Comparison of Exploration Portable Life Support Subsystem (xPLSS) Thermal Modeling to Thermal Vacuum Testing

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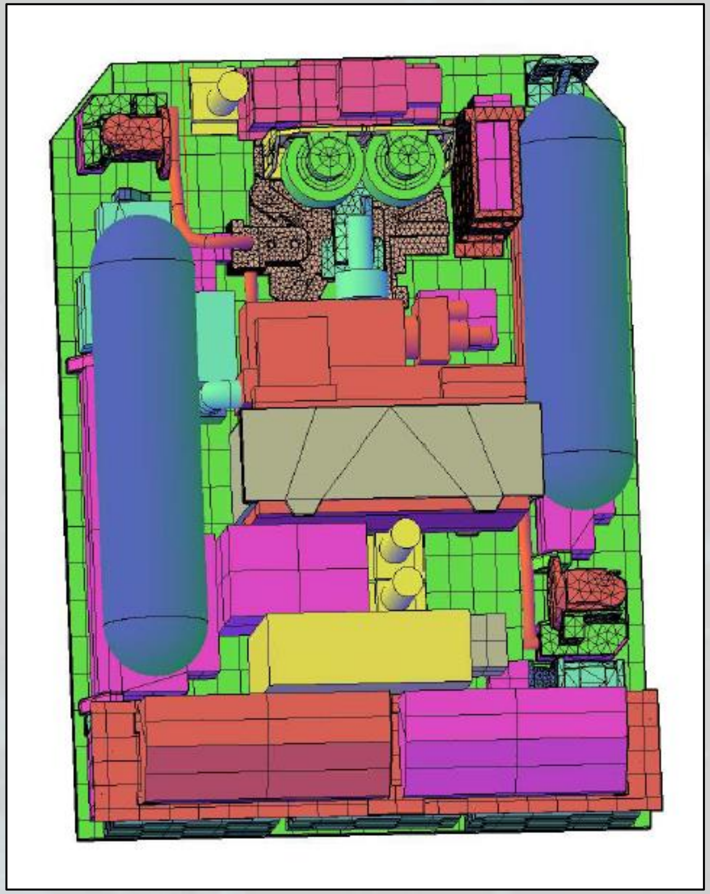
Introduction

- The exploration portable life support system (xPLSS) is one of the major subsystems comprising the Exploration Extravehicular Mobility Unit (xEMU)
- It is responsible for life support functions and houses many high-power controllers and motors
  - Very tight thermal constraints
  - Large concern around heat leaks and component-to-component exchanges
- A detailed thermal model was built for the xPLSS in Thermal Desktop (TD), with the most recent version being completed in 2022
- Thermal vacuum testing of the xEMU in JSC’s Chamber B in late 2023 provided data for validation of this detailed thermal model

Objectives

- Edit the current xPLSS TD model so that the environment and other relevant boundaries can be adjusted to represent Chamber B thermal vacuum (TVAC)
  - Take note of any remaining discrepancies or significant assumptions
- Run simulations representative of select “steady-state” portions of TVAC
  - Include both cold and hot environments
- Compare predictions of the model to TVAC data and assess fidelity and areas that could use improvement



Geometry of the xPLSS TD model

Methodology – The Simulation Model

- The xPLSS TD model is highly detailed representing most major components present in the xPLSS
- Transient operations are governed by FORmula TRANslation (Fortran) logic
- Crewmember (Human Metabolic Simulator (HMS) in the case of TVAC) inputs handled with an integrated version of 41-Node Metabolic Man Model (METMAN)
- Most of the plumbing is modeled using FloCAD
- Conductors and contactors accurate to connection type (e.g., bolted, compression) where information was available, otherwise given a conservative value
- Uniform radiation environment based on a background sink temperature

