CCHP Modeling in Siemens Simcenter and Correlation with JPL SWOT Mission Two-phase Testbed

Lina Li Maricic – ATA Engineering
Ruwan Somawardhana – Jet Propulsion Laboratory, California Institute of Technology

Presented By
Lina Li Maricic

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Objectives

- Validate the constant conductance heat pipes (CCHPs) modeling methodology in Siemens Simcenter for SWOT thermal model
- Demonstrate a close correlation between the thermal model prediction and the ground thermal bed testing for a thermal pallet under steady state conditions

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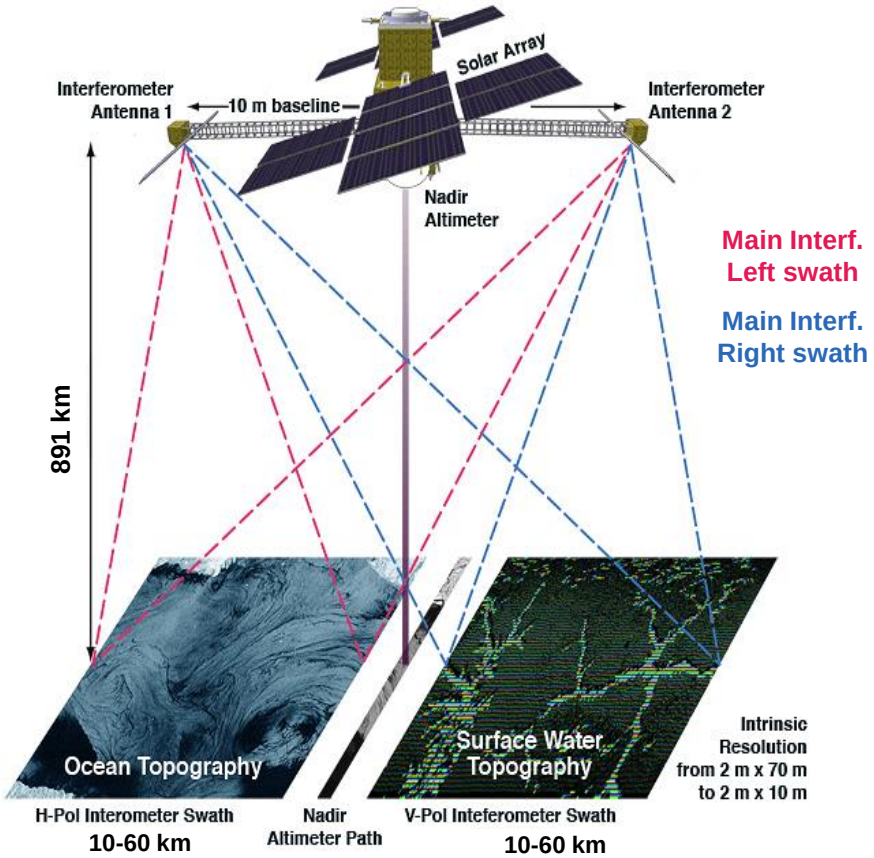
Surface Water and Ocean Topograghy (SWOT) Mission Overview

- JPL Partnered mission with CNES and CSA
- Mission Science
  - Oceanography: Characterize the ocean mesoscale and sub-mesoscale circulation at spatial resolutions of 15 km and greater.
  - Hydrology: To provide a global inventory of all terrestrial water bodies (lakes, reservoirs, wetlands and rivers)
- ATA Engineering, Inc. has been providing JPL thermal analysis support of SWOT mission since 2015



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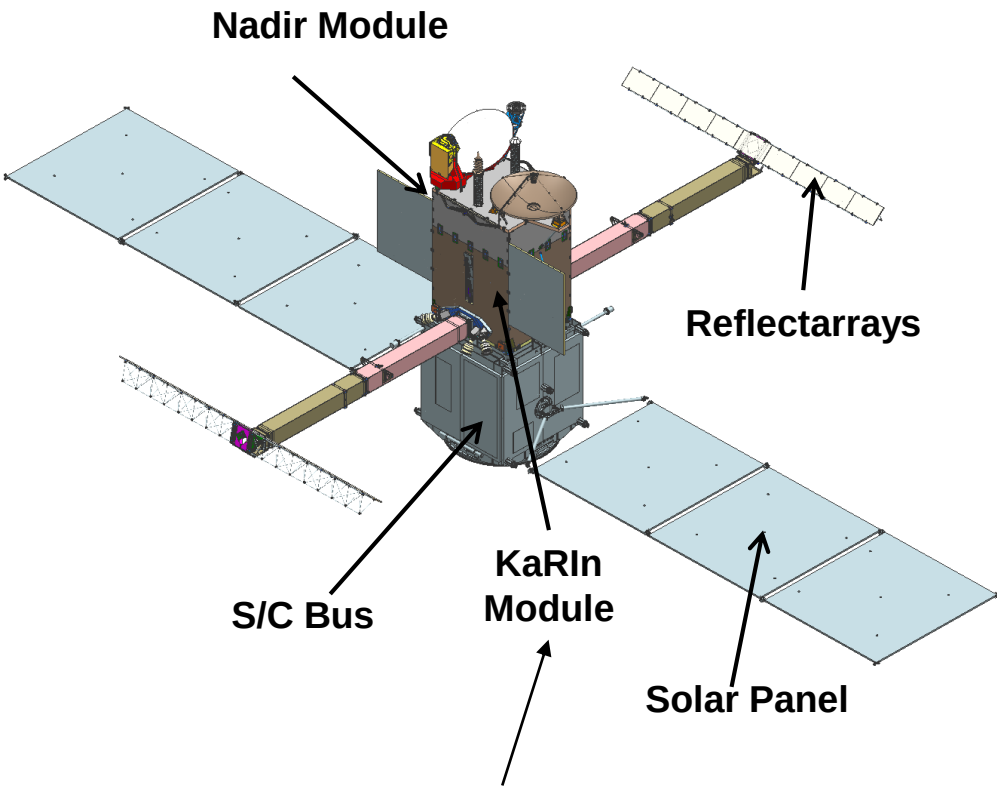
SWOT Thermal Driving Requirements

- Driving requirements fall into following categories
  - Allowed Flight Temperature (AFT) limits: driven by extreme environment
  - Temperature stabilities (dT/dt): KaRIn instrument requires tight temperature stabilities
  - Power constraints: Survival power limitation during post-launch, convergence phase and safe mode
  - Non-Science Modes: Wide range of S/C attitudes during convergence phase and orbit maneuvers are challenging both for cold and hot survival cases



KaRIn electronics mounted to four thermal pallets, and dissipate nearly 1,100 watts of power

