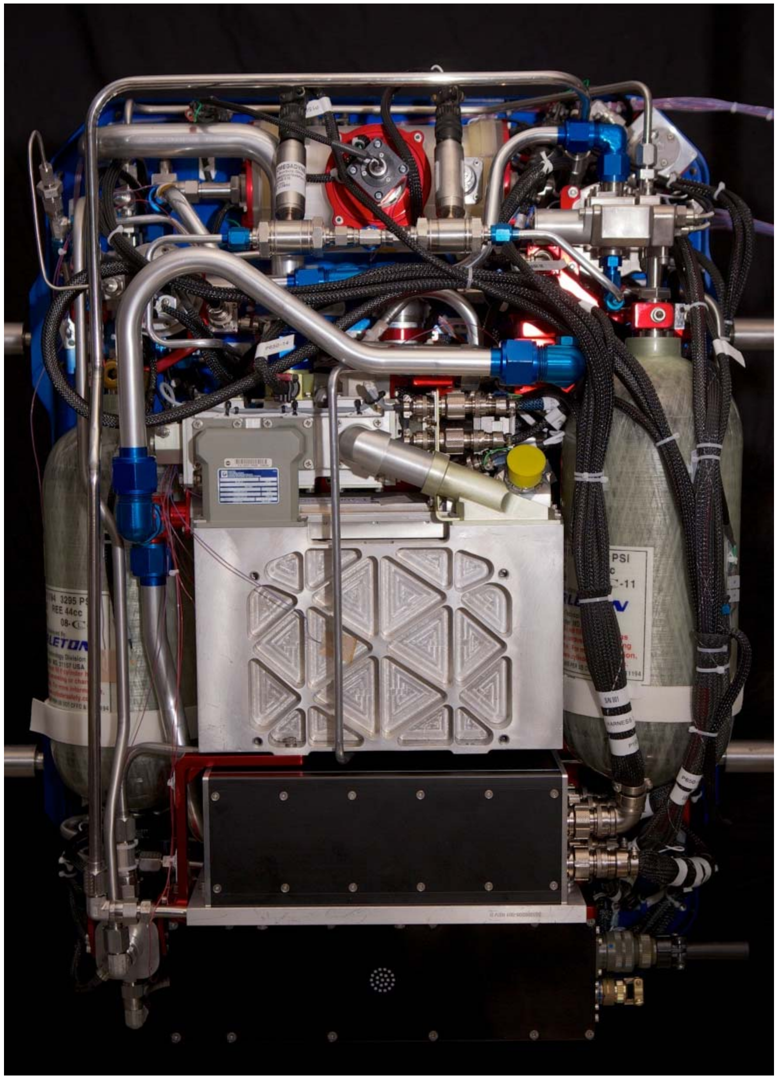
Preliminary Mini-ME testing

- Two units were constructed.
- Preliminary testing results showed heat rejection performance of 95-110W (325-375 BTU/hr)at 50kg/hr flow rate with a 10 degree Celsius outlet temperature.
- Approximately ~10 W of heat leak was observed across the closed gate valve
  - This could cause fiber freezing and loss of feedwater during system standby
- Following preliminary testing, one Mini-ME was installed into the PLSS 2.0 backpack.