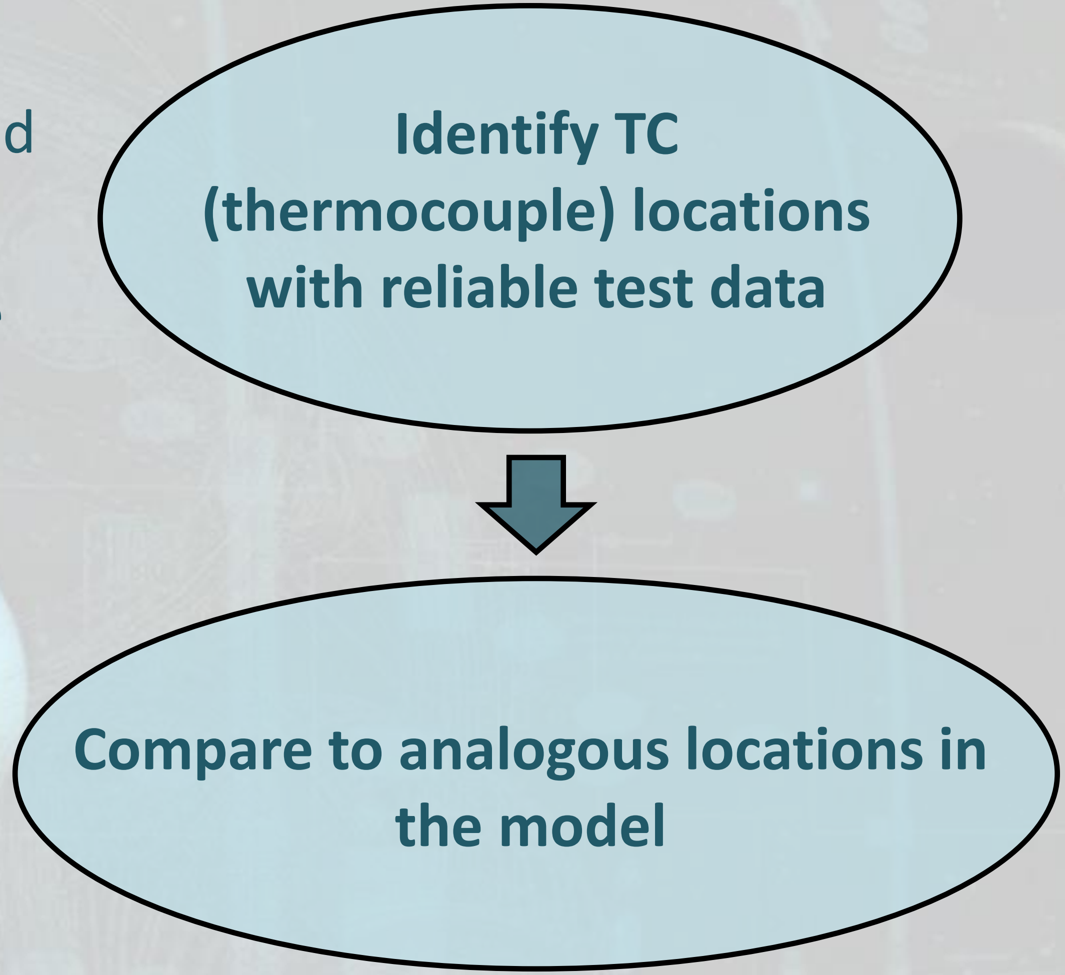
Methodology – Case Matrix

EVA #	Env. Temp (F)	OVL Flow Rate (acfm)	PTCL Flow Rate (lbm/hr)	CO2 Input (g/hr)	H2O Input (g/hr)	Heat Input (BTU/hr)	Half Cycle Time (s)
1	-142.8	5.6	215.0	103.9	0	586	17
2	-130.0	5.6	215.0	51.9	0	1973	297
3	245.5	5.6	215.0	51.8	0	1881	682
4	237.7	5.6	215.0	0.0	0	298	5774
5	238.0	5.6	215.0	69.1	0	363	164

- A single steady-state point was chosen from each of the five Extravehicular Activities (EVAs) attempted in Chamber B TVAC (2 cold, 3 hot), sink temps ranging from -140 to 245 F
  - Steady-state determined by exterior environmental protection garment (EPG) temperatures
- Human metabolic inputs were constant and based on actual settings of the HMS during test
- Half-cycle times set to constant value due to Rapid Cycle Amine (RCA) issues

Methodology – Model Validation

- The means for validation are simple and straightforward
  - We identify areas in the model that correspond to reliable TC's used in the test
  - Then we calculate absolute error between the model and corresponding TC
- Typically, the model temperature is represented as an average of multiple neighboring nodes (if discretization is fine enough)



Methodology – Viable TC's for Comparison

- A total of 27 TC's were used to compare with analog locations in TD model of the xPLSS
- Breakdown of TC locations:
  - Primary Oxygen Assembly (POA) – 5 TC's
  - Secondary Oxygen Assembly (SOA) – 5 TC's
  - Oxygen Ventilation Loop (OVL) – 4 TC's
  - Primary Thermal Control Loop (PTCL) – 5 TC's
  - Auxiliary Thermal Control Loop (ATCL) – 3 TC's
  - Caution and Warning System (CWS) and Exploration Informatics (xINFO) – 5 TC's