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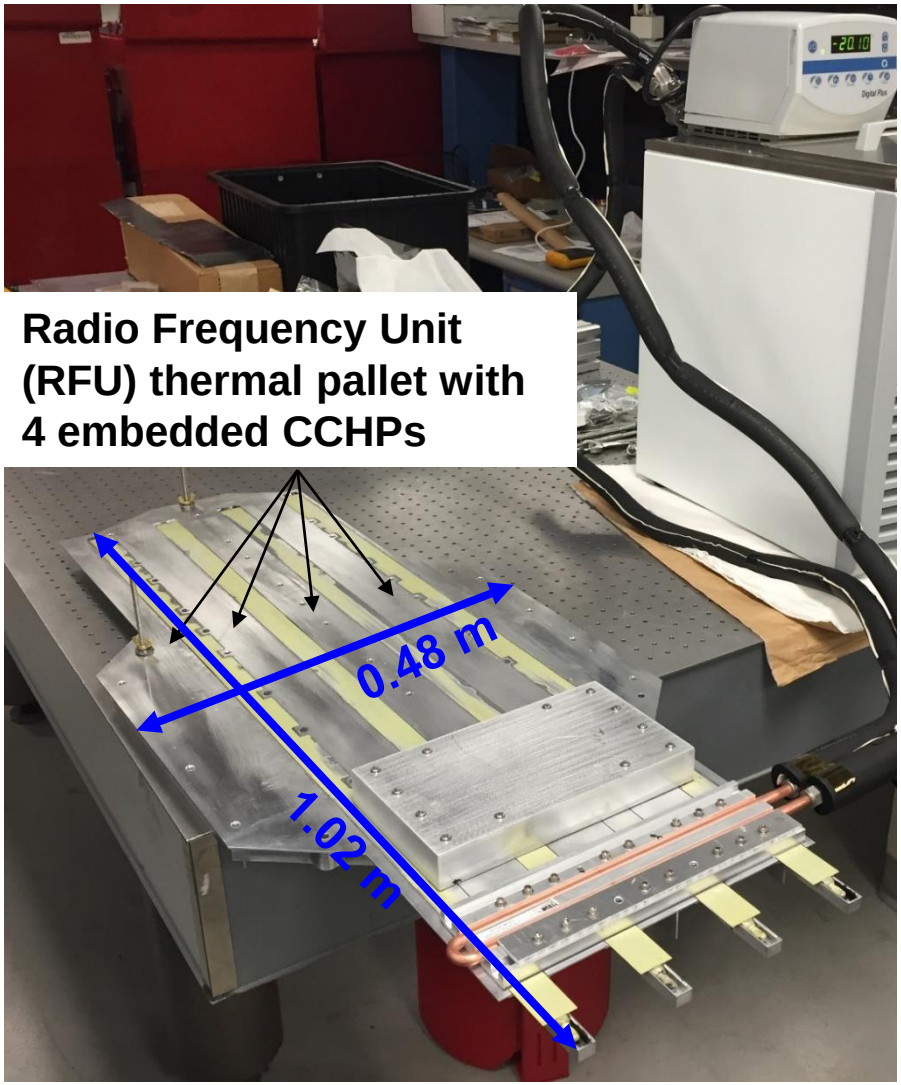
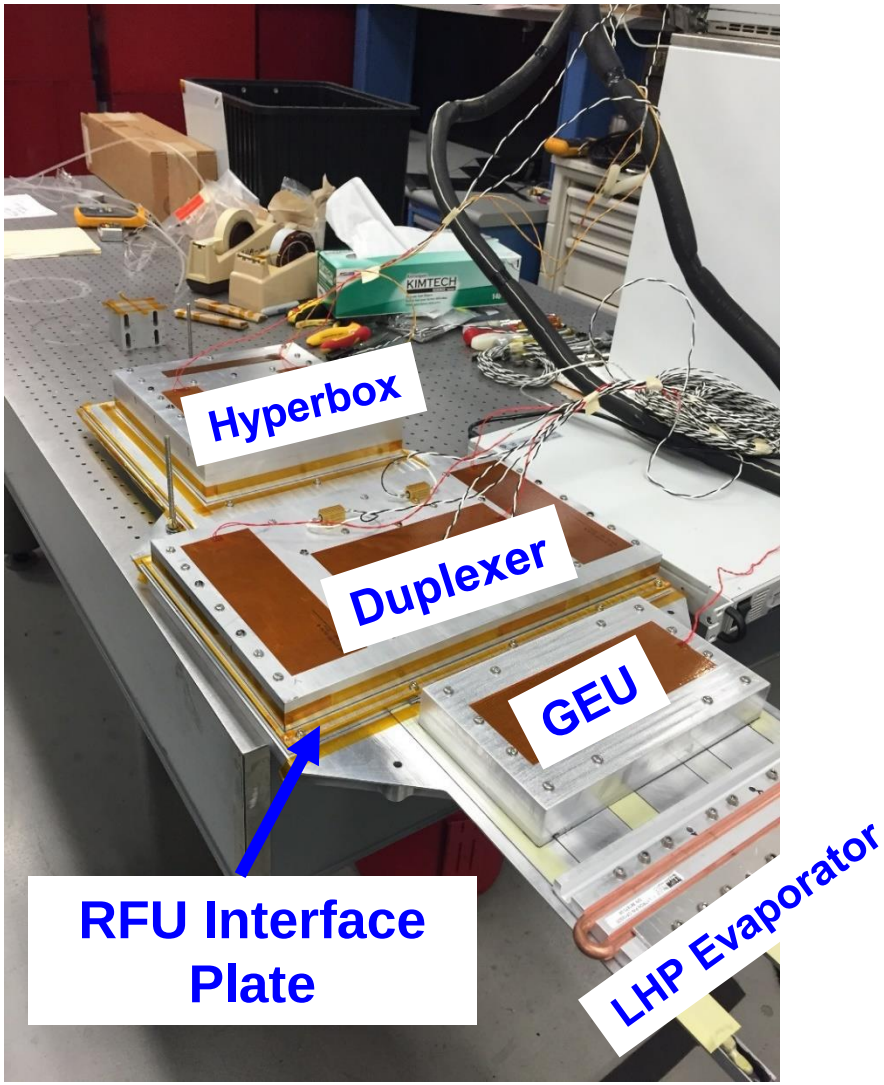
RFU Pallet and Ground Test Setup

RFU pallet in horizontal orientation under nominal power condition





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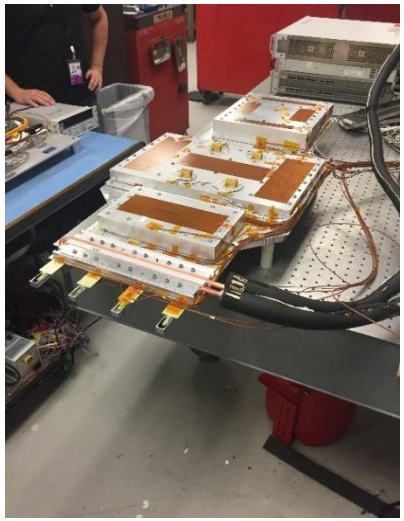
Test Objectives

- Measure steady state temperatures of the RFU pallet, interface plate and electronic boxes
- Characterize degrees of isothermality of the pallet and interface plate
- Derive thermal interface conductances between components and the pallet based on temperature measurements



Multiple tests were conducted under different orientation and power configurations. The test with horizontal orientation and nominal power configuration was correlated only.