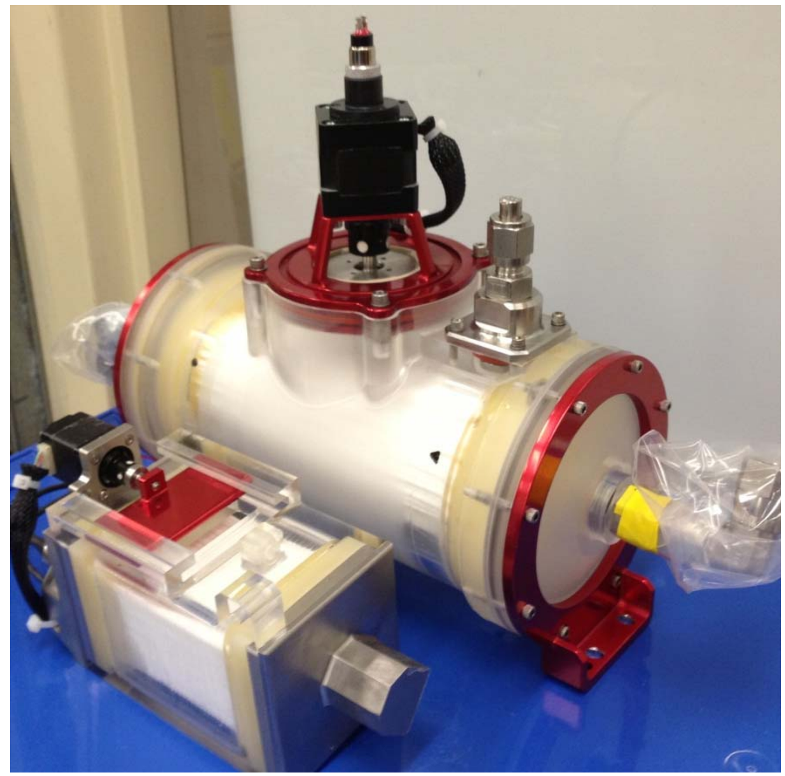


Completed Mini-ME unit

PLSS 2.0



PLSS 2.0



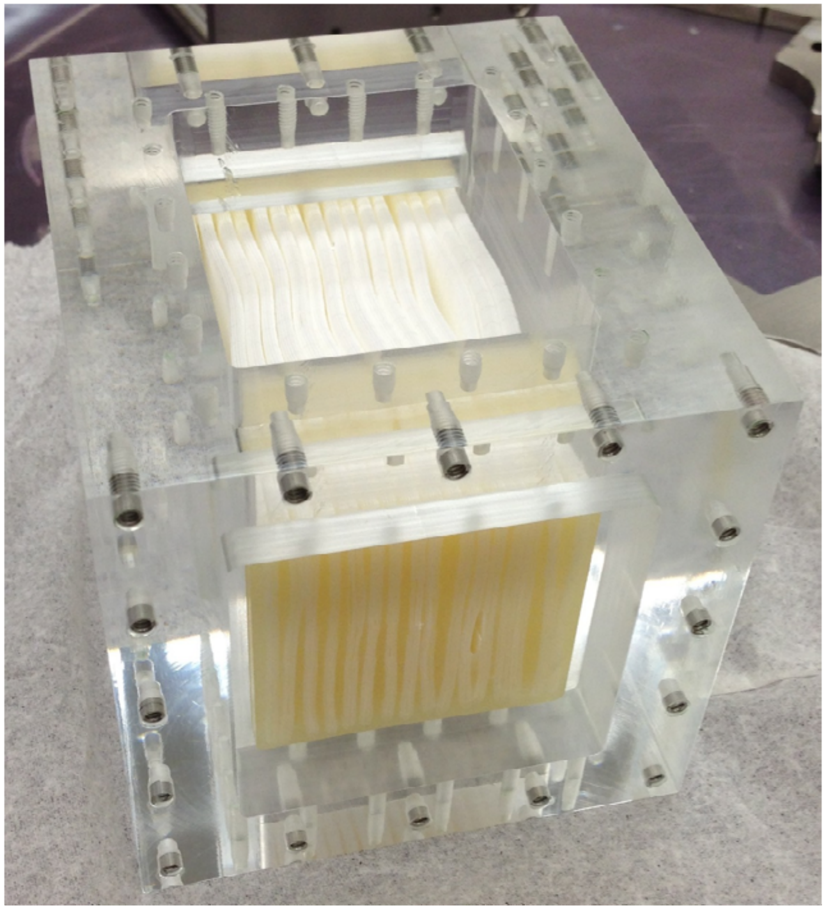
Mini-ME (left), RVP SWME (right)

Subsequent Mini-ME Testing

- Following the preliminary testing of Mini-ME, a study was conducted to:
  - investigate ideal fiber density and packaging in terms of heat rejection
  - Determine smallest valve throat area needed to reject at full capability
- 9 Fiber Density Test Articles (FDTA's) were constructed with different fiber densities and with replaceable valve throat areas.
- Each unit was tested for a total of 24 hours.
- Data from these tests allowed analysts to correlate models to data
- Ideal configuration: 16 bundles of 6 layers (9413 fibers), which produced 165W of heat rejection with a 55kg/hr flow rate

