

# VERITREK

## How to Correlate a Thermal Model using Veritrek™

Veritrek™ allows you to easily correlate a thermal model to measured experimental test data, increasing the model's accuracy in predicting real-world behavior. Uncorrelated models are often based on an assortment of estimated input parameters (e.g. handbook conductance values); and it is hard to know which combination of parameter values accurately predict reality. Typically, model correlation involves institutional knowledge and an iterative “guess and check” method that becomes time-consuming and costly. To overcome these challenges, Veritrek can help you calibrate Thermal Desktop® model parameters to experimental test data using an automated, repeatable, and simple methodology. The following example demonstrates the power and efficiency of using Veritrek to correlate a thermal model. Figure 1 shows the uncorrelated thermal model results versus the correlated thermal model results obtained using Veritrek, for a 6U CubeSat thermal model.

***The goal of this model correlation example is to calibrate a 6U CubeSat Thermal Desktop® model to multiple sets of experimental test data, within a range of ± 3°C.***

**It took one day to correlate the Thermal Desktop® model using Veritrek, and allowed a user to choose the best solution from 20,000 different combinations of model parameters.**

### Temperature Differential [°C] from Thermal Test Data

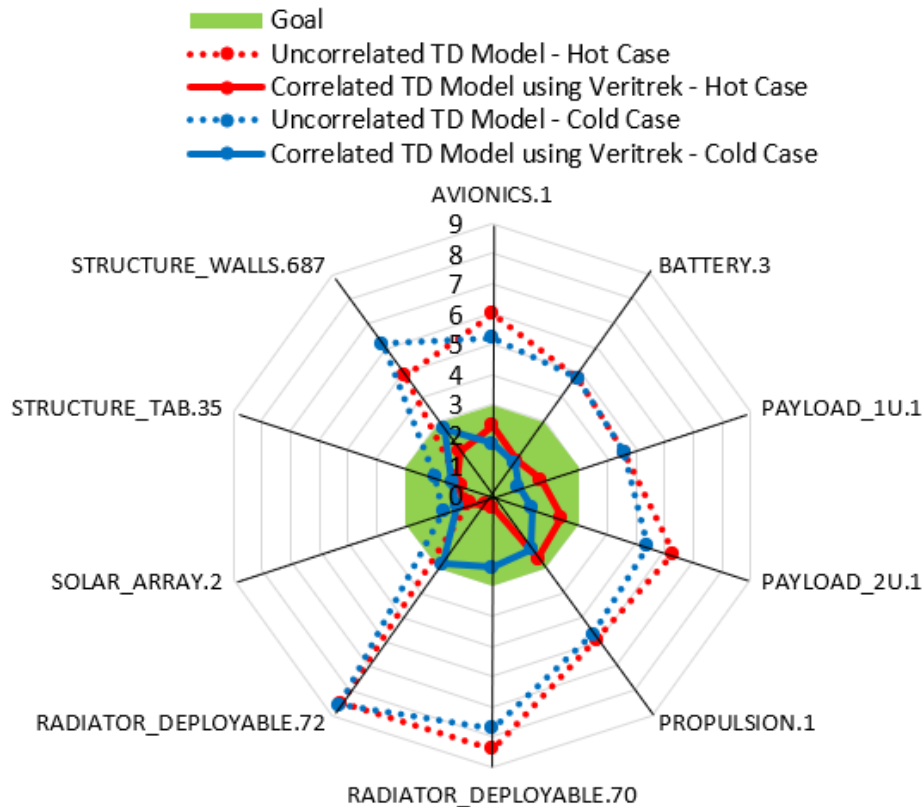


Figure 1: Correlated Thermal Desktop® model results using Veritrek

In this example, a reduced-order model (ROM) of a 6U CubeSat Thermal Desktop® model was built in one day (mostly automated run time), and then 20,000 different combinations of model parameters were investigated in a few seconds to determine the best values to use to most accurately match the model to test data. A preliminary comparison of the uncorrelated thermal model to the experimental test data (Table 1) shows that most modeled results did not match measurements within the required tolerance of  $\pm 3^{\circ}\text{C}$  (colored in red), while only a few did (colored in green).