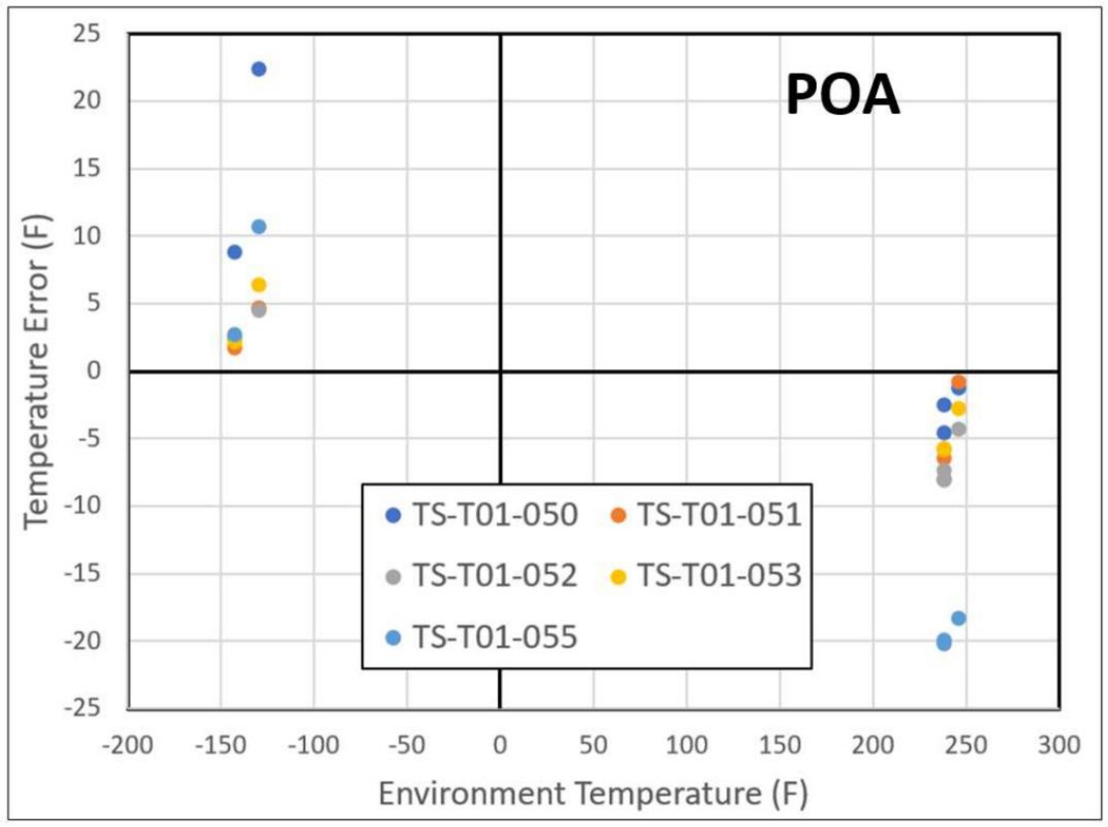
Subsystem	TC Lookup ID#	Description
Component Hardware Temperature Sensors		
xPLSS	TS-T01-050	PV-111, Primary Oxygen Vessel Front End
xPLSS	TS-T01-051	PRV-113, Primary Oxygen Regulator Linear Actuator
xPLSS	TS-T01-052	CON-150, POR Controller Housing
xPLSS	TS-T01-053	POR Regulator Monel Body
xPLSS	TS-T02-050	PV-210, Secondary Oxygen Vessel Front End
xPLSS	TS-T02-051	PRV-213, Secondary Oxygen Regulator Linear Actuator
xPLSS	TS-T02-052	CON-250, SOR Controller Housing
xPLSS	TS-T02-053	SOR Regulator Monel Body
xPLSS	TS-T03-050	GS-322, Suit Inlet Gas Sensor
xPLSS	TS-T03-051	Fan-323, Primary Fan
xPLSS	TS-T03-054	GX-380, Rapid Cycle Amine Valve Housing
xPLSS	TS-T03-055	GX-380, Rapid Cycle Amine Housing
xPLSS	TS-T04-050	CON-450, Thermal Loop Controller Housing
xPLSS	TS-T04-051	HX-440, SWME Valve Housing
xPLSS	TS-T04-052	HX-440, SWME Valve Linear Actuator
xPLSS	TS-T04-053	HX-440, Spacesuit Water Membrane Evaporator Housing
xPLSS	TS-T04-054	TCV-421 Linear Actuator
xPLSS	TS-T05-050	HX-540, Mini-Membrane Evaporator Linear Actuator
xPLSS	TS-T05-051	HX-540, Mini-Membrane Evaporator Housing
xPLSS	TS-T05-052	CON-550, Auxilliary Thermal Loop Controller Housing
xPLSS	TS-T06-051	CON-650, CWS Housing #2
xPLSS	TS-T07-051	Base of Battframe Near Backplate Contact
xINFO	TS-T07-053	INFO - EV-702 Housing Inside Face
xINFO	TS-T07-054	INFO - EV-702 Mounting Plate Bottom #1
xPLSS	TS-T01-055	Primary Regulator - Inlet from POV
xPLSS	TS-T02-055	Secondary Regulator - Inlet from SOV
xPLSS	TS-T07-056	Radio - Between Housing and Battery Rack

Results – Organization of Results

1. POA
   – Comprised of regulator valves, storage vessels, and plumbing
2. SOA
   – Comprised of regulator valves, storage vessels, and plumbing
3. OVL
   – Comprised of fans, the RCA, much plumbing, and carbon dioxide (CO_2) sensors
4. PTCL
   – Comprised of a Spacesuit Water Membrane Evaporator (SWME), a Thermal Control Valve (TCV), and much plumbing within the baseplate of the xPLSS
5. ATCL
   – Comprised of a miniature SWME (MiniME) and much plumbing within the baseplate of the xPLSS
6. CWS/xINFO
   – Comprised of controllers and communications components

