Contact Conduction Fidelity Within Small Satellite System-Level Thermal Analysis

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Overview

Defining contact conduction coefficients is crucial for a system-level thermal analysis on satellites. Thermal analysis must be quick and accurate for many small satellite missions to ensure components stay within operating temperatures. Contact conduction, influenced by surface finish, roughness, anisotropy, and pressure distribution, is a complex research area. The challenge is to determine an 'acceptable' level of fidelity for conduction coefficients under tight timelines. How much do simplifications affect heat distribution in a thermal model?

This research investigates the impact of different contact conduction fidelities on a satellite's heat distribution and provides guidelines for future missions. Using a simplified finite difference model of the UGA Small Satellite Research Laboratory's Multiview Onboard Computational Imager (MOCI) Satellite, a 6U CubeSat funded by the Air Force Research Laboratory's University Nanosatellite Program, the study employs Thermal Desktop software by CR Technologies. Simulations will use varying conductance values, from constant to specifically calculated for each contact point, through ISS orbit scenarios.

The results will compare varied thermal models to hand calculations of MOCI's heat distribution. Future research will include thermal vacuum testing to validate these models against true values.

Methodology

To analyze the effect of different contact conductance values on the relative accuracy of the MOCI thermal model, three separate cases were studied. Each analysis was conducted on the same thermal model of MOCI, simulated at an altitude of 450km, a beta angle of 45°, and with no heaters applied to varying nodes. Points of interest within this analysis were the varying temperature ranges experienced by key electronic components of MOCI. These points of interest include MOCI's S-Band board, ultra-high frequency (UHF) board, and onboard graphics processing unit. Table 1 displays the varying contact conductance configurations simulated throughout this research.

Case 1	Contact conduction based on the number of fasteners, fastener location, fastener type, and method of securement. Each conductance value was individually calculated per interface.
Case 2	Contact conduction based on broad approximation of thermal interface material conductance.
Case 3	Flat conductance value of 10 W/C to all contacts within the thermal model.

Table 1. Analysis Case Descriptions

Contact conductance values within case 1 were calculated following University Nanosatellite Program guidelines. This method returns high-fidelity conductance values that most closely approximate on-orbit behavior. In case 2 conductance values utilized a broad approximation of widely available thermal interface material (TIM) conductance values available in technical data sheets.