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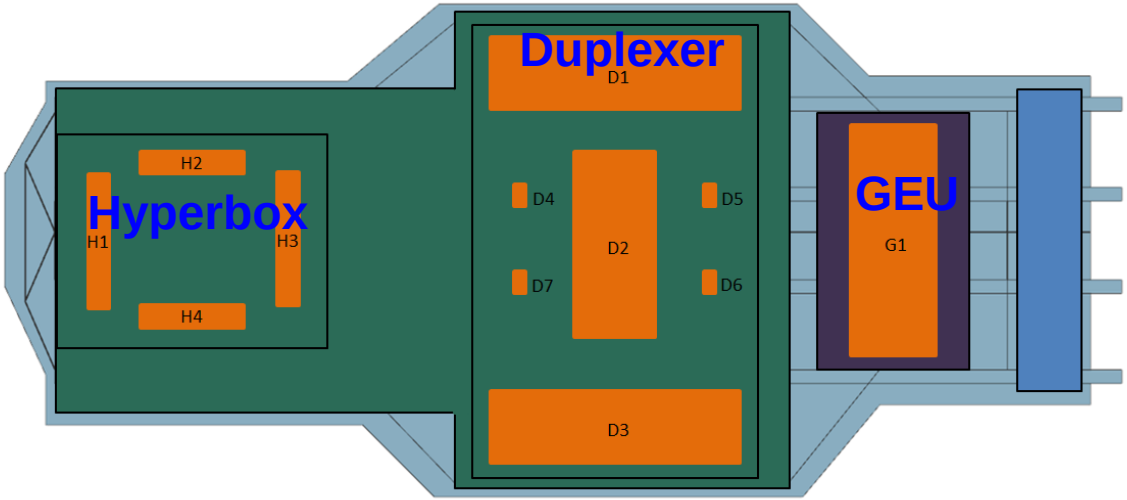
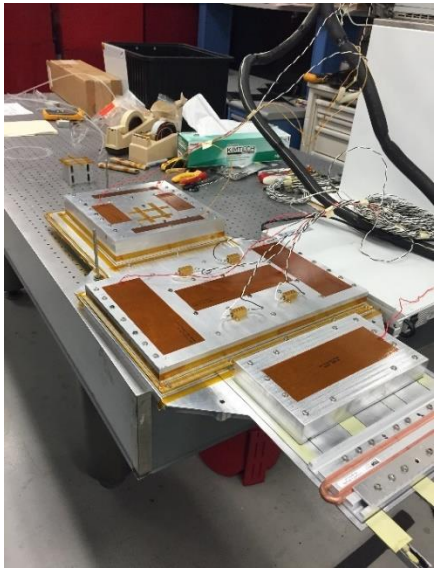
Test: Heater Circuit & Power Input

Heater Group	Nominal Operation Power (W)	Heaters on Circuit
GEU	35.9	G1
Hyperbox	83.4	H1, H2, H3, H4
Duplexer (1)	82.9	D1, D2 ,D3
Duplexer (2)	5.7	D4, D5, D6, D7





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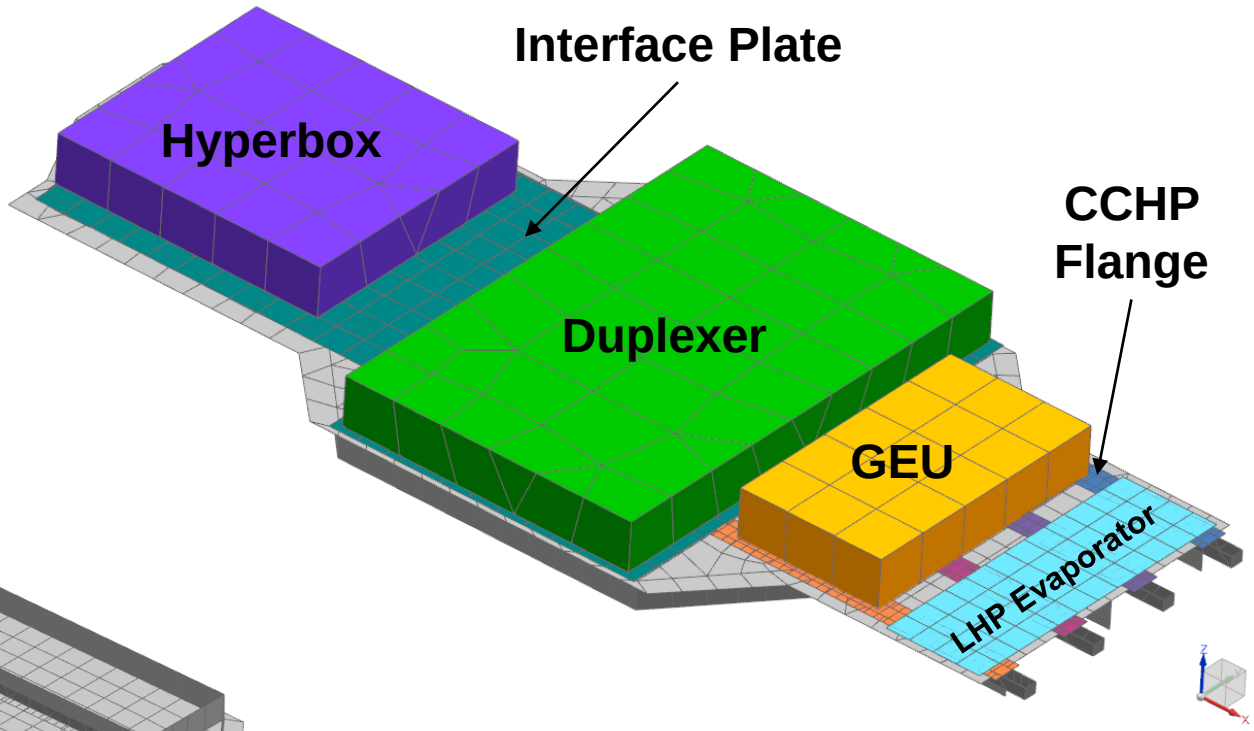
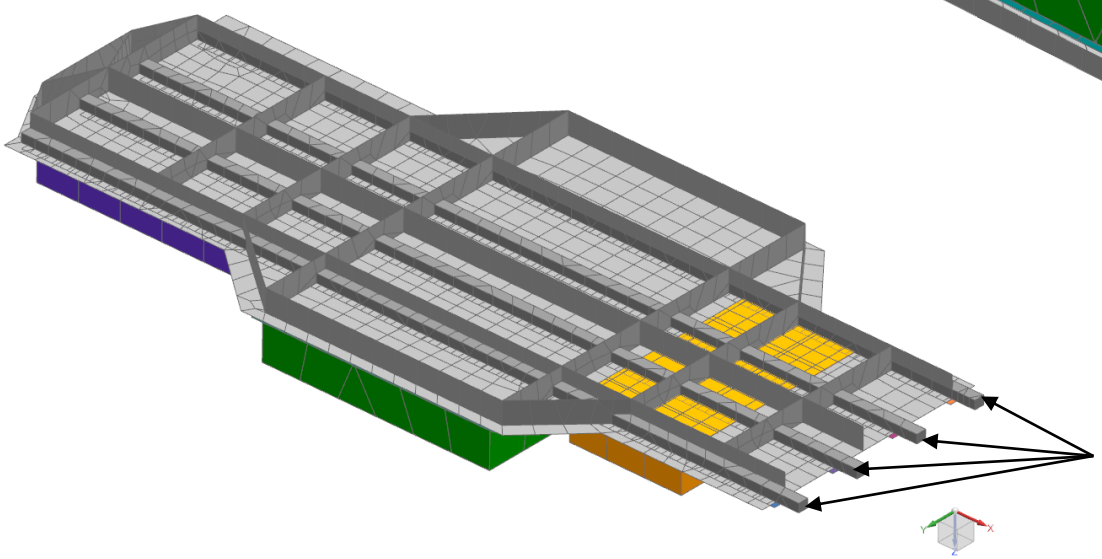
RFU Thermal Pallet Model