Results – POA

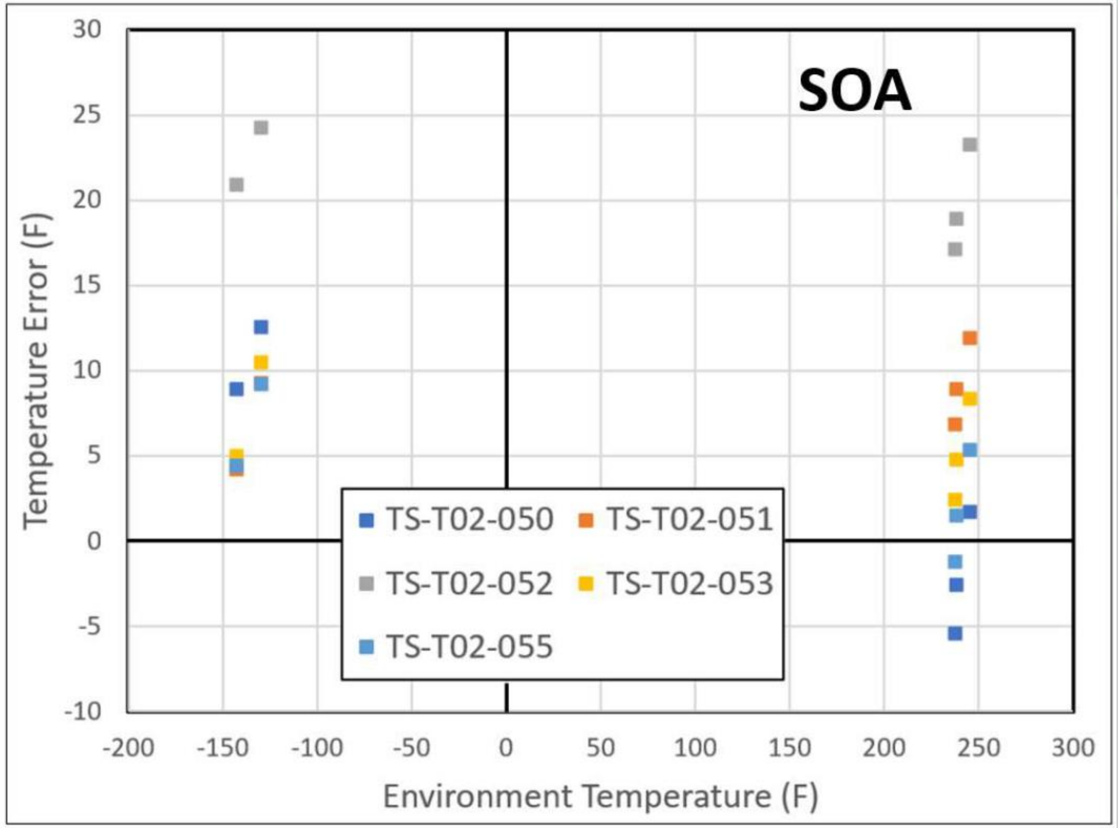
- Errors are exclusively positive in cold cases, negative in hot cases
- This implies a negative trend, where the simulation predicts the TC location as too warm in cold environments, and too cold in warm environments
  - Could be due to an overestimation of insulative performance of the xPLSS cover
  - The POA (as well as the SOA discussed next) is heavily influenced by the sides of the xPLSS cover



Absolute temperature errors on the POA (model vs. TVAC) plotted against environment temperature

Results – SOA

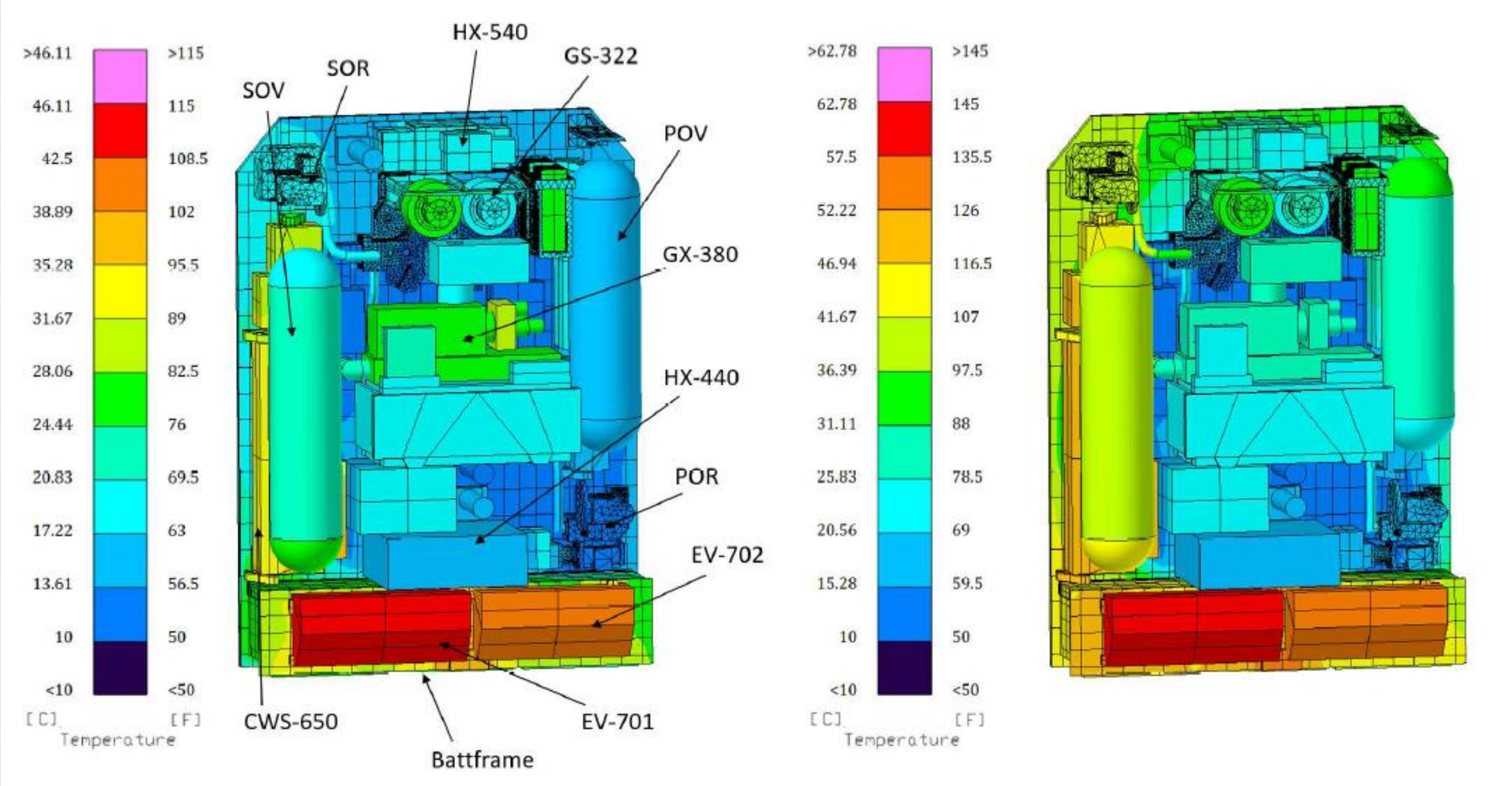
- Errors are generally positive in all cases and larger than those seen for the POA
- Despite not operating most of the test, the SOA is nearly identical to the POA with the exception of placement
- Could it be that neighboring components are propagating error to the SOA, but not the POA, due to proximity?