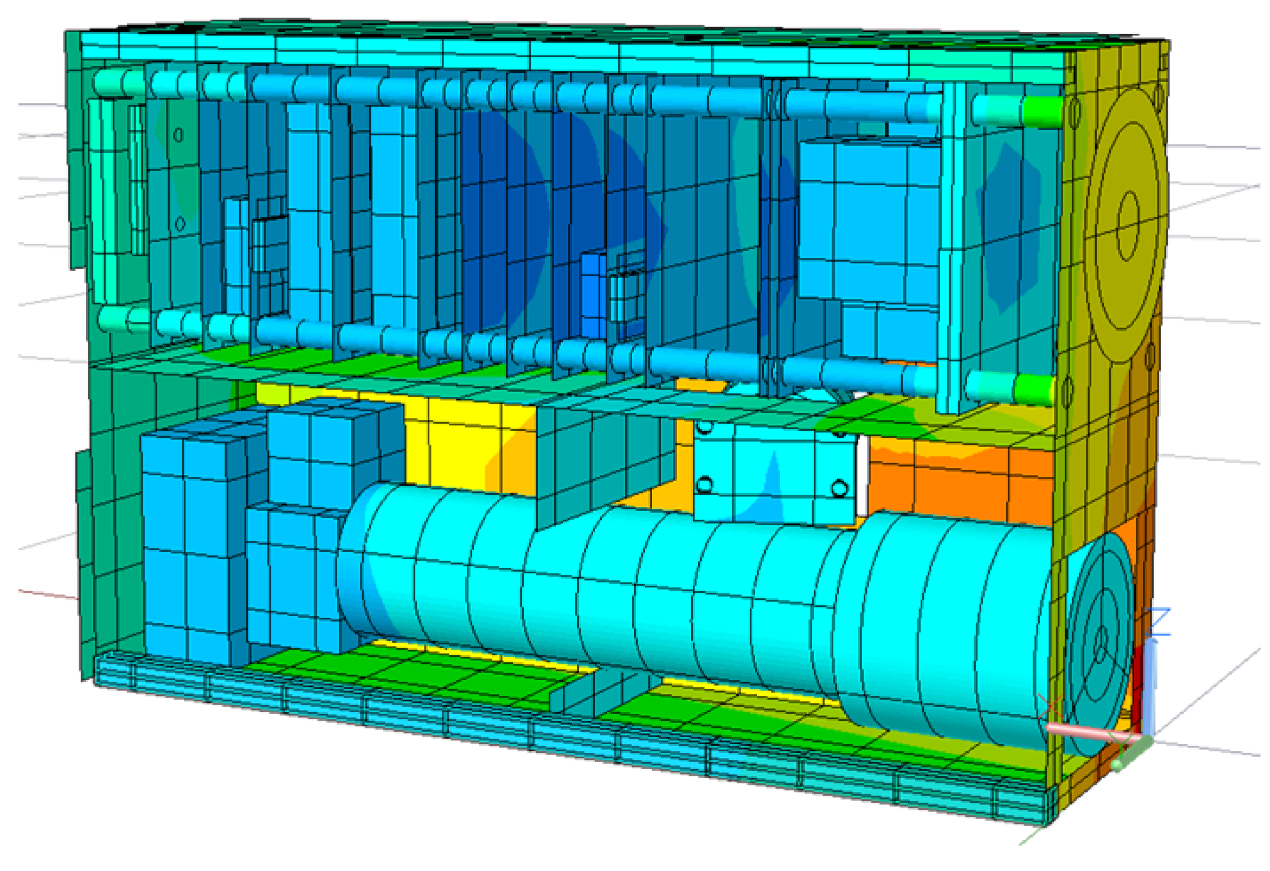

Figure 1. Finite Difference Model of MOCI

Results

Upon completion of each thermal case analysis, overall temperature ranges experienced by the three target boards were taken and averaged for different levels of contact conductance fidelity. Table 2 displays the average temperature range experienced by each target board for the varying thermal cases simulated.

Board of Interest	Temperature Range (°C)					
	Case 1		Case 2		Case 3	
	Min	Max	Min	Max	Min	Max
S-band	-14.07	4.72	-14.06	4.69	-12.64	3.68
UHF	-13.76	5.37	-13.73	5.33	-12.84	5.07
TX2i	-12.04	7.82	-12.12	7.76	-12.31	7.37

Table 2. Resulting Temperature Ranges

Temperature ranges varied between -15 and 8 degrees Celsius, with a maximum total temperature range of 19.88 degrees Celsius being observed in the TX2I board during the second thermal case. Cases 1 and 2 can be seen to be closely correlated at each of the three points of interest as well, while case 3 possesses a higher degree of variation.