Total Number of Elem: 3,162

Top Side



Bottom Side



RFU thermal pallet with 4 embedded CCHPs

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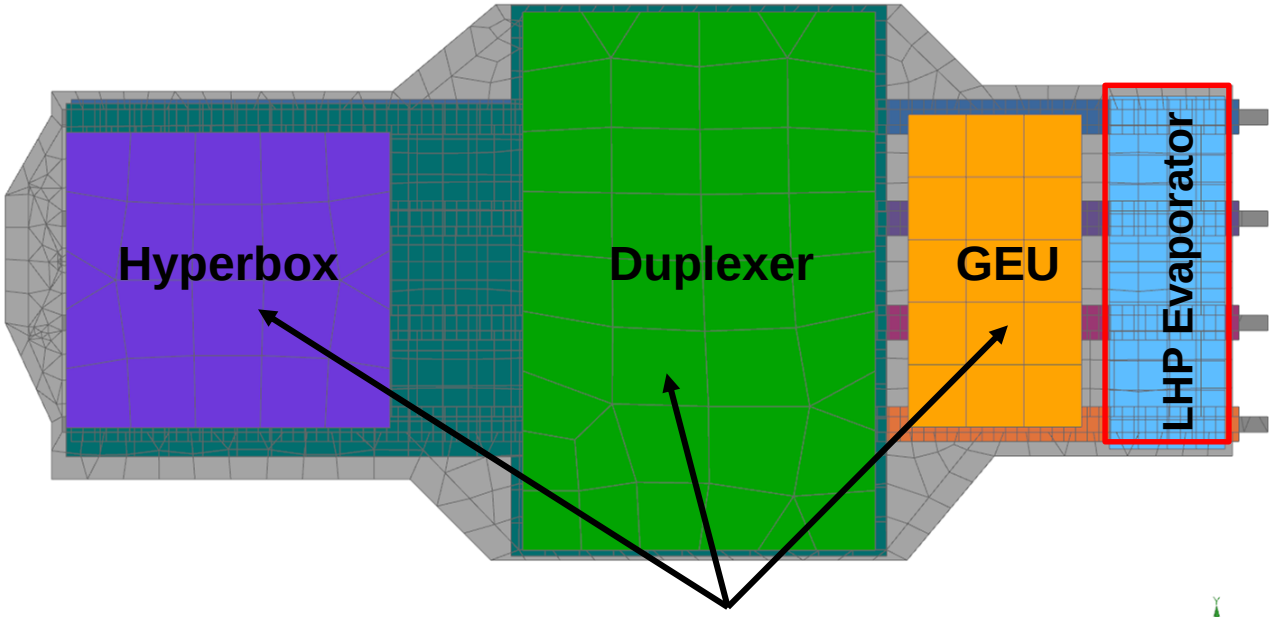
Model: Power Input

Heater Group	Nominal Operation Power (W)
GEU	35.9
Hyperbox	83.4
Duplexer	88.6



Heat load was applied uniformly on the top of each box, which was not consistent with the test. Electronic box temperatures were not of interest of correlation)

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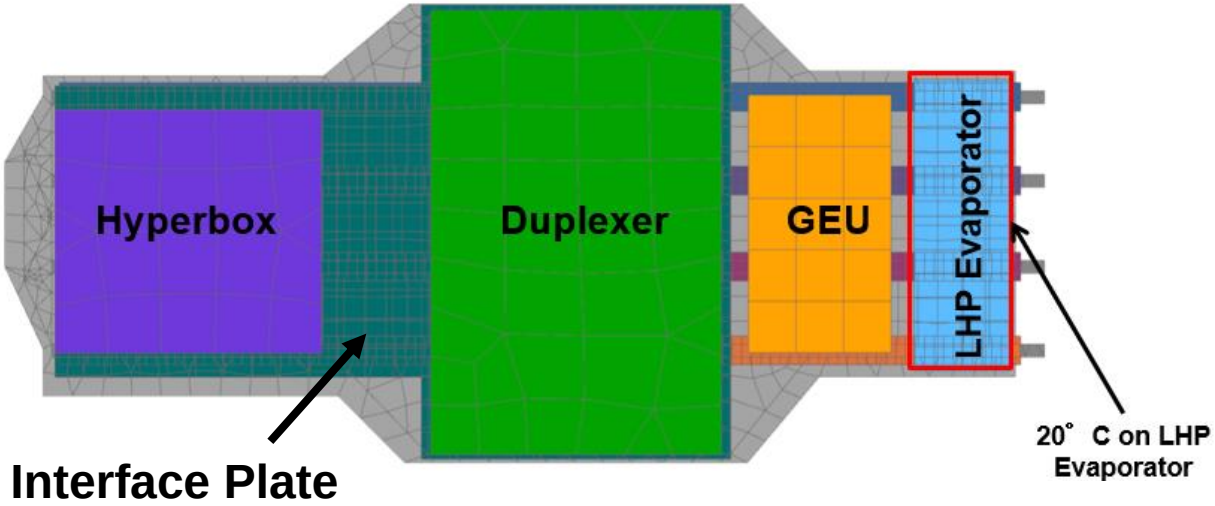
Modeling Assumptions

- Boundary condition: 20° C on LHP evaporator
  - Serves as a heat sink. Model did not intend to characterize detailed thermal response of LHP evaporator
  - In benchtop testing, evaporator was simulated using a 2-pass tube-and-plate heat exchanger with a chiller
- Assume box to interface plate, and interface plate to pallet heat transfer coefficient of 450 W/m²-K
  - Graphite foil (eGraf 1220 – 0.020”) used to reduce contact resistance
  - Test results show higher heat transfer coefficient than what was used in the model
- Temperature dependent Al – 6061 material properties used