Fiber Density Test Article (FDTA)	Bundle Count	Layers	Nominal Fiber Count	Day 4, 0.75 in2 Orifice Plate, 10°C Outlet Heat Rejection (W)	FDTA Outlet Water Mass Flow (kg/hr)	Normalized (10°C Tout, 55 kg/hr mdot) FDTA Day 4, 0.75 in2 Orifice Plate Heat Rejection (W)
2	16	5	7844	127	55.05	127
5	14	6	8236	127	54.95	127
1	16	6	9413	164	54.3	166
3	16	6	9413	158	55.55	156
8	12	7	8236	118	55.2	118
6	14	7	9609	138	54.25	140
4	16	7	10982	158	54.5	159
9	12	8	9413	148	55.2	147
7	14	8	10982	135	54.4	136
Nominal bundle width (in)			1.85			
Nominal fiber density (fibers/inch)			53			
Nominal fiber exposed length (in)			2.25			

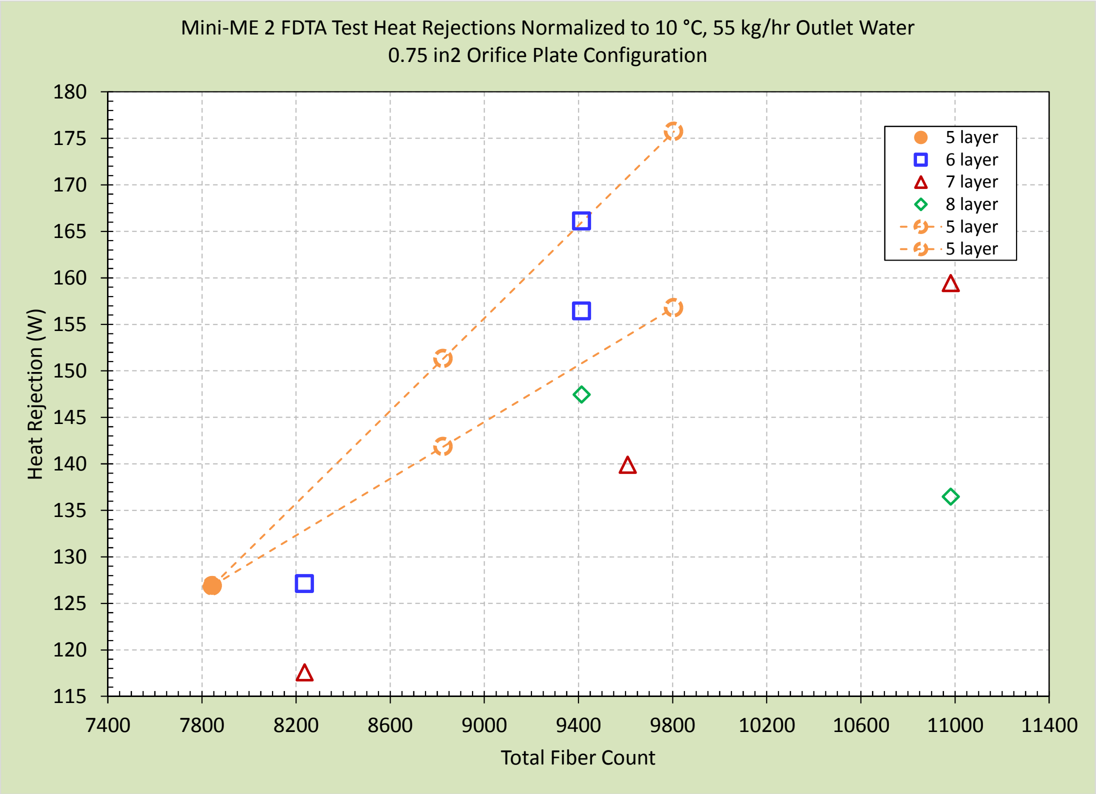
FDTA



Fiber Density Test Article (FDTA)