Table 1: Uncorrelated Thermal Model Data compared to Thermal Test Data

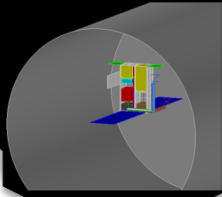
Data	Test	Avionics	Battery	Payload 1U	Payload 2U	Propulsion	Radiator End	Radiator Base	Solar Array	Bus Top	Bus Center
Thermal Test	Cold	-13.8	-12.7	-12.4	-13.1	-14.3	-16.2	-17.1	-23.5	-23.8	-14.4
	Hot	46.2	47.6	46.7	46.3	45.5	40.4	40.5	28.8	28.5	46.4
Uncorrelated Model	Cold	-8.6	-7.9	-7.8	-7.7	-8.6	-8.5	-8.5	-21.8	-21.8	-8.2
	Hot	52.2	52.4	51.3	52.6	51.4	48.8	49.0	29.6	29.6	51.3
Difference	Cold	+5.2	+4.8	+4.6	+5.4	+5.7	+7.7	+8.6	+1.7	+2.0	+6.2
	Hot	+6.0	+4.8	+4.6	+6.3	+5.9	+8.4	+8.5	+0.8	+1.1	+4.9

The Thermal Desktop® model included a TVac chamber to capture two test conditions, hot and cold. Testing included 13 thermocouple locations (3 on the TVac chamber and test fixture, and 10 placed on various locations of the CubeSat that were used for model correlation purposes). Thermal tests included a 3-hour hot and cold soak, where the average soak temperatures for both test conditions were used for model correlation. Eight input parameters were selected to be varied during this model correlation work, including: conductance values between components and the structure, PCB board thermal conductivity, and component optical properties. Model parameters that were adjusted during this model correlation effort include:

- **Conductance Values.** Conductance values connecting different components and subsystems within a CubeSat are usually estimated based on handbook values. As a result, five symbols were created that control the conductance value between five different CubeSat components and the CubeSat structure, and can all be varied as input factors during model correlation. It is anticipated that the conductance value affiliated with both the Attitude Control System (ACS) and the Payload\_2U component will be larger than the other three conductance values, as approximately twice as many bolts were used to connect these two components to the CubeSat structure.
- **Thermophysical Properties.** Thermophysical properties assigned in a thermal model are typically estimated depending on handbook values, vendor material certificates, and/or well-accepted modeling standards (e.g. property files). However, the material conductivity of PCB boards is not as certain and can vary more widely depending on the amount of copper included. As a result, a symbol that controls the conductivity value of the PCB board components in the CubeSat was included and is one input parameter that can be varied during model correlation. A large value for PCB conductivity is anticipated, as PCB boards with high levels of copper were purposefully used in assembling the 6U CubeSat.
- **Optical Properties.** Optical properties assigned in a thermal model are typically estimated depending on a vendor’s material or surface treatment certificate. However, these certified values are typically assigned a range that includes beginning of life (BOL) and end of life (EOL) expected values. As a result, two sensitivity factor symbols were created that get added (or subtracted if the sensitivity factor value is negative) to the optical properties nominal values during the TVac test, which allows for slight variations in the estimated absorptivity and emissivity of each component to be considered.

It is important to note that although only two test conditions, eight model parameters, and ten temperature measurement locations were included in this example; the Veritrek approach for model correlation can support dozens of test conditions, model parameters, and temperature measurement locations in an efficient and effective manner.

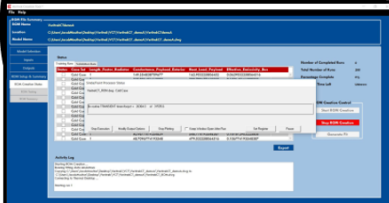
## Replicate TVac Test in Thermal Desktop®



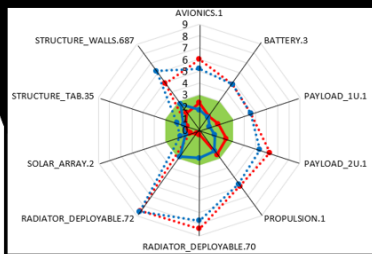
## VERITREK

Setup inputs and  
outputs

## VERITREK ROM Creation



## VERITREK Model Correlation



Using Veritrek's Correlation Analysis feature, you will be able to easily determine several combinations of values for the eight model parameters that will calibrate the thermal model to the experimental test data within the required margin. The following steps show you how to perform this model correlation.