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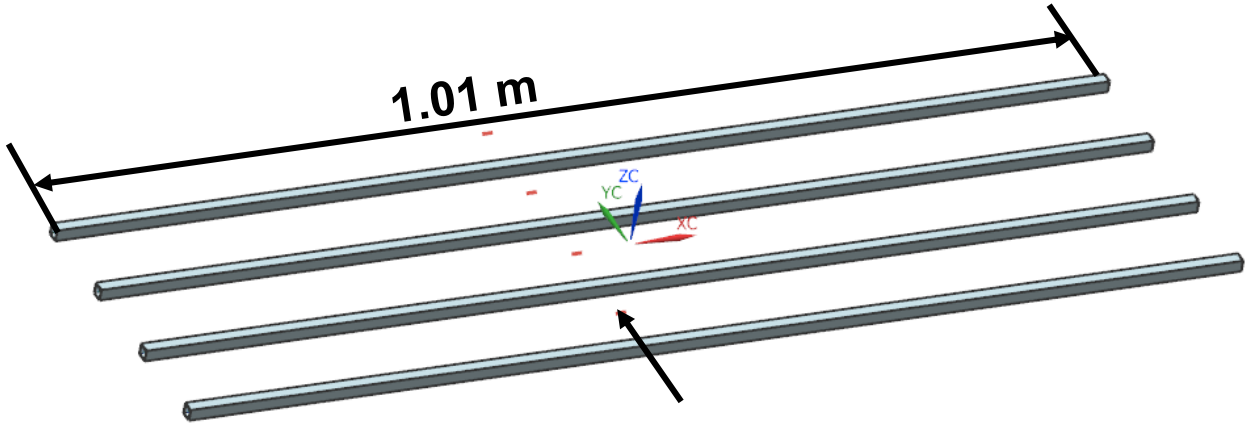
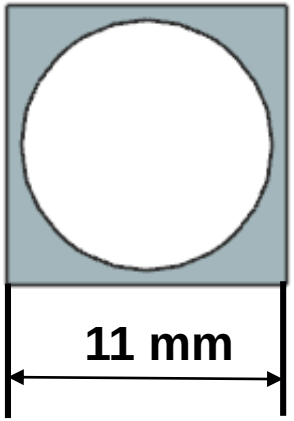
CCHP Modeling in Simcenter

- One meter long Aluminum extrusion CCHP was modeled using 1-D beam elements with user-defined cross-section including solid and fluid area
- One fluid element was created for each CCHP
  - Simcenter TMG cannot model a separate evaporation and condensation heat transfer coefficient based on whether the pipe element is hotter or colder than the fluid
- Manufacture supplied thermal conductance between CCHP and fluid per length was used (78.7 W/(m-K)) as the mean value for evaporation and condensation
- CCHP was bonded to thermal pallet channels, and thermal conductance between CCHP to channels was calculated using bondline's properties



Fluid element (x4)

CCHP cross-section



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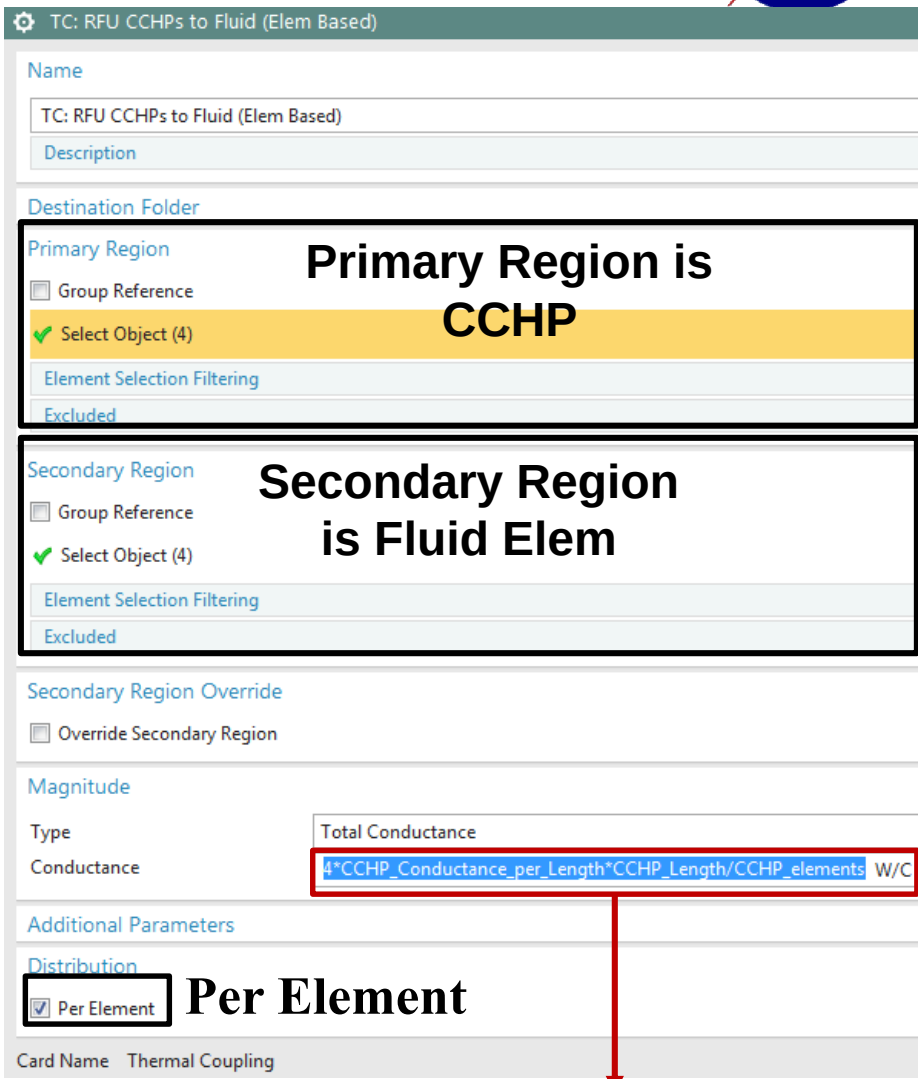
CCHP to Fluid Thermal Conductance Tuned

- CCHP to fluid thermal conductance per element was tuned to correlate to test results
  - CCHP_Conductance_per_Length *CCHP_Length/CCHP_elements
  - Scale factor (SF) = 1, 2, 3 or 4 were used to correlate to test
  - Model 1, 2, 3 or 4 corresponds to each of the four different SF



