Thermal Analysis

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Introduction:

This document is a thermal analysis of the OMEN cube satellite. The OMEN engineering unit is a 3U sized cube satellite created specifically for Saint Louis University's DORRE mission. The cube satellite includes structural components, solar panels, and electrical hardware.

General Test Procedure Background:

The purpose of this test is to analyze the cube satellite's thermal behavior under various orbit conditions. An emphasis will be placed on the various temperatures that electronic flight hardware experiences, as all electronic components have temperature ranges in which they must remain to be functional. The test will be conducted using the thermal analysis software Thermal Desktop.

Assembly

To conduct the thermal analysis, a thermal model of the spacecraft was created in Thermal Desktop. The model consists of 55 thin 2D shells, 9 3D solids, and 460 nodes. Below are images comparing the realistic CAD of the cube satellite (left) with the thermal model (right). The first image set has no components hidden, so the primary structure and solar panels are the only components visible. In the thermal model, the primary structure is in blue, and the solar panels are in red.

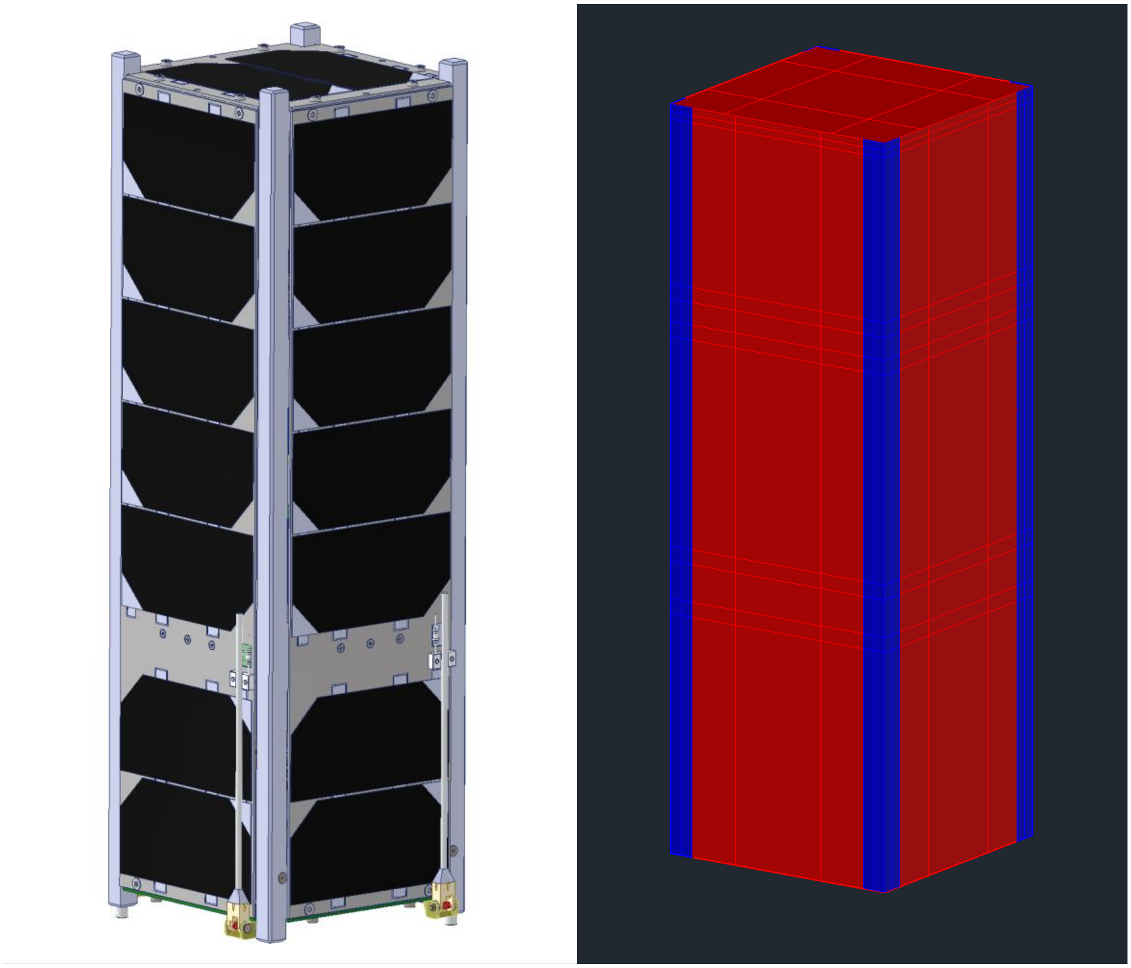

Figure 1. CAD and Thermal Model

The second image set has an outer face hidden to reveal the interior components of the spacecraft. In the thermal model, electronic hardware is in green, aluminum mounting plates are in pink, steel and aluminum mounting rods are in orange, and structural ribs are in yellow.