**Step 1: Replicate the thermal test environment in your Thermal Desktop® model.**

**Step 2: Use your Thermal Desktop® model's symbols to setup input factors for your reduced-order model (ROM).** Include the model parameters that can be varied for model correlation, as input factors.

Name	Nominal	Min	Max
Cond_ACS_to_Struc	2.1	0.05	10.0
Cond_Avionics_to_Struc	1.1	0.05	10.0
Cond_Payload1U_to_Struc	1.1	0.05	10.0
Cond_Payload2U_to_Struc	2.1	0.05	10.0
Cond_RadiatorHinge	2.5	0.05	10.0
PCB_k	25	0.50	60.0
SensFac_Abs	0	-0.07	0.12
SensFac_Emiss	0	-0.01	0.12

**Step 3: Define the output responses that you want to track.** Track the nodes in the thermal model that align with the thermocouple locations used during the thermal test.

Name	Type	Temperature		
		Min	Mean	Max
AVIONICS.1	Node		✓	
BATTERY.3	Node		✓	
PAYLOAD_1U.1	Node		✓	
PAYLOAD_2U.1	Node		✓	
PROPULSION.1	Node		✓	
RADIATOR_DEPLOYABLE.70	Node		✓	
RADIATOR_DEPLOYABLE.72	Node		✓	
SOLAR_ARRAY.2	Node		✓	
STRUCTURE_TAB.35	Node		✓	
STRUCTURE_WALLS.687	Node		✓	

**Step 4: Create and test your reduced-order model in the Veritrek Creation Tool.** This is performed automatically by Veritrek.

**Step 5: Use the Veritrek Exploration Tool's Correlation Analysis feature to find the best combination of input factor settings to use in order to match the thermal model's results to the test data.**

Input Values				
Include	Factor Name	Low Value	High Value	Nominal Value
<input type="checkbox"/>	Case Sets	Cold TVac	Hot TVac	Cold TVac
<input checked="" type="checkbox"/>	Cond ACS to Struc [W/C]	0.05	10.0	0.05
<input checked="" type="checkbox"/>	Cond Avionics to Struc [W/C]	0.05	10.0	0.05
<input checked="" type="checkbox"/>	Cond Payload1U to Struc [W/C]	0.05	10.0	0.05
<input checked="" type="checkbox"/>	Cond Payload2U to Struc [W/C]	0.05	10.0	0.05
<input checked="" type="checkbox"/>	Cond RadiatorHinge [W/C]	0.05	10.0	0.05
<input checked="" type="checkbox"/>	PCB k [W/m/C]	0.5	60.0	0.5
<input checked="" type="checkbox"/>	SensFac Abs	-0.07	0.12	-0.07
<input checked="" type="checkbox"/>	SensFac Emiss	-0.01	0.12	-0.01

Experimental Outputs			
Include	Output Name	Measured	Margin +/-
<input checked="" type="checkbox"/>	AVIONICS.1 Temp [C]	-13.8	3.0
<input checked="" type="checkbox"/>	BATTERY.3 Temp [C]	-12.7	3.0
<input checked="" type="checkbox"/>	PAYLOAD_1U.1 Temp [C]	-12.4	3.0
<input checked="" type="checkbox"/>	PAYLOAD_2U.1 Temp [C]	-13.1	3.0
<input checked="" type="checkbox"/>	PROPULSION.1 Temp [C]	-14.3	3.0
<input checked="" type="checkbox"/>	RADIATOR_DEPLOYABLE.70 Temp [C]	-16.2	3.0
<input checked="" type="checkbox"/>	RADIATOR_DEPLOYABLE.72 Temp [C]	-17.1	3.0
<input checked="" type="checkbox"/>	SOLAR_ARRAY.2 Temp [C]	-23.5	3.0
<input checked="" type="checkbox"/>	STRUCTURE_TAB.35 Temp [C]	-23.8	3.0
<input checked="" type="checkbox"/>	STRUCTURE_WALLS.687 Temp [C]	-14.4	3.0

**Step 5a: Setup Veritrek runs to replicate each test condition and test criteria.**

In this example, two runs were setup to replicate the Cold and Hot thermal tests. The “Input Values” section allows you to define the test conditions and set the design space that Veritrek will use to explore different combinations of model parameters. In this example, the test conditions were explicitly controlled via two different case sets with symbol overrides in the underlying Thermal Desktop® model. Be sure and select a discrete setting for the Case Sets input factor.