SF*CCHP_Conductance_per_Length*CCHP_Length/CCHP_elements

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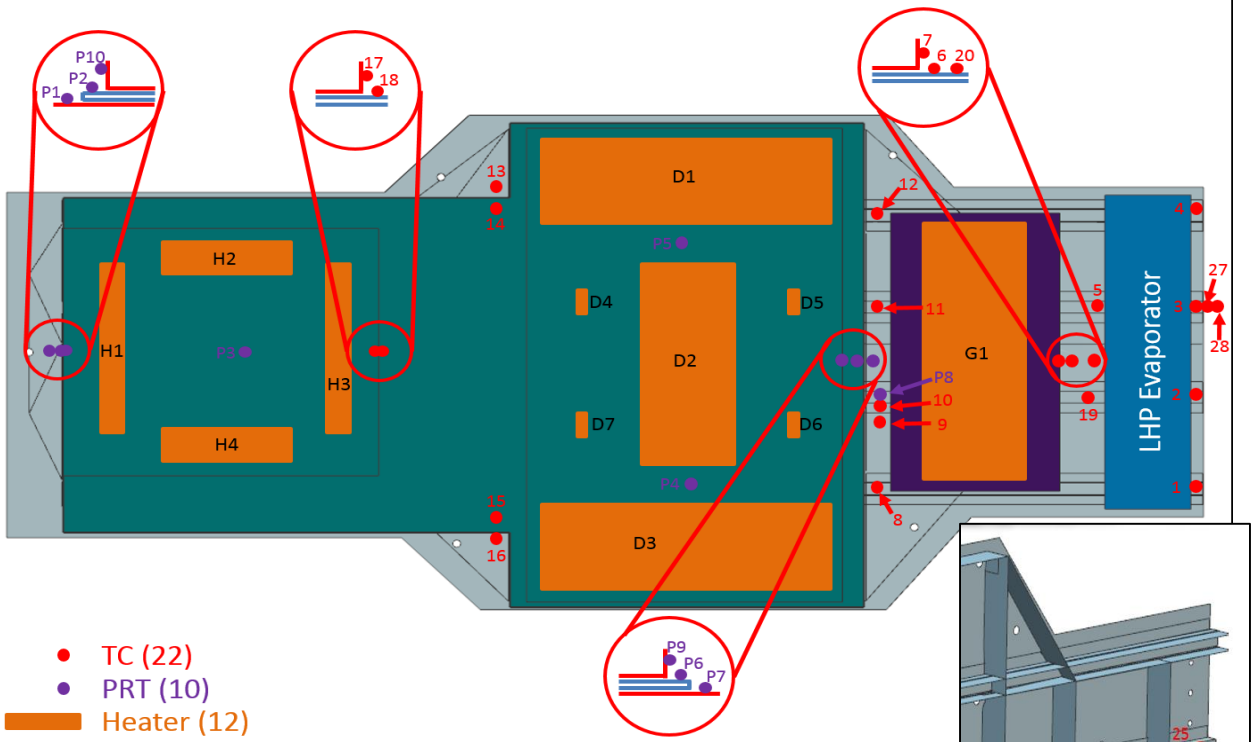
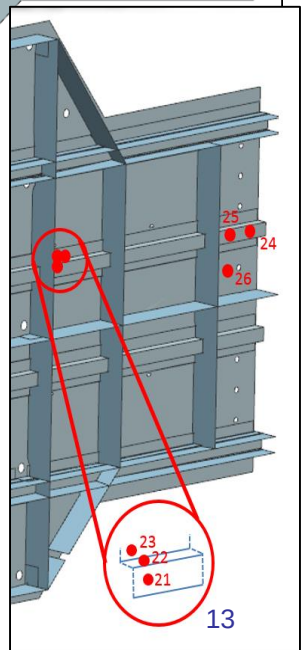
Test Sensor Locations and Temperatures

Location	Sensor ID	Sensor Name	Test Temp (°C)
RFU Pallet	1	PRT1	29.1
	2	PRT7	27.9
	3	PRT8	27.0
	4	TC 3	20.5
	5	TC 4	20.2
	6	TC 5	26.9
	7	TC 6	27.3
	8	TC 8	28.1
	9	TC 9	28.2
	10	TC10	24.5
	11	TC11	24.8
	12	TC12	24.4
	13	TC13	26.3
	14	TC16	26.4
	15	TC19	26.1
	16	TC20	25.8
	17	TC21	25.7
	18	TC22	25.5
	19	TC23	25.6
	20	TC24	25.3
	21	TC25	25.5
	22	TC26	20.8
	23	TC27	23.4
	24	TC28	24.5
Interface Plate	25	PRT2	30.1
	26	PRT6	29.8
	27	TC14	27.0
	28	TC15	27.1
	29	TC18	25.4
Electronic Boxes	30	PRT9	26.3
	31	PRT10	26.7
	32	TC7	27.4
	33	TC17	25.7
	34	PRT3	27.8
	35	PRT4	27.3
	36	PRT5	32.3

Thermal Pallet Top





Electronic box interface temperatures are important. Temperatures on electronic boxes were not of interest at the time of correlation. They were not correlated to the model.

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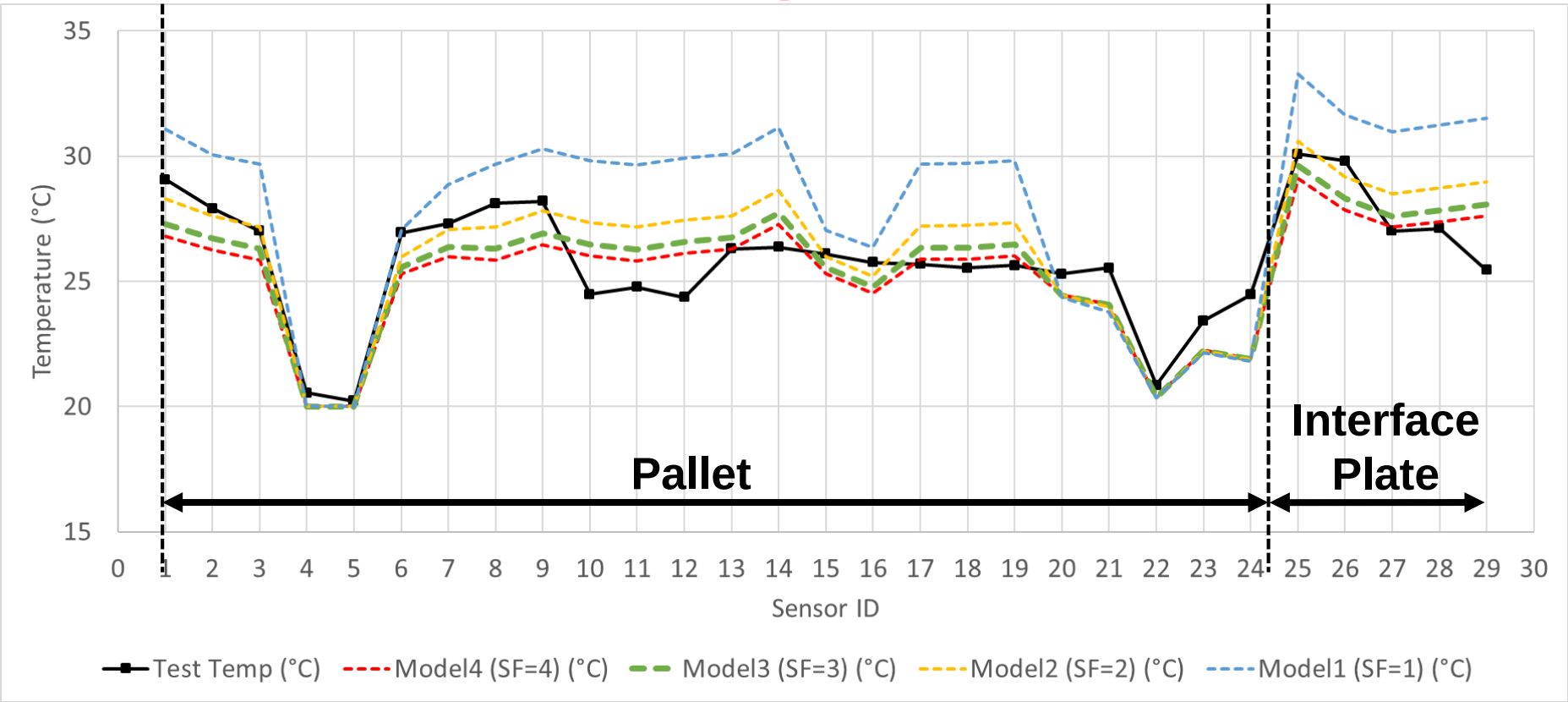
Model 3 (SF = 3) Demonstrates Close Correlation To Test With The Least Average RMS ΔT

