

# **DEVELOPMENT OF A REDUCED ORDER MODEL FOR THE THERMAL CONTROL OF MICRO SATELLITES**

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## **ABSTRACT**

In this research project, a new method of designing a satellite thermal control system (TCS) has been developed. Using the system dynamics tool Simulink, a lumped capacity (LC) model was developed that can accurately and quickly predict satellite system temperatures during orbit. The results of this model were compared those of a three dimensional finite element (FE) simulation performed in Comsol Multiphysics. The results of the two simulations showed very close agreement, completing the preliminary stage of the LC model validation. This new modeling system can be easily expanded for optimization and the conceptual design of the TCS for the LEONIDAS 1 micro-satellite.

## **INTRODUCTION**

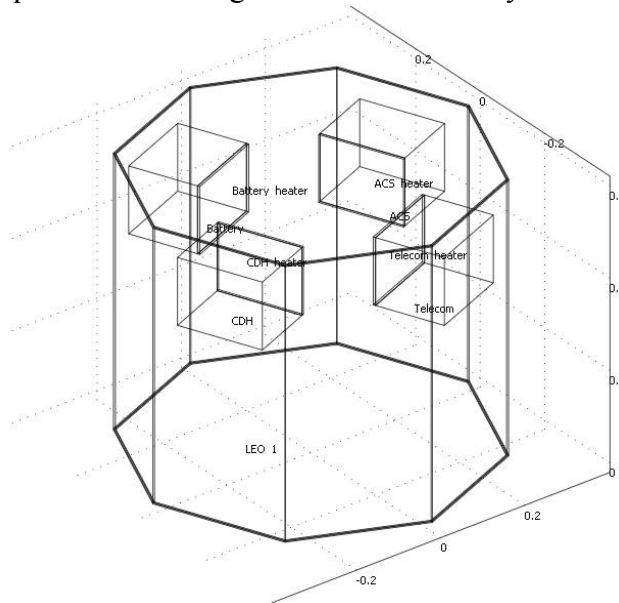
Satellites are becoming increasingly important in our lives today, whether it be by weather prediction, GPS navigation, or simply browsing Google Earth. The TCS is a critical component of a satellite. It ensures that all internal systems operate within their required temperature limits, and it affects the operating life and performance of each system. Traditionally, thermal systems are designed by using estimated models and confirming them with sophisticated simulation programs. The back of the envelope calculations used to create these estimated models are too approximate, while the simulation programs are too complex. With inaccurate and time consuming models, there is either not enough detail or time to optimize these models through analysis or simulation; the resultant system being far from the best design. What has been proposed is an intermediate system that will have greater accuracy than the preliminary calculations, and have much faster simulation times than the complex programs. With fast simulation times, many accurate models can be examined and an optimum design can be achieved. To ensure that a modeling system is accurate, certain steps must be taken to perform a validation. Initially, traditional calculations give a good starting point for experimentation. Subsequently, thorough comparisons to more complex and accepted models would demonstrate the accuracy of the system and reveal the areas of its strengths and deficiencies.



The power distribution unit (PDU) distributed current at prescribed voltages to the battery, C&DH, Telecom, ACS, and heaters. The four primary systems and their heaters had a mass, heat capacity, electrical resistance, and irreversible Ohmic heat generation by the Joule effect. The battery also has a reversible heat generation term accounting for the entropy change for the electrochemical cell. Each system was connected to the radiator by a dimensioned piece of structure which has a thermal capacitance, and an equivalent thermal resistance. The radiator was given a mass, heat capacity, area, emittance, and absorptance and was exposed to the assumed space temperature. External heat loading could be applied by solar, albedo, and Earth IR radiation with respective view factors. For the validation only the solar heat load was applied to the radiator.

### Part C: Finite Element Model Design

The CAD capabilities in Comsol Multiphysics were used to generate the octagonal geometry of the satellite. Four boxes were placed in the upper part of the satellite representing the battery, telecom, ACS, and C&DH systems. Thin plates were attached to each box representing the heaters of each system. Heat from the various systems would flow to the radiator by conduction through the aluminum structure. For simplicity and with the exception of the radiator, the boundary conditions for the inner and outer faces of the satellite were assumed to be perfectly thermally insulated. The top panel of the satellite was selected to be the radiator, where the internal and external heat was rejected by way of radiation. A tetrahedral mesh was used, and solved using a quadratic LaGrange finite element analysis.