Absolute temperature errors on the SOA (model vs. TVAC) plotted against environment temperature

Results – SOA

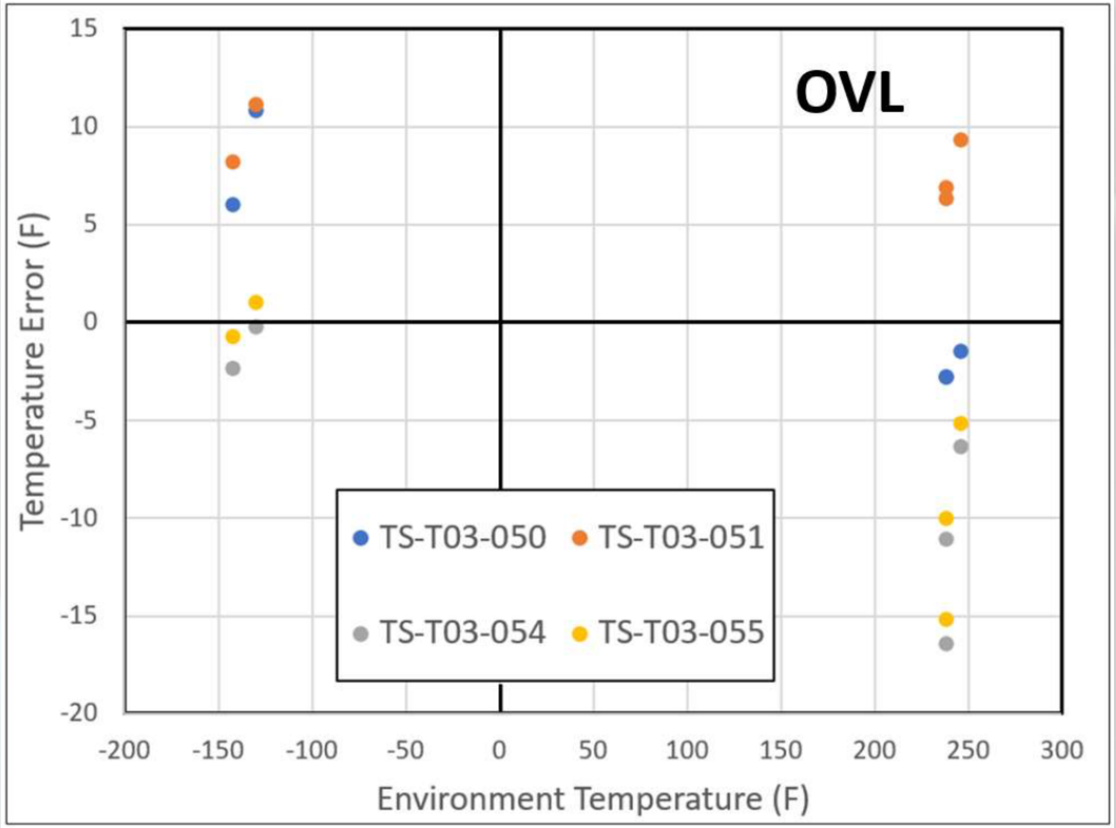
- The thermal contours show how the CWS-650, directly below the secondary oxygen vessel (SOV) and adjacent to multiple SOA components, is very warm in both the cold and hot cases
- If the CWS-650 temperature error is high (as will be shown later), this could propagate to its closest neighbor, the SOA