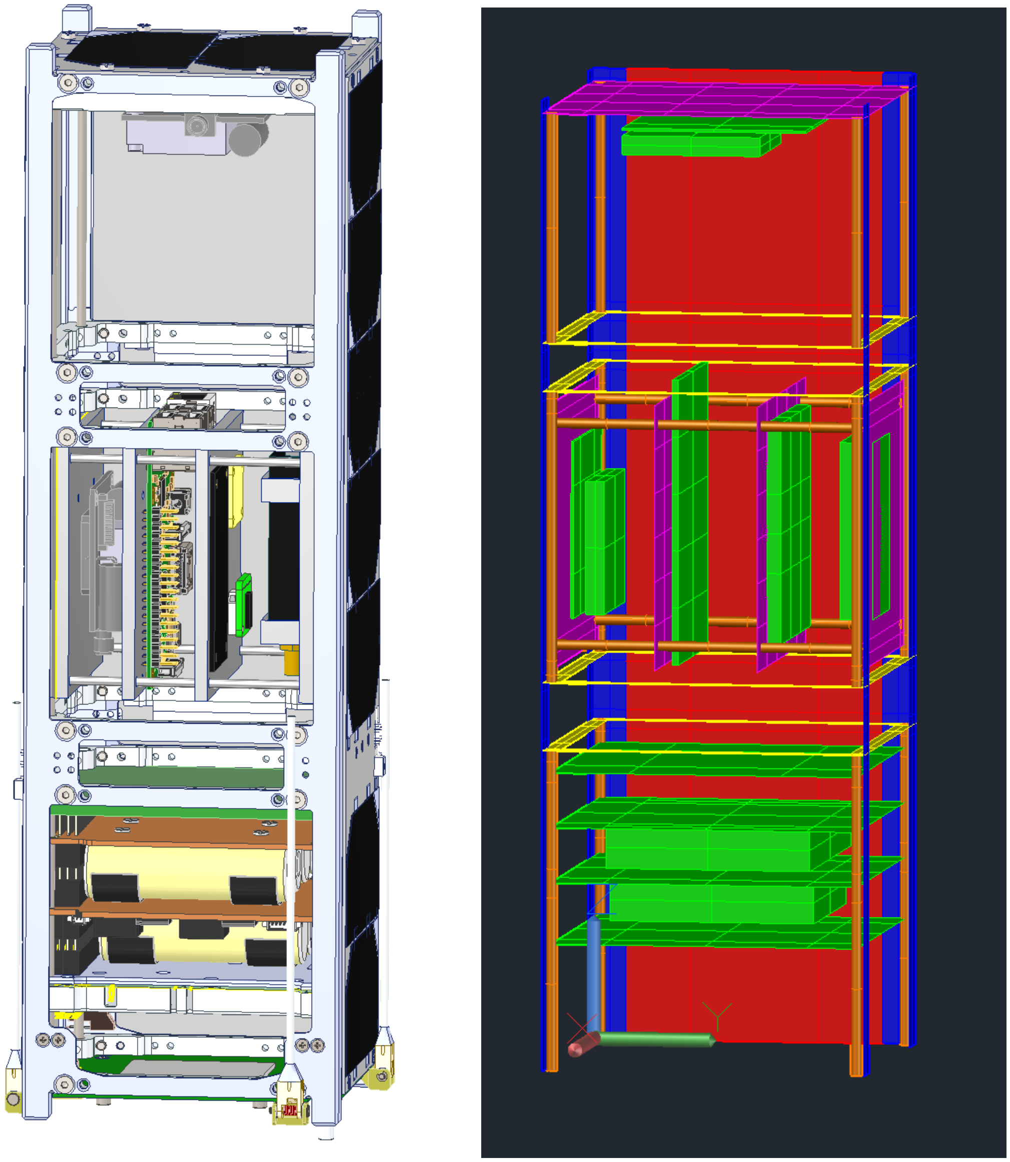

Figure 2. CAD and Thermal Model with Panels Hidden

It should be noted that many components were either excluded or simplified in the thermal model. This is because a more realistic thermal model with more nodes would have been inconvenient to create; this downside would not have been offset by a slightly more representative solution. The simplified thermal model included only the components that affect how heat is transferred throughout the spacecraft and the components that can only function within a small temperature range. Lastly, the thermal model with all nodes visible and panels hidden is shown in the figure below.