	Model4 ΔT (°C)	Model3 ΔT (°C)	Model2 ΔT (°C)	Model1 ΔT (°C)
Average ΔT	-0.54	-0.21	0.47	2.67
Minimum ΔT	-2.56	-2.57	-4.82	0.12
Maximum ΔT	2.18	2.64	5.48	6.06
RMS ΔT	1.34	1.32	2.13	3.18



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Tabulated Temperature Comparison Between Test and Models

Location	Sensor ID	Sensor Name	Test Temp (°C)	Model4 (SF=4) (°C)	Model4 ΔT (°C)	Model3 (SF=3) (°C)	Model3 ΔT (°C)	Model2 (SF=2) (°C)	Model2 ΔT (°C)	Model1 (SF=1) (°C)	Model1 ΔT (°C)
RFU Pallet	1	PRT1	29.1	26.8	-2.3	27.3	-1.8	28.3	-0.8	31.1	2.0
	2	PRT7	27.9	26.3	-1.6	26.7	-1.2	27.6	-0.3	30.0	2.1
	3	PRT8	27.0	25.8	-1.2	26.3	-0.7	27.2	0.2	29.7	2.7
	4	TC 3	20.5	20.0	-0.5	20.0	-0.5	20.0	-0.5	20.0	0.5
	5	TC 4	20.2	20.0	-0.2	20.0	-0.2	20.0	-0.2	20.0	0.2
	6	TC 5	26.9	25.3	-1.6	25.5	-1.4	26.0	-1.0	27.1	0.1
	7	TC 6	27.3	26.0	-1.3	26.4	-0.9	27.1	-0.2	28.9	1.6
	8	TC 8	28.1	25.8	-2.3	26.3	-1.8	27.2	-0.9	29.7	1.6
	9	TC 9	28.2	26.5	-1.7	26.9	-1.3	27.8	-0.4	30.3	2.1
	10	TC10	24.5	26.0	1.5	26.5	2.0	27.3	2.9	29.8	5.3
	11	TC11	24.8	25.8	1.1	26.3	1.5	27.2	2.4	29.6	4.9
	12	TC12	24.4	26.1	1.7	26.6	2.2	27.4	3.1	29.9	5.6
	13	TC13	26.3	26.3	0.0	26.7	0.4	27.6	3.5	30.1	3.8
	14	TC16	26.4	27.3	0.9	27.7	1.4	28.6	2.3	31.1	4.8
	15	TC19	26.1	25.3	-0.8	25.5	-0.6	26.0	-0.1	27.0	0.9
	16	TC20	25.8	24.5	-1.2	24.8	-1.0	25.2	-4.8	26.4	0.6
	17	TC21	25.7	25.9	0.2	26.3	0.6	27.2	1.5	29.7	4.0
	18	TC22	25.5	25.9	0.4	26.3	0.8	27.2	1.7	29.7	4.2
	19	TC23	25.6	26.0	0.4	26.5	0.8	27.3	1.7	29.8	4.2
	20	TC24	25.3	24.4	-0.8	24.5	-0.8	24.5	-0.8	24.4	0.9
	21	TC25	25.5	24.1	-1.4	24.0	-1.5	24.0	-1.6	23.8	1.8
	22	TC26	20.8	20.4	-0.5	20.4	-0.5	20.3	-0.5	20.3	0.5
	23	TC27	23.4	22.3	-1.2	22.2	-1.2	22.2	-1.2	22.1	1.3
	24	TC28	24.5	21.9	-2.6	21.9	-2.6	21.9	-2.6	21.8	2.7
Interface Plate	25	PRT2	30.1	29.1	-1.0	29.6	-0.5	30.6	0.5	33.3	3.2
	26	PRT6	29.8	27.8	-2.0	28.3	-1.5	29.2	-0.6	31.7	1.9
	27	TC14	27.0	27.2	0.2	27.6	0.6	28.5	5.5	31.0	4.0
	28	TC15	27.1	27.4	0.3	27.8	0.7	28.7	1.6	31.2	4.1
	29	TC18	25.4	27.6	2.2	28.1	2.6	29.0	3.5	31.5	6.1
				Average ΔT	-0.54	Average ΔT	-0.21	Average ΔT	0.47	Average ΔT	2.67
				Minimum ΔT	-2.56	Minimum ΔT	-2.57	Minimum ΔT	-4.82	Minimum ΔT	0.12
				Maximum ΔT	2.18	Maximum ΔT	2.64	Maximum ΔT	5.48	Maximum ΔT	6.06
				RMS ΔT	1.34	RMS ΔT	1.32	RMS ΔT	2.13	RMS ΔT	3.18

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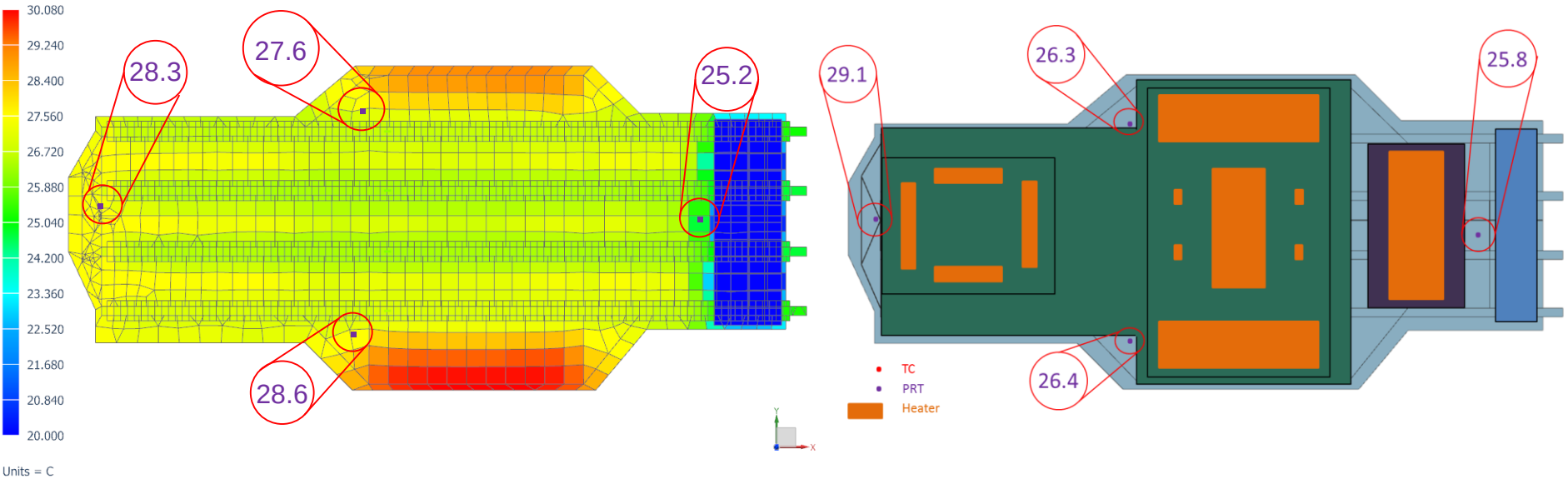
Model-2 Shows Closer Correlation to Test in Temperature Gradient along Pallet Length