Thermal contours showing the xPLSS TD model interior with Case 1 (cold) on the left and Case 3 (hot) on the right

Results – OVL

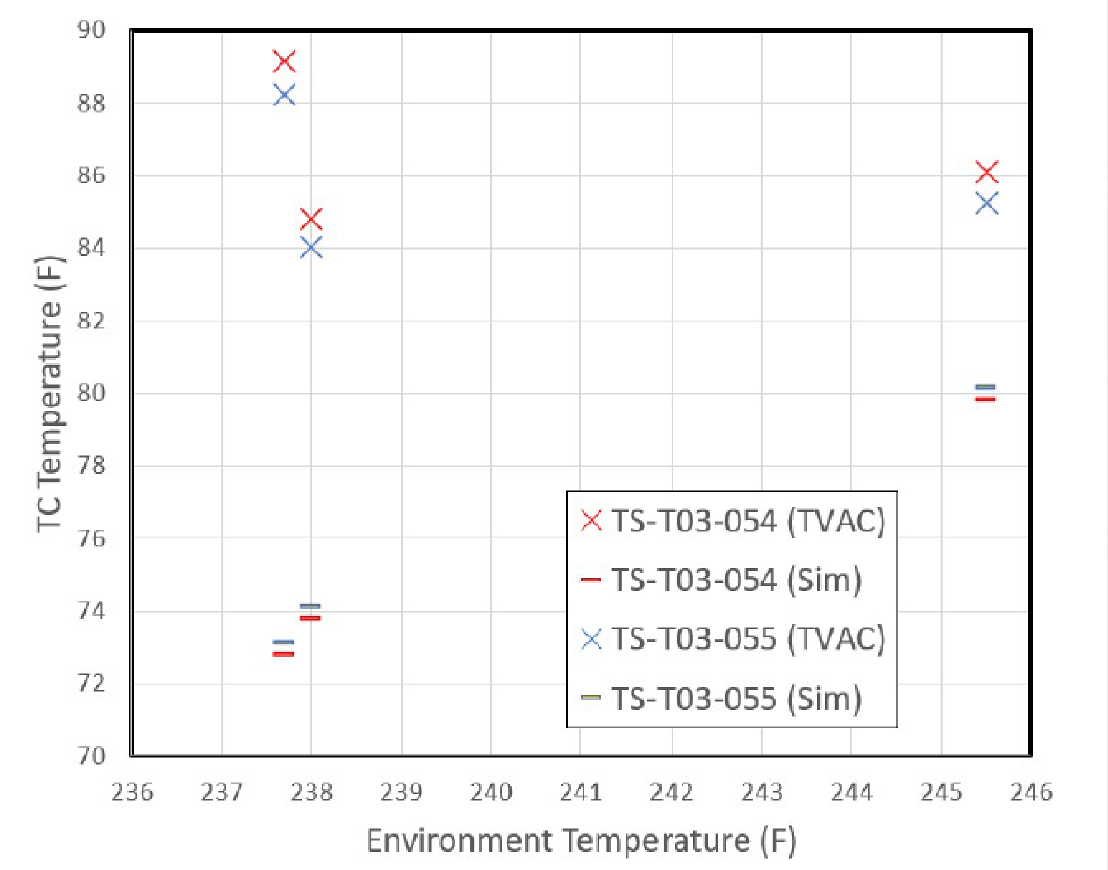
- Errors generally positive in the hot cases, negative in the cold cases
- Exception: TS-T03-051, the primary fan TC has positive errors in all cases (largest too)
  - Could be due to overestimation of fan motor heat dissipation
- RCA bracket temperatures (TS-T03-054 and TS-T03-055) cluster together but have significant spread case-to-case



Absolute temperature errors on the OVL (model vs. TVAC) plotted against environment temperature

