HEAT REJECTION ANALYSIS PROCESS FOR EARLY THERMAL ASSESSMENT

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ABSTRACT

Sierra Nevada Corporation (SNC) has developed a heat rejection analysis process for use at the beginning of space programs or during proposal efforts in order to quantify the heat rejection capability of each spacecraft panel. This analysis technique provides early identification of likely thermal problems, inputs on desired spacecraft bus component locations, and approximate heater power needs without needing to build a detailed thermal model. This analysis approach is useful because it prevents time and resources from being used on building a detailed model too early in a program, when the design will inevitably change. It also allows for early thermal inputs on the design that may be missed if a detailed model is built only after vehicle-level designs are in place.

This paper provides an overview of the simplified model, examples of using the results to inform early thermal design inputs, and discusses limitations of the method.

NOMENCLATURE, ACRONYMS, ABBREVIATIONS (STYLE = “HEADING 1”)

CBE	current best estimate
GEO	geosynchronous earth orbit
LEO	low earth orbit
LV	launch vehicle
MLI	multi-layer insulation
PL	payload
SMAD	Space Mission Analysis and Design
SNC	Sierra Nevada Corporation

INTRODUCTION

Sierra Nevada Corporation (SNC) has developed a heat rejection analysis process for use at the beginning of space programs or during proposal efforts in order to quantify the heat rejection capability of each spacecraft panel. This analysis technique provides early identification of likely thermal problems, inputs on desired spacecraft bus component locations, and approximate heater power needs without needing to build a detailed thermal model. This analysis approach is useful because it prevents time and resources from being used on building a detailed model too early in a program, when the design will inevitably change. It also allows for early thermal inputs on the design that may be missed if a detailed model is built only after vehicle-level designs are in place.

The heat rejection analysis provides insight into the following areas:

- How much power can the bus reject if all unblocked structure is used as radiator area?
- Comparison of the total spacecraft and individual panel capability vs heat load
- It does NOT predict any component temperatures.

This paper provides an overview of the simplified model, examples of using the results to inform early thermal design inputs, and discusses limitations of the method.

MODEL SETUP

This analysis makes use of a low-fidelity model with only the external surfaces and external components to account for radiator blockage and view factors. The internal components are represented with boundary nodes, and are not modeled discretely. For this paper, a generic satellite bus was modeled as shown in Figure 1. This example model is 272 nodes, and was developed in Thermal Desktop 6.1 Patch 20.

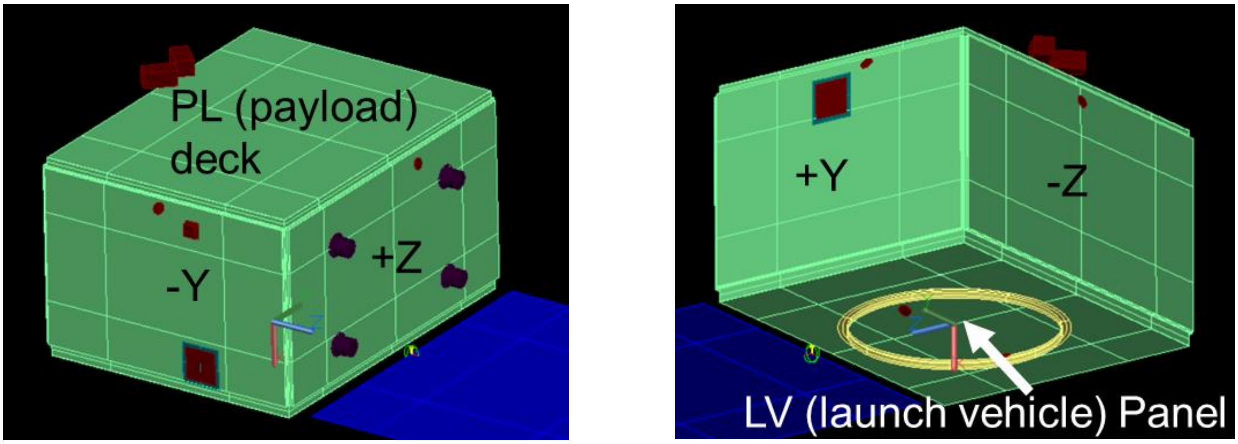


Figure 1. Generic satellite bus model with panel definitions.

Boundary nodes are then used to hold the bus at a bulk-average temperature to capture the heat rejection capability at that temperature. There are a number of ways to accomplish this. In this example, the model is built using solids with two nodes through the thickness, with the internal-facing nodes held as boundary nodes. The heat rejection capability is the power required to hold the temperature, or the heat load into the boundary nodes. Note that if the boundary nodes are exposed to the external environment, the heat load will include the environmental heating rates in addition to the power required to hold the temperature, and the heating rates will need to be subtracted out.