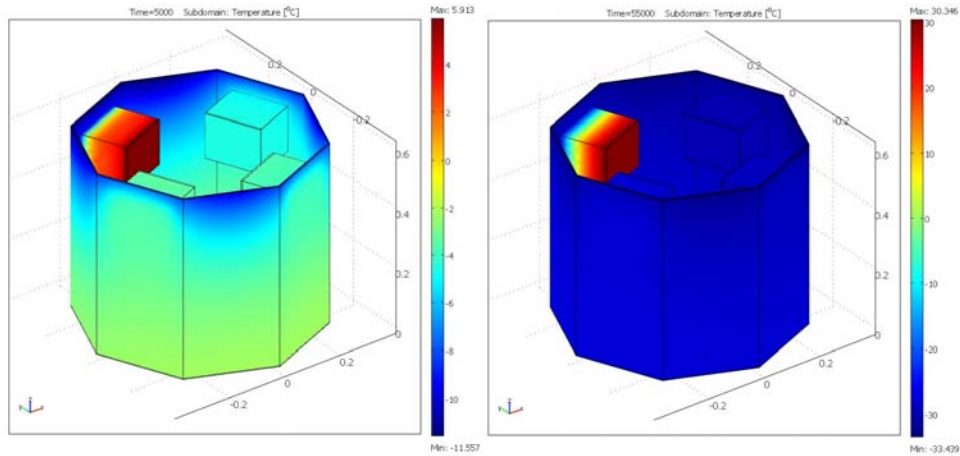
**Figure 2 – Three dimensional geometry of the LEONIDAS-1 micro satellite with four primary systems and their respective heaters.**

### Part D: Lumped Capacity Model Validation

Both the LC model and the FE model were simulated using the same parameters. The LC model parameters of thermal resistance between the systems and the radiator were estimated from the topography in the FE geometry.