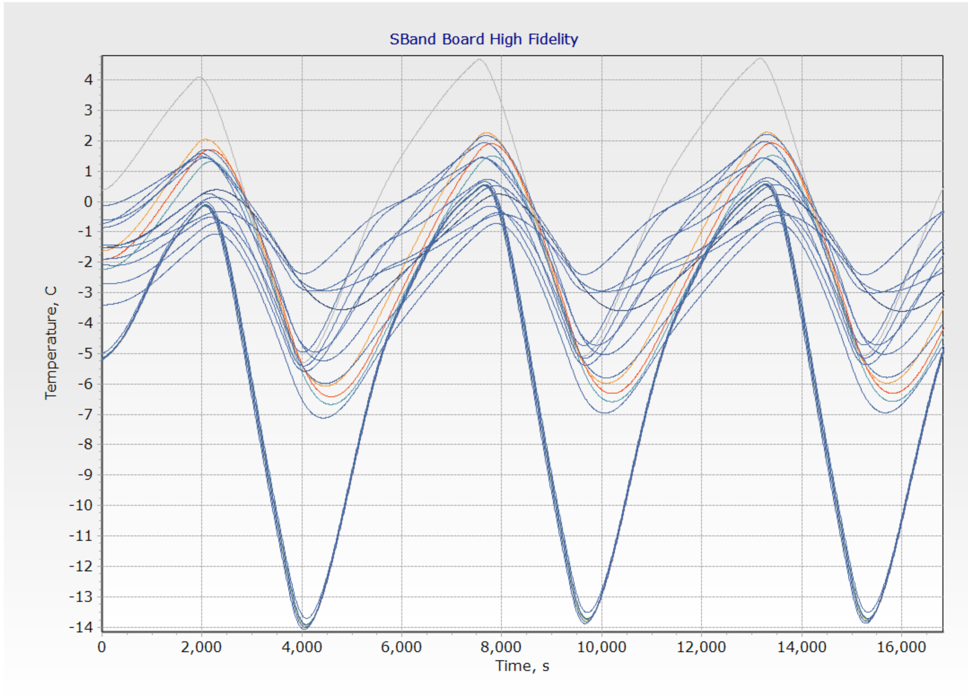

Figure 2. SBand High Fidelity Temperature Results

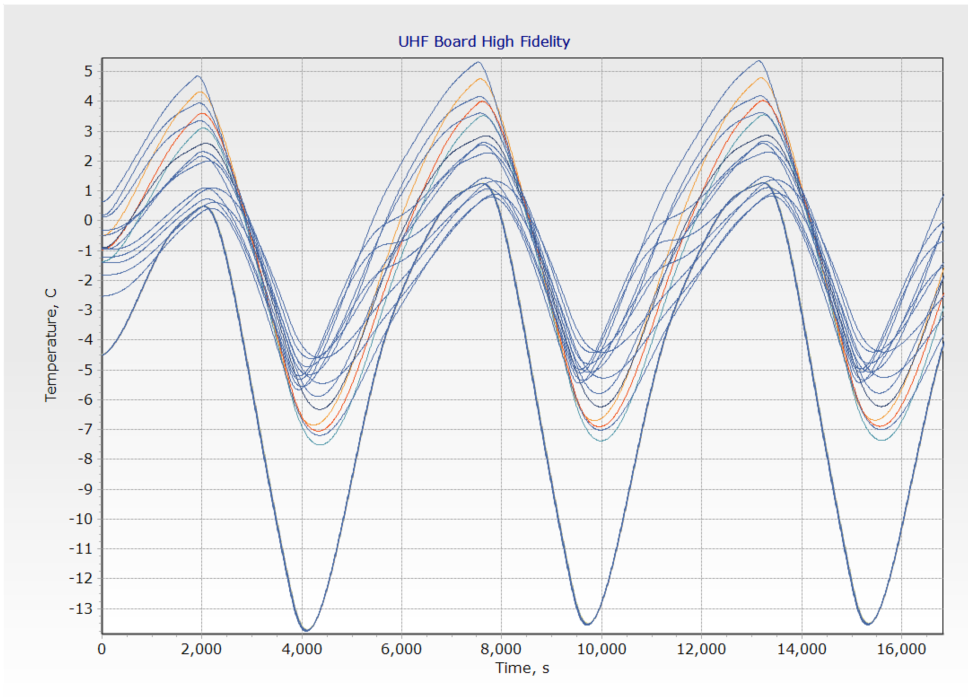

Figure 3. UHF High Fidelity Temperature Results

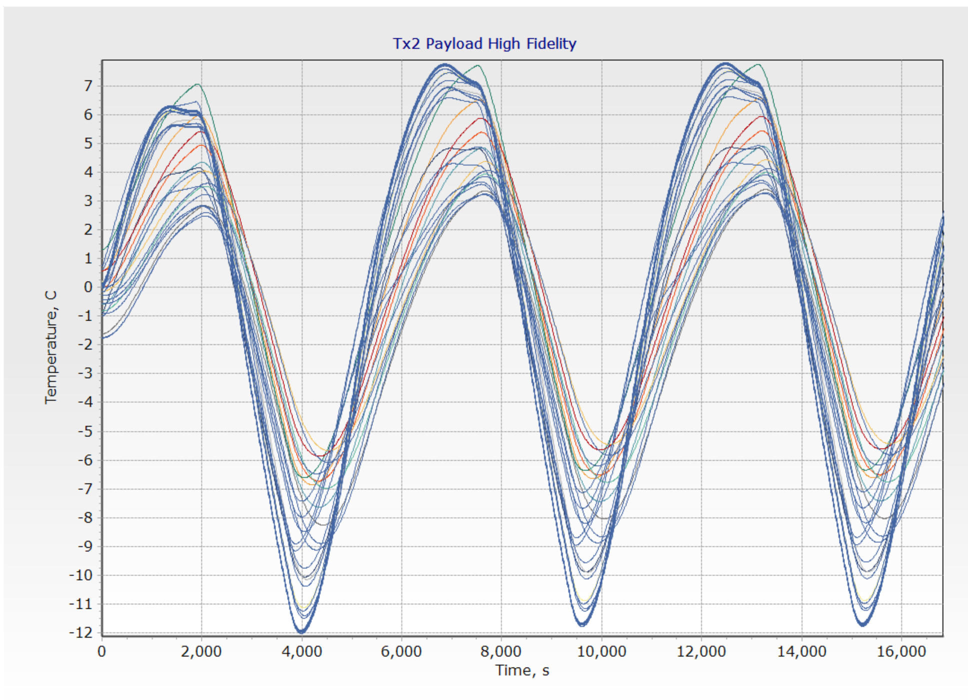

Figure 4. Processing Payload High Fidelity Temperature Results

Conclusion

While contact conductance values did vary between cases, it can be concluded that the variation in these contact conductance values did not always produce an appreciable difference in the simulated temperature ranges experienced by each of the three components. Specifically, variances between cases 1 and 2 displayed an average difference in simulated temperature extremes of 0.02 degrees Celsius. Notably, case 3 produced a larger variance in temperature specifically on the S-Band element of the finite difference model, with an average thermal variance of 0.72 degrees Celsius. However, these variances were the largest seen amongst all cases ran. The results of these simulations display that conducting thermal analyses on small satellites does not require incredibly high fidelity contact conductance values to produce valuable and reliable information on the satellite's performance in an on-orbit environment. In effect, the additional benefit of spending more development time on proofing out thermal management systems and their relations to the mission's concept of operations provides a significant benefit compared to raising the fidelity of a given finite difference model.