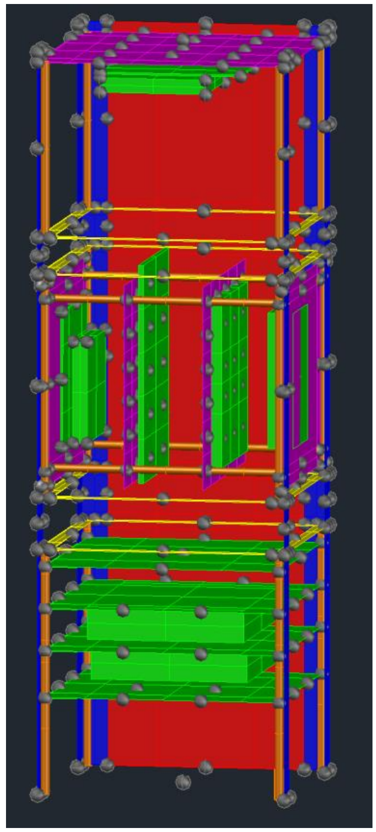

Figure 3. Thermal Model with Panels Hidden and Nodes Visible

Analysis conditions

There are two loading conditions that will be applied to the spacecraft during this analysis: hot orbit loading conditions and cold orbit loading conditions. The hot orbit loading conditions simulate when the heat flux into the spacecraft is at a maximum, whereas the cold orbit loading conditions simulate when the heat flux into the spacecraft is at a minimum. The conditions during the hot and cold orbit are detailed in the table below.

	Hot Orbit	Cold Orbit
Altitude (km)	408	408
Orbit Period (min)	90	90
Beta Angle (deg)	90	0
Solar Heat Flux (W/m^2)	1421	1289
Albedo Constant	0.4	0.2
IR Heat Flux from Earth (W/m^2)	261	218
Component Waste Heat Output (W)	3.46	1.82
Initial Temperature (K)	293	293

Figure 4. Orbit Loading Conditions

By simulating the most extreme heat flux conditions and designing the spacecraft to withstand such conditions, the spacecraft will withstand whatever thermal conditions it encounters while in orbit.

Hot Orbit Results and Analysis

Both simulations ran for 500 minutes (roughly 5.5 orbits) so as to let most components reach a constant fluctuation in temperature. The behavior of the spacecraft under the hot orbit loading conditions will be analyzed first. Below is a graph of the temperature of every node on the model as a function of time during the hot orbit.