Results – OVL

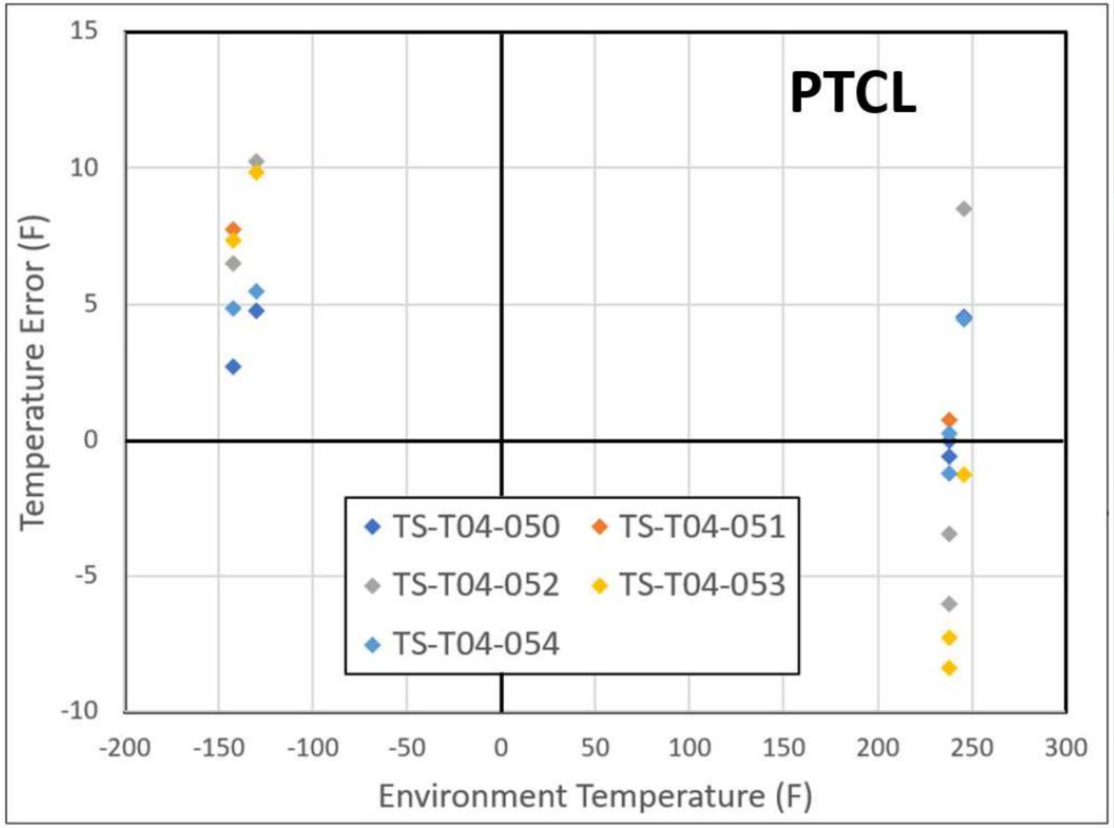
- Investigating the RCA bracket temperatures more closely
- Temperature estimations by the TD model (Sim) have a monotonic trend
- TVAC data points are not as consistent
- While the majority of the xPLSS was at steady-state for the five cases analyzed, the RCA may have some transient behavior affecting results



Absolute temperatures of the RCA bracket from TVAC (X) and simulation (-) plotted against environment temperature

Results – PTCL

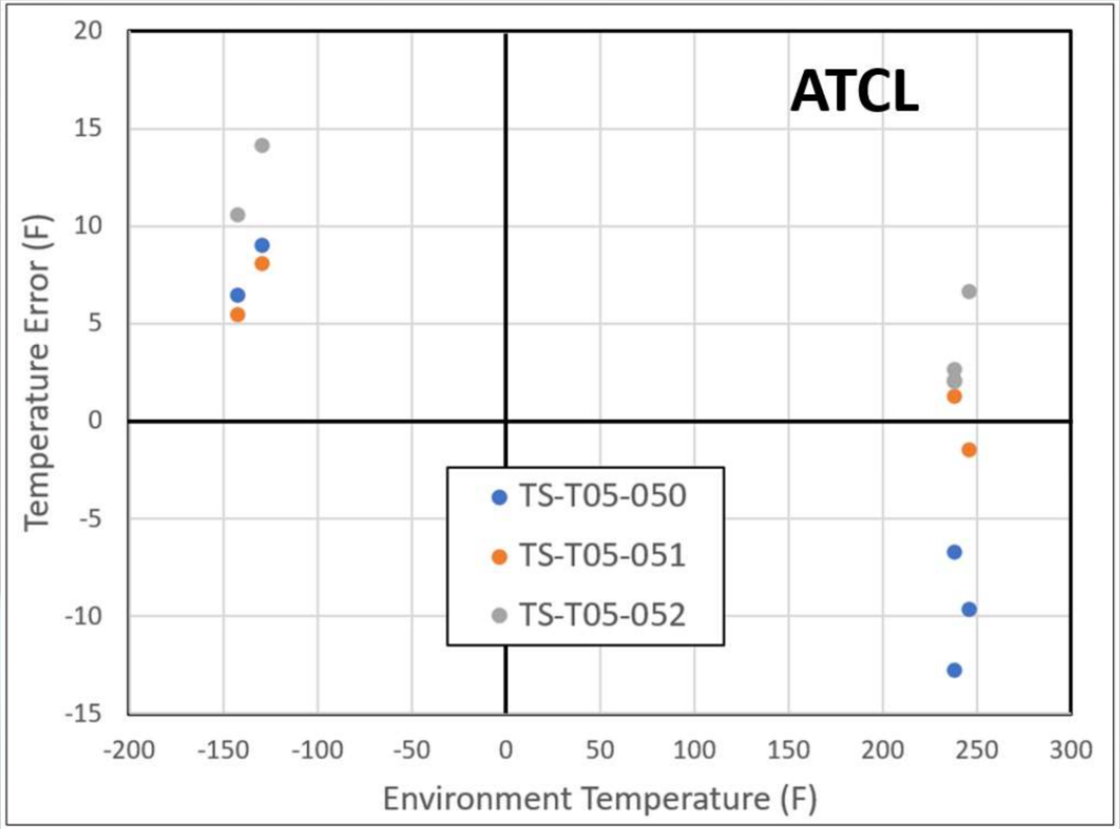
- Errors generally positive in the hot cases, negative in the cold cases, but smallest of the other groups
- There is no apparent reason why, but it could be that the heat loads applied to components in this group are more accurate
- Largest errors are on the SWME Back Pressure Valve motor and housing (TS-T04-052 and TS-T04-053), possibly due to coarse discretization