In the “Experimental Outputs” section, set the “Measured” value to the value measured during the thermal test. The values used in this example come from the Thermal Test Data of Table 1. Setting a margin value will automatically filter the results to show only those results that fit within the specified margin criteria.  $\pm 3^{\circ}\text{C}$  was used in this example.

Case Sets	Cond ACS to Struc [W/C]	Cond Avionics to Struc [W/C]	Cond Payload1U to Struc [W/C]	Cond Payload2U to Struc [W/C]	Cond RadiatorHinge [W/C]	PCB k [W/m/C]	SensFac Abs	SensFac Emiss	Group Factor of Performance
Cold TVac	9.15	9.13	6.42	8.48	0.73	47.53	-0.034	0.116	45.5
Hot TVac	9.15	9.13	6.42	8.48	0.73	47.53	-0.034	0.116	45.5
Cold TVac	5.83	9.53	4.81	5.58	0.42	36.86	-0.051	0.113	50.4
Hot TVac	5.83	9.53	4.81	5.58	0.42	36.86	-0.051	0.113	50.4
Cold TVac	9.97	4.07	2.66	9.80	0.47	39.04	0.089	0.117	54.8
Hot TVac	9.97	4.07	2.66	9.80	0.47	39.04	0.089	0.117	54.8
Cold TVac	8.45	9.80	5.25	4.28	0.73	43.22	-0.034	0.093	59.1
Hot TVac	8.45	9.80	5.25	4.28	0.73	43.22	-0.034	0.093	59.1
Cold TVac	4.36	8.96	5.82	4.85	0.33	36.54	0.113	0.117	59.3
Hot TVac	4.36	8.96	5.82	4.85	0.33	36.54	0.113	0.117	59.3
Cold TVac	6.61	8.57	6.74	5.88	0.86	55.37	0.002	0.105	61.5
Hot TVac	6.61	8.57	6.74	5.88	0.86	55.37	0.002	0.105	61.5
Cold TVac	8.26	9.09	7.19	6.01	0.56	26.25	0.066	0.088	63.4
Hot TVac	8.26	9.09	7.19	6.01	0.56	26.25	0.066	0.088	63.4

Two very different combinations of input parameters that both meet the margin criteria

**Step 5b: Add 20,000 points to all runs.**

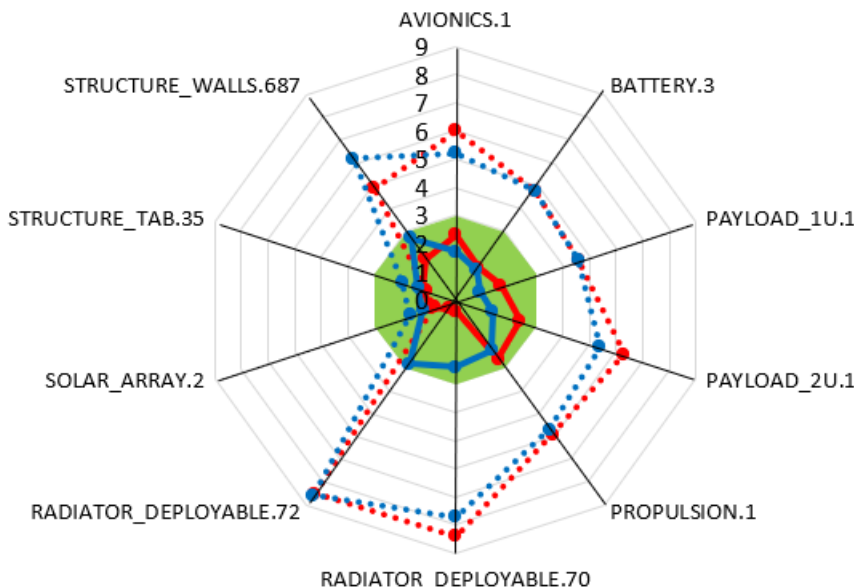
Veritrek automatically generates 20,000 different combinations of model parameters, filters those based on the user-defined margin, and sorts the acceptable values in a list in the Output Response pane. The best results are organized at the top of the list. It is likely that there are several good solutions, and it is possible to have very different combinations of model parameters.