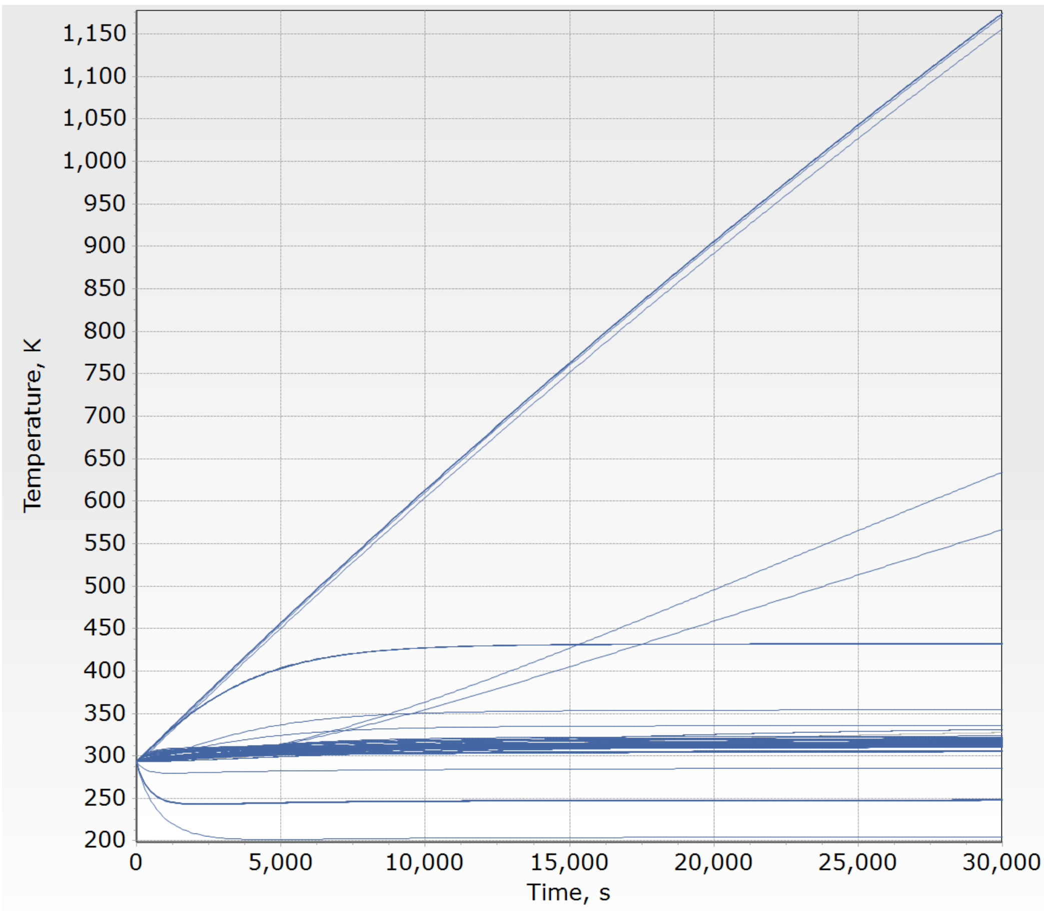

Figure 5. Node Temperature during Hot Orbit

With important exceptions, most nodes stayed near 300 K during the entirety of the analysis. This steady thermal state was reached because the orbit's 90-degree beta angle never takes the satellite into the Earth's shadow. A table summarizing temperature results for critical components is shown below. A component's low and high critical temperature define the temperature boundaries outside of which the component will permanently fail.

Component	Low Critical Temp (K)	High Critical Temp (K)	Lowest Temp (K)	Highest Temp (K)	Needs heating?	Needs cooling?
EPS	233	398	293	340		
EnTRX	233	398	293	312		
Raspberry Pi 3B	233	358	293	315		
IMU	233	398	293	315		
RTC	233	398	293	320		
Watch Dog	253	373	293	310		
Iridium 9603 (Z+)	233	358	293	1200		✓
Iridium 9603 (Second Struct)	233	358	293	430		✓
Side Solar Panels	213	398	240	315		
Z+ Solar Panel	213	398	200	310	✓	

Figure 6. Component Temperature Extremes during Hot Orbit

Most components stay well within their functional temperature range. The components that do not stay within their critical temperature range are the two Iridiums and the Z+ solar panel. The Iridiums heat up far beyond their limit. These components generate a substantial amount of waste heat, and their design is not conducive to heat being conducted through and then out of the component. The parts comprising the Iridiums have free space between them, so the only thermal conductor between many Iridium parts are small screws. Furthermore, the Iridiums are mounted such that they are not entirely flush with their mounting plates. This also lessens heat dissipation. Considering the high temperatures that both Iridium's experienced, both components need additional mediums through which to dissipate heat.

The Z+ solar panel experienced temperatures slightly below its critical limit. This is because the Satellite's Z- face is constantly facing the Earth, meaning the Z+ panel gets no substantial radiation from the sun or the Earth during this Beta-90 orbit. Because the Z+ panel experienced temperatures below its limit, it needs additional mediums through which it can receive heat.

Cold Orbit Results and Analysis

The behavior of the spacecraft under the cold orbit loading conditions is analyzed second. Below is a graph of the temperature of every node on the model as a function of time during the cold orbit.