There are several variations on this method that could be used:

- Use a 2-sided surface with the internal nodes held as boundary nodes
- Use "insulation" nodes on top of boundary nodes to act as the surface exposed to the external environment
- Use a single-sided surface with nodes held as boundary nodes
    - As noted above, if this method is used, heat load into the boundary nodes will include environmental heating rates, and these must be subtracted out
- Look at the actual heat rejection to space instead of the heat load into the boundary nodes
    - If you use this method, environmental loads must be subtracted out of the total heat rejection to space, similar to external boundary nodes

For the hot case, the boundary nodes should be held at 30 °C. Even though most components can get much hotter, the bulk average temperature does not account for spacecraft gradients or orbital swings. Additionally, dissipating components are generally hotter than the radiator, cooler sections of the radiator have less heat rejection capability, and certain components such as batteries have narrower limits than other components. Therefore, the relatively low bulk-average temperature of 30 °C is often a better indicator of actual rejection capability even when most components have a high limit of 61 °C. Furthermore, this analysis approach has been completed at SNC using 30 °C, 40 °C, and 50 °C boundary node temperatures, and it has been observed that the 40 °C and 50 °C temperatures tend to over predict the heat rejection capability.

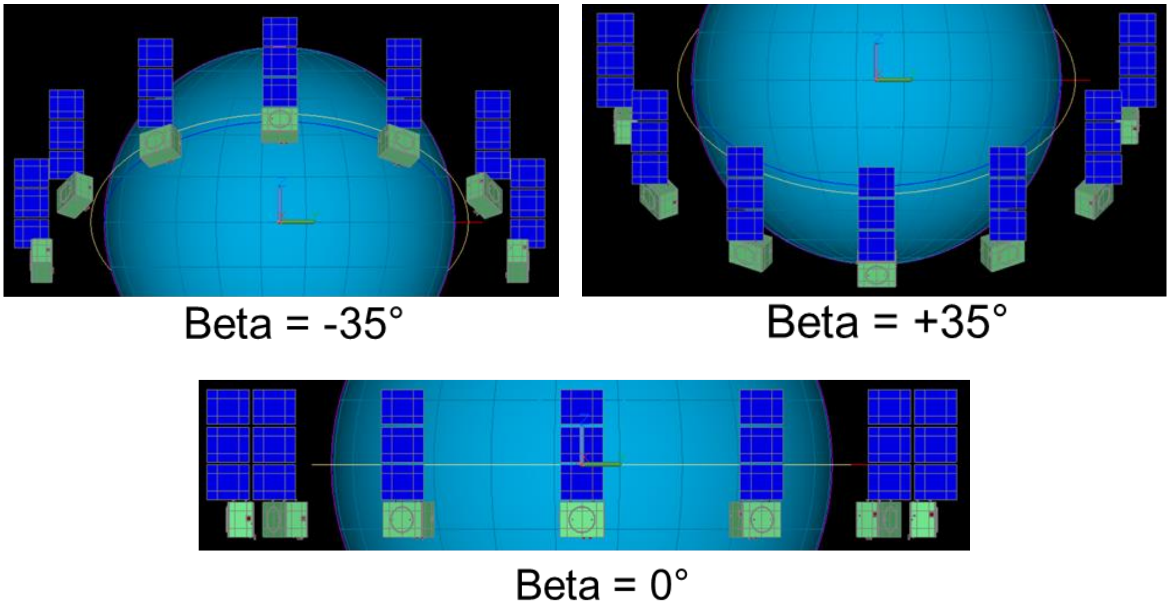
If a heater power approximation is also desired, additional setup is required. First, add multi-layer insulation (MLI) to the heat rejection model such that heat rejection capability is equal to 125% of the total contingency heat load. The additional 25% factor is to allow margin for any changes that occur between the preliminary bus configuration and the final one. For example, components may move or be entirely replaced, or the total power dissipation may turn out to be higher than originally estimated.

Once the MLI configuration has been estimated, the cold case should hold panels at a bulk-average temperature of 0 °C. Note that the analyst may decide to change the temperature based on the overall bus temperature requirements. The heater power is the power required to hold that temperature with the current best estimate (CBE) heat load removed.

USING THE RESULTS

This section demonstrates how to use the results of the analysis. For this example analysis, only three beta angles were considered, but for a real program or proposal, a full beta sweep should be investigated. Figure 2 shows the orbit, as viewed from the sun, at the three beta angles for reference.

The attitude analyzed was a nadir-pointing payload with +Y pointing toward the velocity vector.



Beta = -35°

Beta = +35°

Beta = 0°

Figure 2. Beta angles analyzed as viewed from the sun.

Biased environments and optical properties for the hot and cold cases are stacked using the same methods as a traditional bounding thermal analysis using a detailed model.

Heat Rejection Capability

Table 1 shows the results of the heat rejection analysis for the example beta angles, alongside three example cases of panel by panel bus dissipation, which are discussed below. Note that the +Z panel has a negative minimum heat rejection capability. This indicates that environmental inputs are higher than the radiation to deep space during at least one part of the orbit.