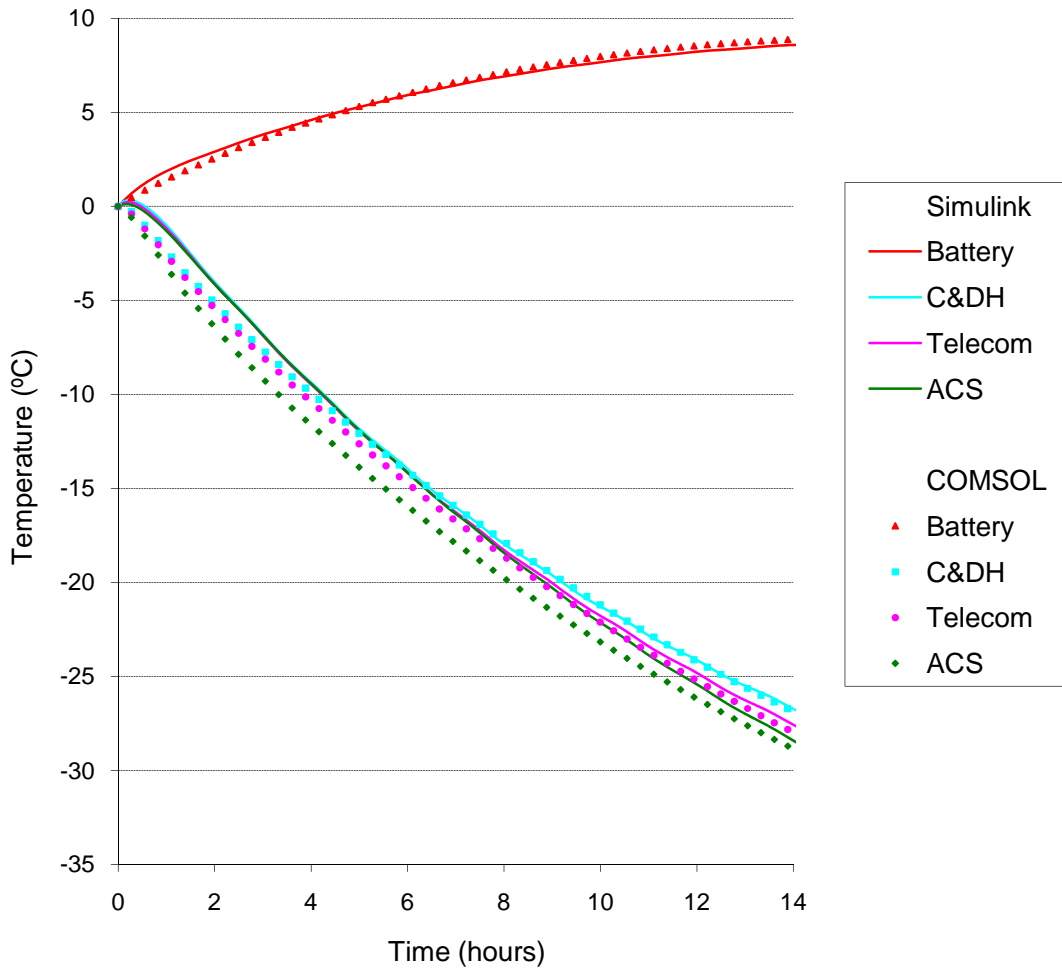
## RESULTS

The radiator area was calculated from the equations given on page 456 of the SMAD III handbook to be 500 cm<sup>2</sup> for the LEONIDAS-1 micro satellite. The surface temperatures can be seen in Figure 3 for two times during simulation. In both orbital times, it can be seen that the battery remains the hottest component, and affects the largest area. While the temperatures of the Telecom, ACS, and C&DH achieve near equilibrium with the structure, the temperature gradient continues to increase between the battery and the structure.



**Figure 3 - Surface temperatures of the various components in the satellite model after one orbit (left) and after 10 orbits (right). The top radiator panel has been removed for enhanced visibility of the individual component temperatures. Refer to Figure 2 for the equipment placement.**

The four primary system temperatures as functions of time can be seen in Figure 4 for both satellite models. The battery temperature can be seen rising slowly to nearly 10°C while the temperatures of the Telecom, ACS, and C&DH drop to nearly -30°C. The temperatures of the Telecom, ACS, and C&DH diverge slowly in the LC model but remain evenly spaced in the FE model. The heat fluctuations due to solar radiation were found to have a very small effect on the system temperatures. By comparing the results of both simulations, it was found that the connection between the battery and the radiator had the highest thermal resistance. A correlation was noticed between the heat output of each component and its thermal resistance to the radiator. The simulation time for the LC model was under two seconds.



**Figure 4 - Primary system temperatures inside the satellite during 10 orbits. The results from the LC model can be seen as solid lines while those from the 3-D FE model can be seen as markers.**

## DISCUSSION

The solar heat fluctuation had a much smaller effect on the systems temperatures than expected. This can be attributed to the very small view factor used, and due to the majority of the satellite being perfectly thermal insulated. The battery's large thermally affected area shows that the effective length of the battery-radiator connection is greater than that of the other components. Because of the larger effective length, the increased thermal resistance of the connection can be explained. By examining Figure 4, good agreement could be seen between the results of the two separate simulations. Some of the small differences between the two models can be attributed to the way the thermal resistances were modeled. In the LC model, the resistances between the systems and the radiator did not interact, while in the FE model they did. The FE model's radiator also had thickness and inertia while the LC's radiator did not. These modeling variations explain some differences in the temperature trends seen in Figure 4.

## **CONCLUSION**

The results of the two simulations showed very close agreement, confirming the Simulink lumped capacity model as a potentially viable design tool. Once fully validated, this system will be put to the test in the design of the thermal control system for the LEONIDAS 1 micro-satellite. With simulation times of less than two seconds, millions of scenarios can be examined for optimal design characteristics. This optimization ability makes the reduced order model a very powerful tool that could redefine the way satellite systems are designed.

## **ACKNOWLEDGEMENTS**

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## **REFERENCES**

W. J. Larson and J. R. Wertz (eds.) "Space Mission Analysis and Design", 3<sup>rd</sup> edition, Space Technology Library, Springer, New York, 1999.