FDTA Analysis

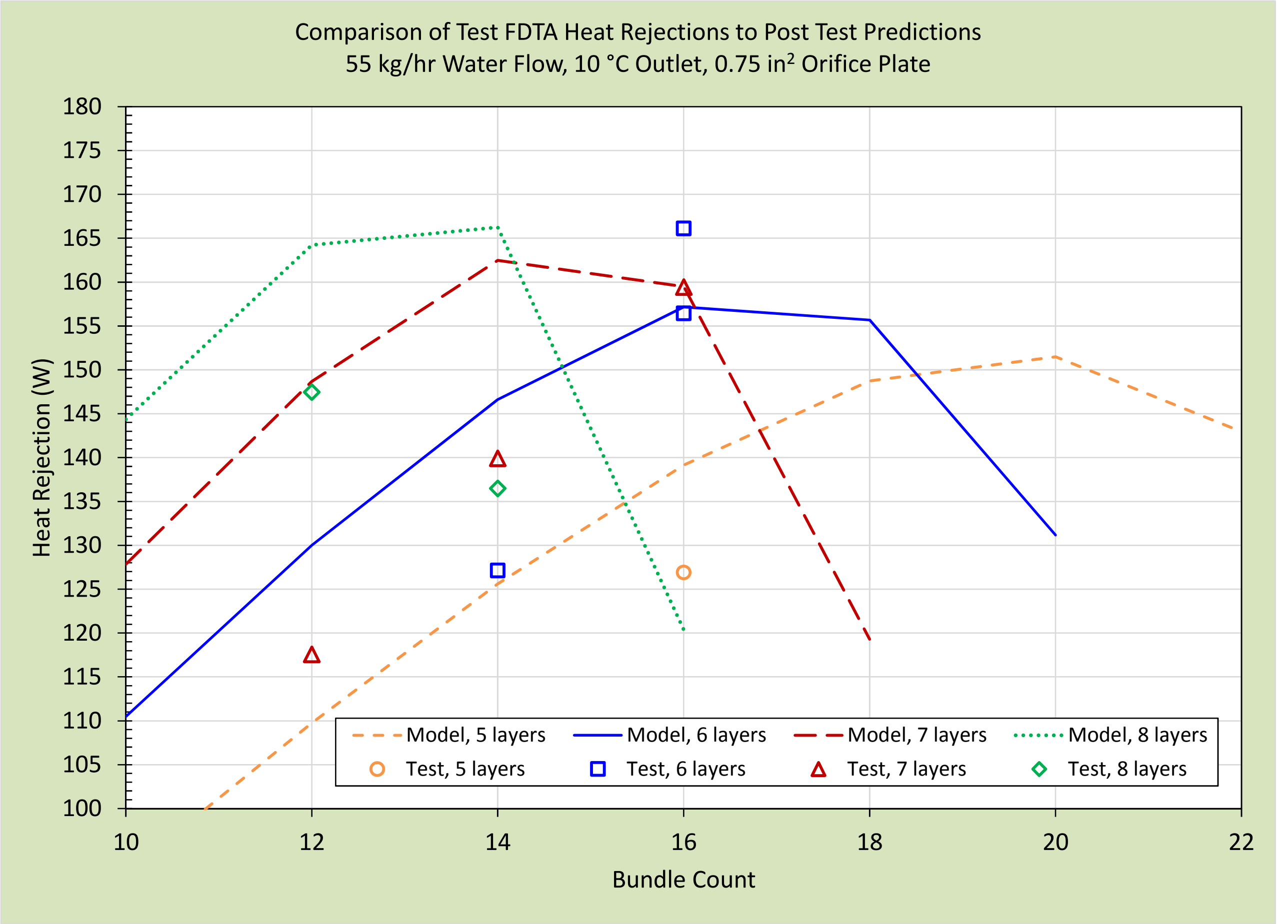
- Valve throats of 0.75in^2, 1in^2 and 4in^2 were investigated.
  - No difference between 0.75in^2 and 4 in^2
- Fiber density and packaging:
  - Most data points show that fewer layers yield greater heat rejection for same fiber count
  - Strongly suggests optimum packaging is higher bundle count and fewer layers
  - Limits of this approach would require additional testing