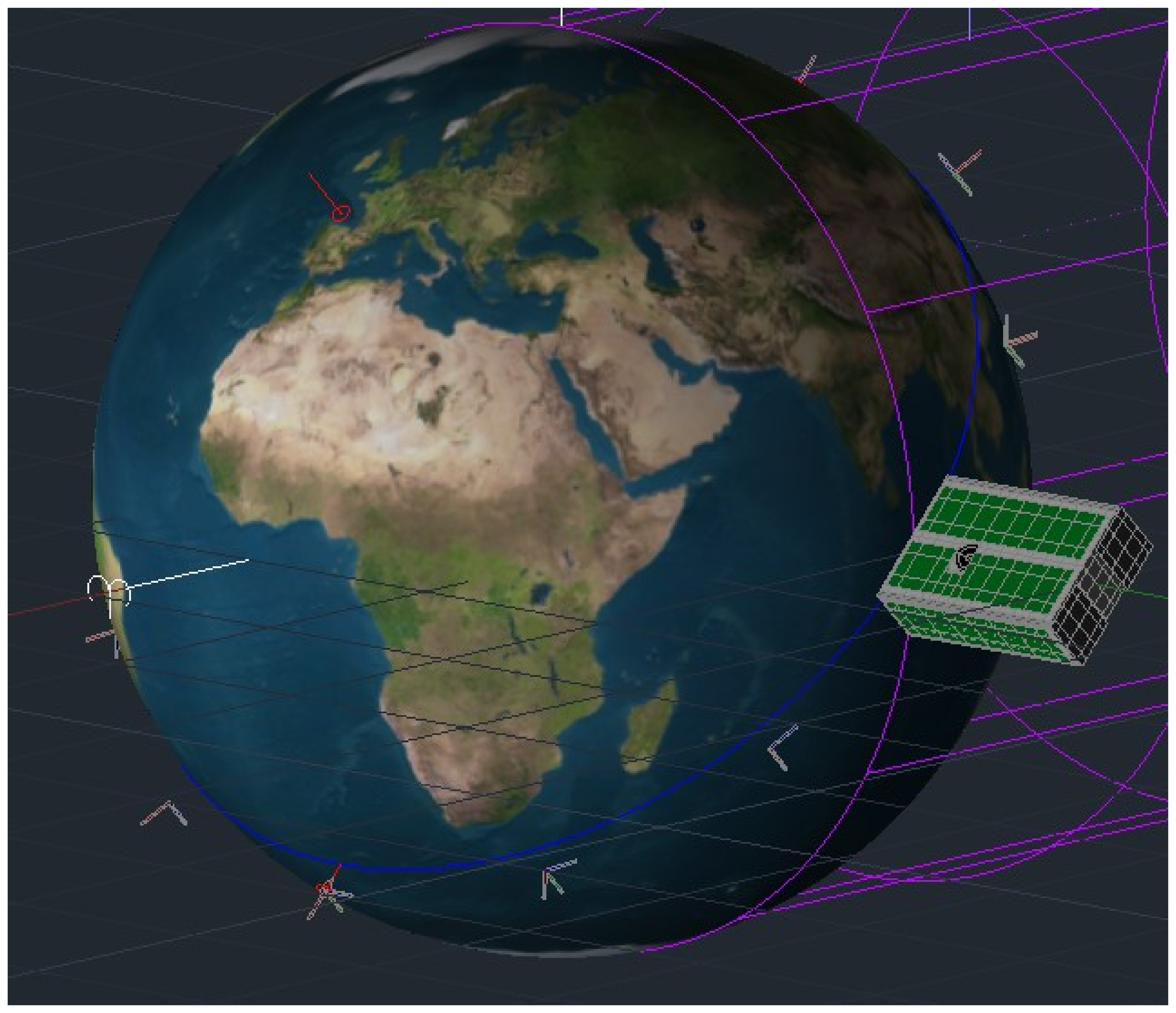

Figure 5. Visualization of Orbital Parameters Used in Analysis

For missions with slim margins and equipment that is exceptionally sensitive to nominal operating ranges, it can be beneficial to run these simulations with increased fidelity for added certainty before integration and flight. Yet, with increased fidelity comes an increase in development time and mission schedule necessary to accurately calculate and account for all contact conductance coefficients. By utilizing rough approximations of thermal contact conductance values for developmental simulations, a program can ensure that they will remain in a nominal operating range as time is spent refining the finite difference model to it's required fidelity. From there final thermal simulation results can be utilized to adjust thermal management systems and final design decisions, in effect allowing for faster satellite iteration and quicker development time.

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