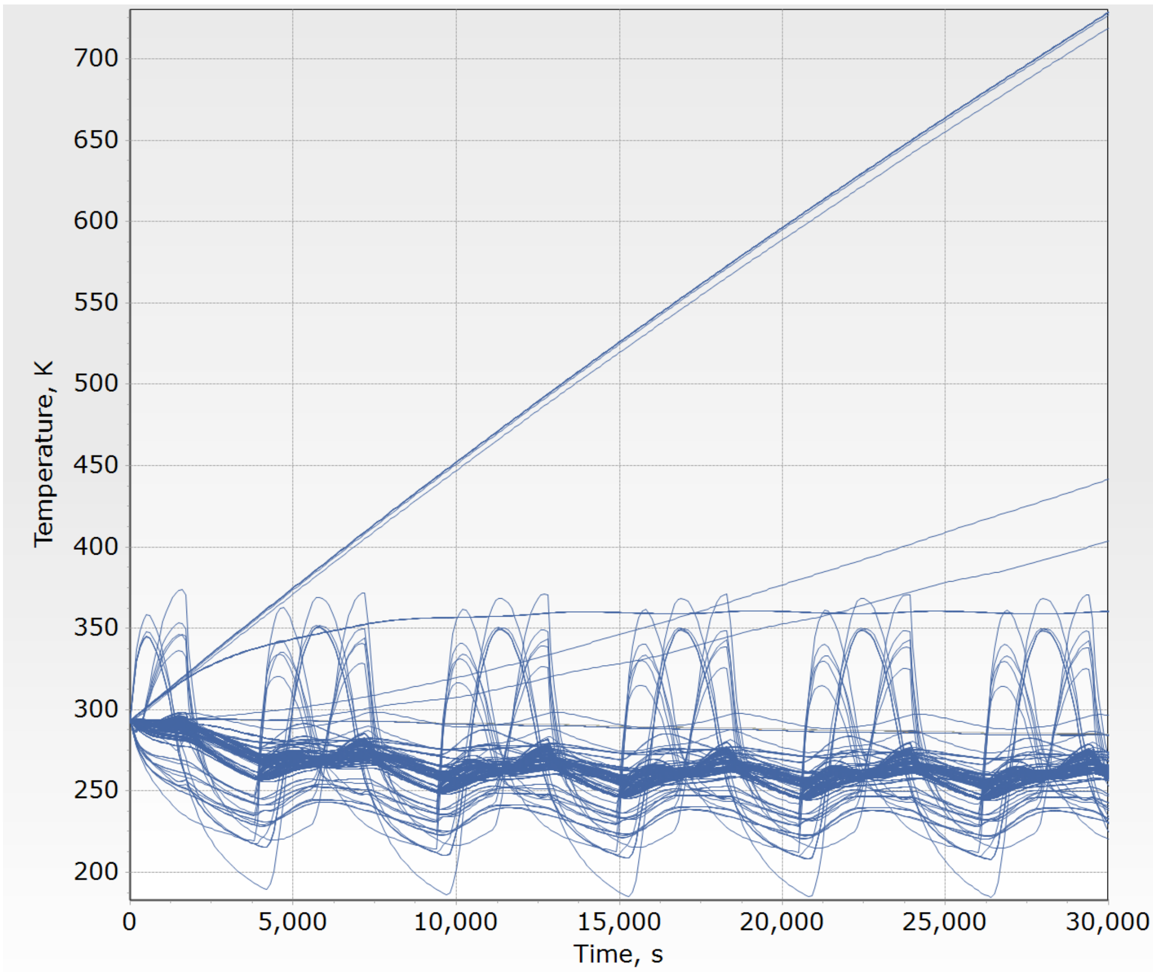

Figure 7. Node Temperature during Cold Orbit

Node temperature during the cold orbit is more varied and cyclical than the hot orbit, as the cold orbit has periods in and out of the Earth's shadow. A table summarizing temperature results for critical components is shown below. A component's low and high critical temperature define the temperature boundaries outside of which the component will permanently fail.

Component	Low Critical Temp (K)	High Critical Temp (K)	Lowest Temp (K)	Highest Temp (K)	Needs heating?	Needs cooling?
EPS	233	398	252	295		
EnTRX	233	398	260	293		
Raspberry Pi 3B	233	358	255	293		
IMU	233	398	255	293		
RTC	233	398	255	293		
Watch Dog	253	373	265	293		
Iridium 9603 (Z+)	233	358	250	730		✓
Iridium 9603 (Second Struct)	233	358	250	360		✓
Side Solar Panels	213	398	210	370	✓	
Z+ Solar Panel	213	398	190	370	✓	

Figure 8. Component Temperature Extremes during Cold Orbit

Again, most components stay within their operational temperature ranges during the cold orbit, but there are exceptions. Even during the cold orbit, the Iridiums experienced the same issue as before, whereby they have too little heat dissipation. The Z+ solar panel also had a recurring issue, whereby it fell below its critical temperature range. Although during a beta-0 orbit the Z+ panel spends time exposed to the sun, that heating was not enough to offset the time spent in the Earth's shadow with no substantial inward heat flux. The side solar panels also dropped slightly below their critical temperature range. During a beta-0 orbit, the side panels receive much less sunlight than they did during the hot orbit, and they still receive minimal radiation from the Earth. Because the side panels experienced temperatures below their limit, they need additional mediums through which they can receive heat.