Model-2 Temperatures | **Test Temperatures**



Sensor ID	Sensor Name	Test dT - Along Pallet Length (°C) [PRT 1/TC 20)	Model4 dT - Along Pallet Length (°C) [PRT 1/TC 20]	Model3 dT - Along Pallet Length (°C) [PRT 1/TC 20]	Model2 dT - Along Pallet Length (°C) [PRT 1/TC 20]	Model1 dT - Along Pallet Length (°C) [PRT 1/TC 20]
1	PRT1	3.3	2.3	2.5	3.1	4.7
16	TC20					
Sensor ID	**Sensor Name**	**Test dT - Across Pallet Width (°C) [PRT 1/TC 20)**	**Model4 dT - Across Pallet Width (°C) [TC13/TC16]**	**Model3 dT - Across Pallet Width (°C) [TC13/TC16]**	**Model2 dT - Across Pallet Width (°C) [TC13/TC16]**	**Model1 dT - Across Pallet Width (°C) [TC13/TC16]**
13	TC13	0.1	1.0	1.0	1.0	1.0
14	TC16					

Larger dT predicted across pallet width is likely due to lower heat transfer coefficient between components used in models

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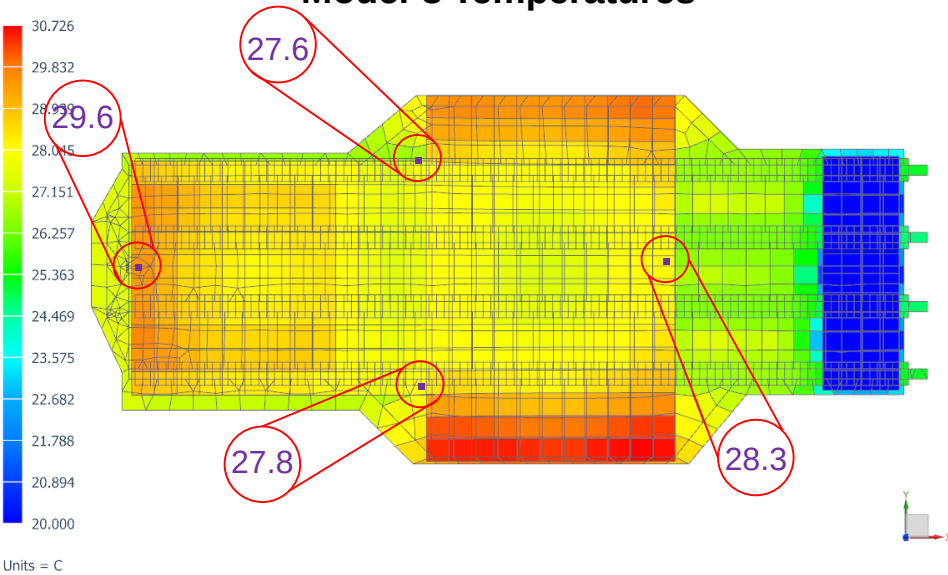
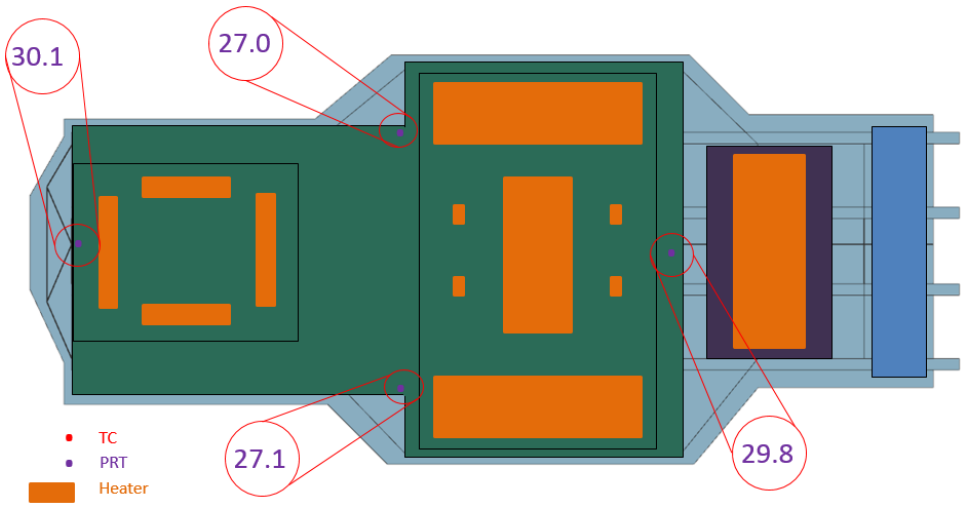
Similar Temperature Gradients Predicted on RFU Interface Plate and All Larger than Test

Model-3 Temperatures



Test Temperatures



Sensor ID	Sensor Name	Test dT - Along Interface Length (°C) [PRT2/PRT6]	Model4 dT - Along Interface Length (°C) [PRT2/PRT6]	Model3 dT - Along Interface Length (°C) [PRT 1/TC 20]	Model2 dT - Along Interface Length (°C) [PRT2/PRT6]	Model1 dT - Along Interface Length (°C) [PRT2/PRT6]
25	PRT2	0.3	1.3	1.3	1.4	1.6
26	PRT6					
Sensor ID	**Sensor Name**	**Test dT - Across Interface Width (°C) [TC14/TC15]**	**Model4 dT - Across Interface Width (°C) [TC14/TC15]**	**Model3 dT - Across Interface Width (°C) [TC14/TC15]**	**Model2 dT - Across Interface Width (°C) [TC14/TC15]**	**Model1 dT - Across Interface Width (°C) [TC14/TC15]**
27	TC14	0.1	0.2	0.2	0.2	0.3
28	TC15					

Larger dT is likely due to lower heat transfer coefficient between components used in models

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Conclusions

- A SWOT pallet thermal model with CCHPs in Simcenter was correlated to the ground test in horizontal orientation under nominal power configuration
- CCHP to fluid thermal conductance is the key parameter to have a correlated model
- Manufacture supplied CCHP to fluid thermal conductance value is overly conservative in thermal model. Scale factors (SF) need to be applied to achieve closer correlation.
  - If the objective is to have the least RMS ΔT for all sensors on pallet and interface plate, SF of 3 should be used.
  - Although SF of 2 gives the closest correlation in temperature gradients along RFU pallet length direction (only), SF of 2 over predicts temperatures in many locations.

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Acknowledgements

- The test was done by Ben Furst at JPL and under the direction of Ruwan Somawardhana in 2015
- Many thanks to JPL SWOT thermal team: Ruwan Somawardhana, Howard Tseng, Louis Tse, and Eug Kwack for support of this correlation effort and this paper

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