FDTA Analysis

Test predictions and post-test heat rejections

- One dimensional model correlated to FDTA 3 test heat rejection
  - **Fiber wall porosity adjusted**
    - 11.25% final value
  - **Valve orifice choked flow coefficient of 0.6**
- Largest over-predictions were those of 12/7, 14/7, and 14/8 TAs
- 7 layers peak behavior not seen in test data



Forward Work

- The Mini-ME and ACL will be tested as an integrated system in PLSS 2.0, beginning in September.
- The next generation of Mini-ME hardware (Mini-ME2) is currently being designed.
  - Goals:
    - New valve with 0W heat leak
    - More heat rejection (350W)
- Mini-ME2 will be tested independently, and ultimately integrated into the next round of PLSS testing (PLSS 2.5).

Acknowledgments

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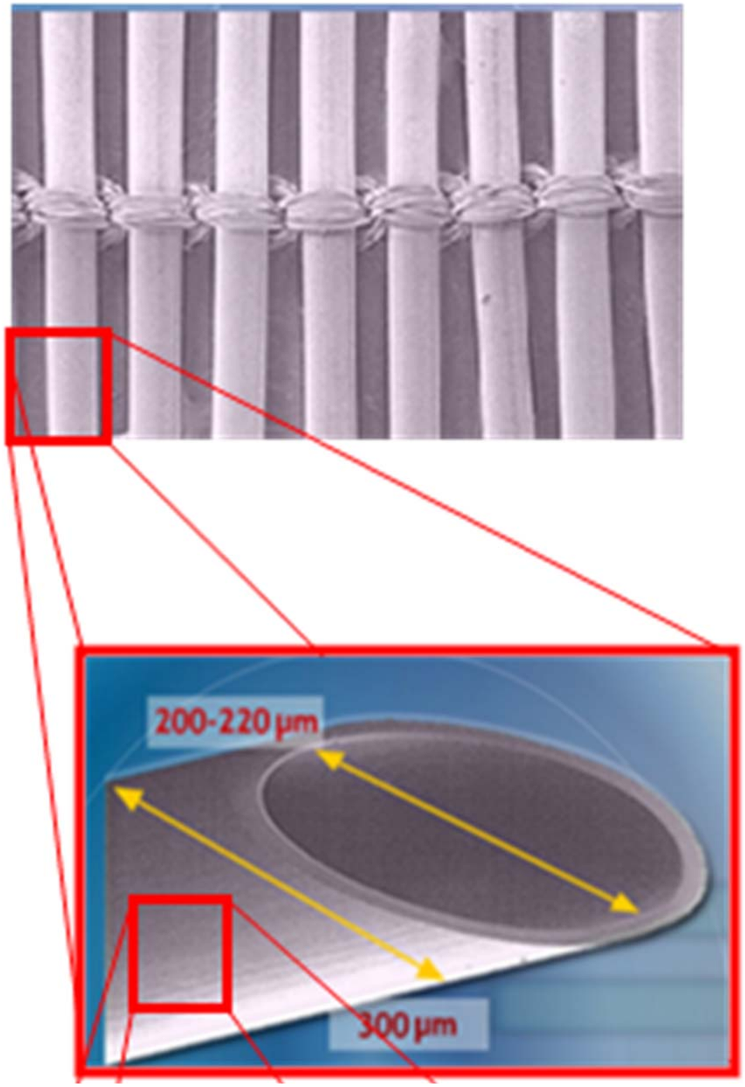
Back-up



FDTA Analysis

Normalized heat rejections plotted with respect to bundle count and layers

- **Linear q_{rej} increase of 6 and 7 layer TAs vs. bundle count**
  - Showed no sign of peaking, contrary to expectations
- **8 layer TA q_{rej} decreased vs. bundle count**
- **TA 2 (16/5): fewest fibers, q_{rej} on par with or better than 14/6 and 12/7, which had more fibers**