Table 1. Heat Rejection Analysis Results with Three Example Bus Dissipation Cases

			nZ	nY	pZ	pY	LV Panel	Total	
Panel capability	Min Heat Rejection over an orbit [W]	n35	91	48	125	48	118	430	
		0	184	25	81	26	92	408	
		p35	194	48	-16	49	124	399	
		Min	91	25	-16	26	92	218	
	Orbit Avg Heat Rejection [W]	n35	139	132	153	132	258	814	
		0	199	127	135	127	253	842	
		p35	204	132	86	132	263	817	
		Min	139	127	86	127	253	732	Total*1.25
Internal bus dissipation	Case 1 Contingency Heat Load [W]		40	32	24	32	80	208	260
	Case 2 Contingency Heat Load [W]		200	100	150	90	300	840	1050
	Case 3 Contingency Heat Load [W]		110	170	10	140	120	550	688

In Case 1, each panel has sufficient orbital average heat rejection capability for the components mounted to it. The panels may still require heat pipes or spreaders, but overall the thermal design is not likely to be overly complicated. Additionally, depending on component sensitivity, orbital variations may require additional thermal management of components mounted to the +Z panel due to the instantaneous negative heat rejection.

In Case 2, the +/-Z and LV (launch vehicle) Panels all have more heat load than they can reject. In addition, the total heat load of 840 W is higher than the heat rejection capability of 732 W. For this design, the bus structure does not provide enough radiator area, and more may need to be added. Alternatively, one might look at creative solutions to increase heat rejection capability or lower the heat load.

In Case 3, the +/-Y panels have more heat load than they can reject, but overall the bus capability is sufficient. Thus, these problem areas can likely be mitigated either by moving components around within the bus or by using heat straps or heat pipes to move the heat load from the +/-Y panels to adjacent panels that have extra capability.

Heater Power Approximation

Table 2 shows the results of the heater power approximation for Case 1 from Table 1. MLI was added such that the minimum heat rejection at 30 °C still exceeds the contingency heat load for each panel.

Table 2. Heater Power Approximation for Case 1

		nZ	nY	pZ	pY	LV Panel	Total
30°C Heat Rejection [W]	n35	57	47	65	46	110	324
	0	79	45	53	45	111	333
	p35	82	47	34	46	113	321
	Min	57	45	34	45	110	291
0°C Power Req'mnt [W]	n35	37	30	40	30	75	213
	0	52	30	32	29	77	219
	p35	54	30	16	30	77	208
	Max	54	30	40	30	77	232
CBE Heat Load [W]		32	26	19	26	64	166
Contingency Heat Load [W]		40	32	24	32	80	208
Heater Power Requirement [W]		22	5	21	4	13	66

The top section of the table shows the hot case results showing that the MLI configuration allows for sufficient heat rejection in the hot case at each individual beta angle assessed. The section labelled 0 °C Power Requirement shows how much power is required on each panel in order to hold the bus at a 0 °C bulk-average temperature. The heater power required is the max power requirement minus the CBE heat load, as shown on the bottom row. Thus the overall estimated heater power in this case is 66 W orbit-average.

Note that the max heater power will be at least 25% greater than the orbit-average once individual heaters are sized.

COMPARISON TO DETAILED MODEL AND ONE-NODE MODEL

Table 3 shows a comparison of the results of a low-fidelity heat rejection model with a high-fidelity traditional model as well as a 1-node model calculation based on Spherical Satellite Analysis from Space Mission Analysis and Design (SMAD) 3rd Edition[1]. For radiator requirements, all three methods agree very well with each other. They do not agree as well for heater power, but heat rejection model is conservative and provides a rough early approximation.

Table 3. Comparison to Detailed Model and One-Node Model

	Heat Rejection Model	Traditional Model	SMAD 1-Node Calculation
Heat Rejection Capability [W]	313	--	--
Orbit-Average Heat Load [W]	92	99	92
Radiator Area Required [in^2]	679	716	651
Radiator Area Required per Watt [in^2/W]	7.4	7.3	7.1
Heater Power Requirement [W]	48	35	38

This data is from an SNC program where the heat rejection model was used for estimates in the proposal phase.

LIMITATIONS OF THE METHOD

It's important to note that this method does have limitations, and design decisions made based on these results should be considered preliminary. Holding the spacecraft at a bulk-average temperature inherently assumes perfect heat-spreading. It's an indicator of what's possible, and may inform the analyst on whether heat straps or heat pipes are needed to move heat to adjacent panels, but will not tell you if a heat pipe or spreader is needed within an individual panel. Additionally, it does not account for spacecraft gradients or orbital temperature swings.

This method has been used successfully for Low Earth Orbit (LEO) and Geosynchronous Earth Orbit (GEO) environments for buses sized approximately a few feet in each dimension. Different bus sizes may require a different bulk temperature than 30°C.

CONCLUSIONS

SNC has developed a standard method to quickly assess a proposed bus configuration. This method has been used successfully during proposals and early phases of a program to provide identification of likely thermal problems, provide inputs on desired spacecraft bus component locations, and approximate heater power needs without needing to build a detailed thermal model.

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CONTACT

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