Absolute temperature errors on the PTCL (model vs. TVAC) plotted against environment temperature

Results – ATCL

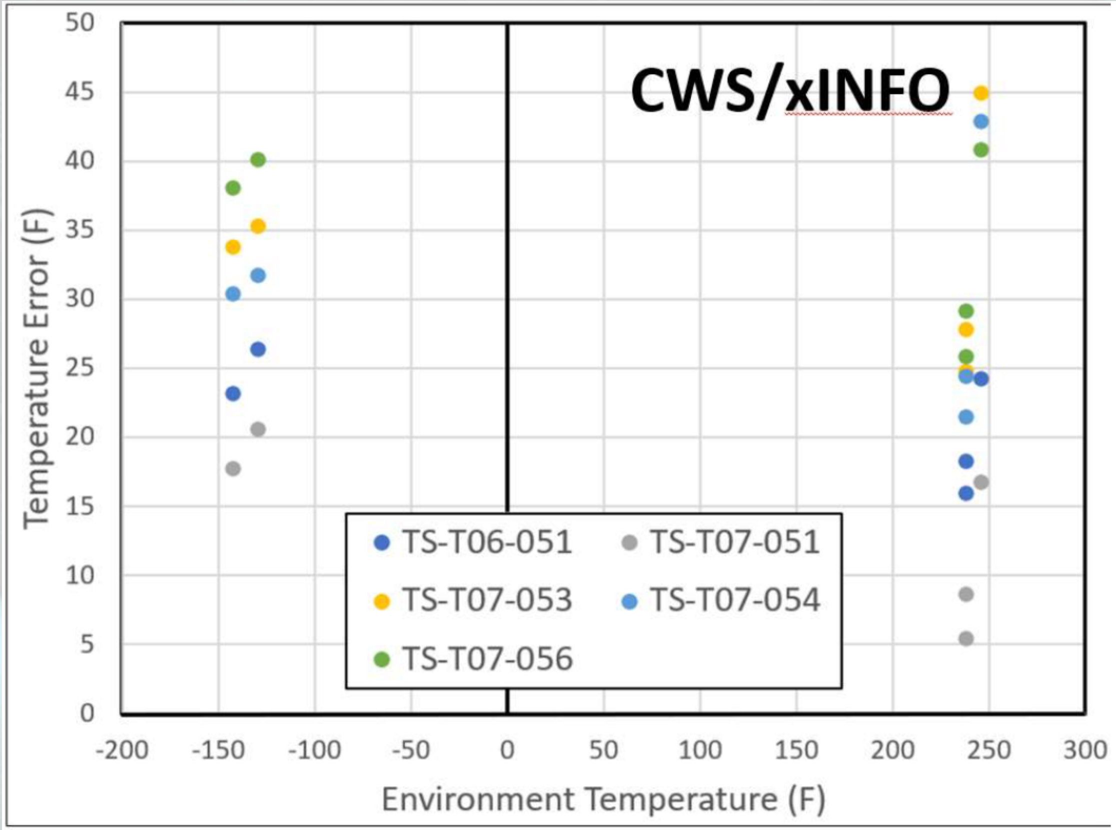
- Similar error trend to previous groups, especially PTCL
- Largest errors on CON-550 (TS-T05-052), which are positive in all cases
  - Heat dissipation on this controller may be overestimated
- The ATCL components are also heavily influenced by the top of the xPLSS cover



Absolute temperature errors on the ATCL (model vs. TVAC) plotted against environment temperature

Results – CWS/xINFO

- Largest errors of all the groups analyzed, positive in all cases
- Each of these components has relatively low detail in the TD model
- Further, each component is accompanied by a heat dissipation that may be overestimated



Absolute temperature errors on the CWS/xINFO (model vs. TVAC) plotted against environment temperature

Discussion

- Overall, temperature errors were not egregious and followed a consistent trend with the model predicting warmer temperatures in the cold cases and cooler temperatures in the hot cases
- Most errors may be attributed to:
  - Coarse discretization on the relevant component
  - Uniformity of the simulation radiation environment
  - Inaccurate heat dissipation on electronics
- Coarse discretization can easily be addressed by simply refining the mesh on components that saw large errors in this study (e.g., any of the controllers, the primary oxygen vessel (POV) and SOV)
  - Some components may require more interior detail in addition to mesh refinement, such as the EV-701, EV-702, SWME housing, MiniME housing, and others

Discussion (cont'd)

- The uniformity of the radiation environment is the most difficult factor to address, and involves edits to the model that may be cumbersome to the thermal modeler
  - First option: split the xPLSS exterior surface into different areas, each with their own sink temperature that can be adjusted until exterior temperature match test data
  - Second option: model the actual environment, in this case the interior of Chamber B, both heater cages, and any Mylar coverings/dividers
- The heat dissipation applied to electronic components can be modified by using an efficiency factor that converts only a percentage of this energy to heat
- These changes and simple increases in detail can go a long way in improving the fidelity of the xPLSS TD model

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