Note that although 20,000 points was used in this example, you may add more or less depending on your specific application.

Case Sets	Cond ACS to Struc [W/C]	Cond Avionics to Struc [W/C]	Cond Payload1U to Struc [W/C]	Cond Payload2U to Struc [W/C]	Cond RadiatorHinge [W/C]	PCB k [W/m/C]	SensFac Abs	SensFac Emiss	Group Factor of Performance
Cold TVac	9.15	9.13	6.42	8.48	0.73	47.53	-0.034	0.116	45.5
Hot TVac	9.15	9.13	6.42	8.48	0.73	47.53	-0.034	0.116	45.5
Cold TVac	5.83	9.53	4.81	5.58	0.42	36.86	-0.051	0.113	50.4
Hot TVac	5.83	9.53	4.81	5.58	0.42	36.86	-0.051	0.113	50.4
Cold TVac	9.97	4.07	2.66	9.80	0.47	39.04	0.089	0.117	54.8
Hot TVac	9.97	4.07	2.66	9.80	0.47	39.04	0.089	0.117	54.8
Cold TVac	8.45	9.80	5.25	4.28	0.73	43.22	-0.034	0.093	59.1
Hot TVac	8.45	9.80	5.25	4.28	0.73	43.22	-0.034	0.093	59.1
Cold TVac	4.36	8.96	5.82	4.85	0.33	36.54	0.113	0.117	59.3
Hot TVac	4.36	8.96	5.82	4.85	0.33	36.54	0.113	0.117	59.3
Cold TVac	6.61	8.57	6.74	5.88	0.86	55.37	0.002	0.105	61.5
Hot TVac	6.61	8.57	6.74	5.88	0.86	55.37	0.002	0.105	61.5
Cold TVac	8.26	9.09	7.19	6.01	0.56	26.25	0.066	0.088	63.4
Hot TVac	8.26	9.09	7.19	6.01	0.56	26.25	0.066	0.088	63.4

### Temperature Differential [°C] from Thermal Test Data

- Goal
- Uncorrelated TD Model - Hot Case
- Correlated TD Model using Veritrek - Hot Case
- Uncorrelated TD Model - Cold Case
- Correlated TD Model using Veritrek - Cold Case



By performing a model correlation with Veritrek, you were able to identify a set of acceptable symbol settings that allowed your Thermal Desktop® model to match the thermal test data within the margin criteria ( $\pm 3^\circ\text{C}$ ) for all ten measured thermocouple locations and for both hot and cold test conditions. By leveraging the power of a reduced-order model, you were able to quickly try 20,000 different combinations of input factor settings while Veritrek performed the filtering and sorting for you based on your search criteria. A typical manual “guess and check method” may only allow for the testing of a handful of combinations before deciding on the best one. As a result, Veritrek provides more confidence in the chosen solution and does it in a simple, automated, and repeatable method that anyone can follow.

Get Started

### Step 5c: Choose a single Veritrek result for correlating your model.

In this example, you may choose the solution where the conductance values affiliated with the ACS and Payload\_2U components are larger than the other three conductance values, since you knew from the beginning that several more fasteners were used to attach these components to the 6U CubeSat structure. In addition, this solution also includes the anticipated high PCB k value.

### Step 5d: Run your Veritrek result through Thermal Desktop® to confirm your correlated model results.

Take the model parameter values chosen during Step 5c, and plug them in to your Thermal Desktop® model’s symbol deck. Run each test’s case set, and document the results.

Note that the accuracy of your ROM is tested and verified in the Creation Tool during Step 4, prior to using the ROM for model correlation purposes. You should expect to see slight differences between the Veritrek results and the Correlated Thermal Desktop® model results.



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