State-of-the-Art Thermal Analysis Methods and Validation for Small Spacecraft

Kristina Hogstrom

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CALIFORNIA INSTITUTE OF TECHNOLOGY

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Introduction

- Thermal analysis is integral part of development cycle
- Inadequate thermal system → decreased performance or damage
- Overly conservative thermal system → excessive cost and weight
- Smaller satellite → less room for control components

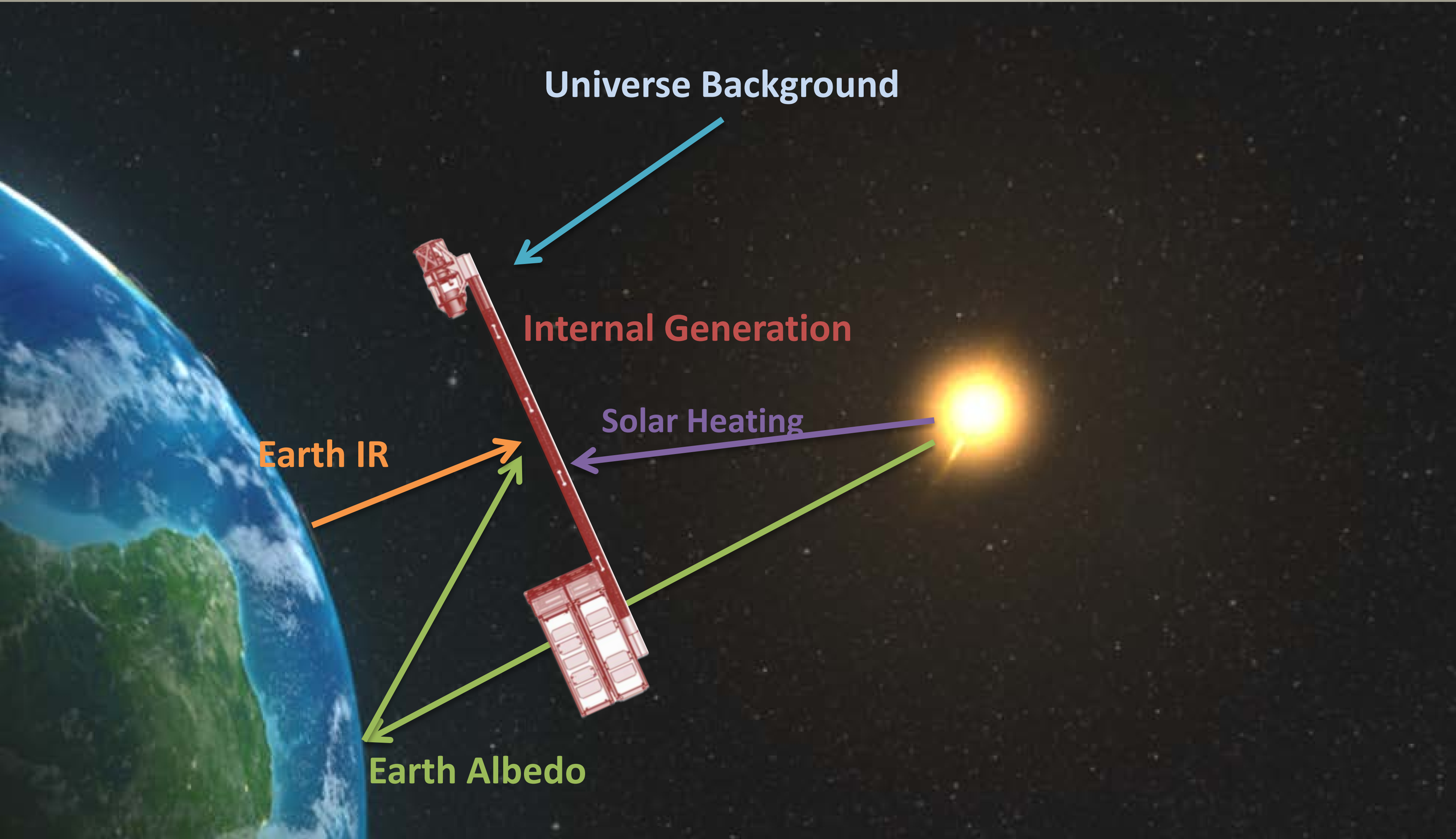
Outline

- Orbital environment
- Component operational temperature ranges
- Thermal control methods
- Thermal testing
- Analysis methods
- Analysis results
- Conclusions and applications

Sources

- NASA’s Guidelines for Thermal Analysis of Spacecraft Hardware
- Robert Miyake’s lecture on Spacecraft Design Thermal Control Subsystem, JPL 2008
- UT Austin FASTRAC twin 25 kg satellites, orbit TBD at time of thermal analysis
- NASA Ames 3U PharmaSat, 40.5 degree 460 km (P-POD) orbit

Orbital Environment



Orbital Environment

- Magnitude of heat fluxes highly dependent on location of spacecraft in orbit
- Worst case hot and cold scenarios established by maximizing and minimizing heat loads
- Orientation also affects heat loads
- If orbit is unknown, test possible orbits and establish worst case scenarios for orbits that maximize and minimize shadow time.

Operating Temperature Ranges

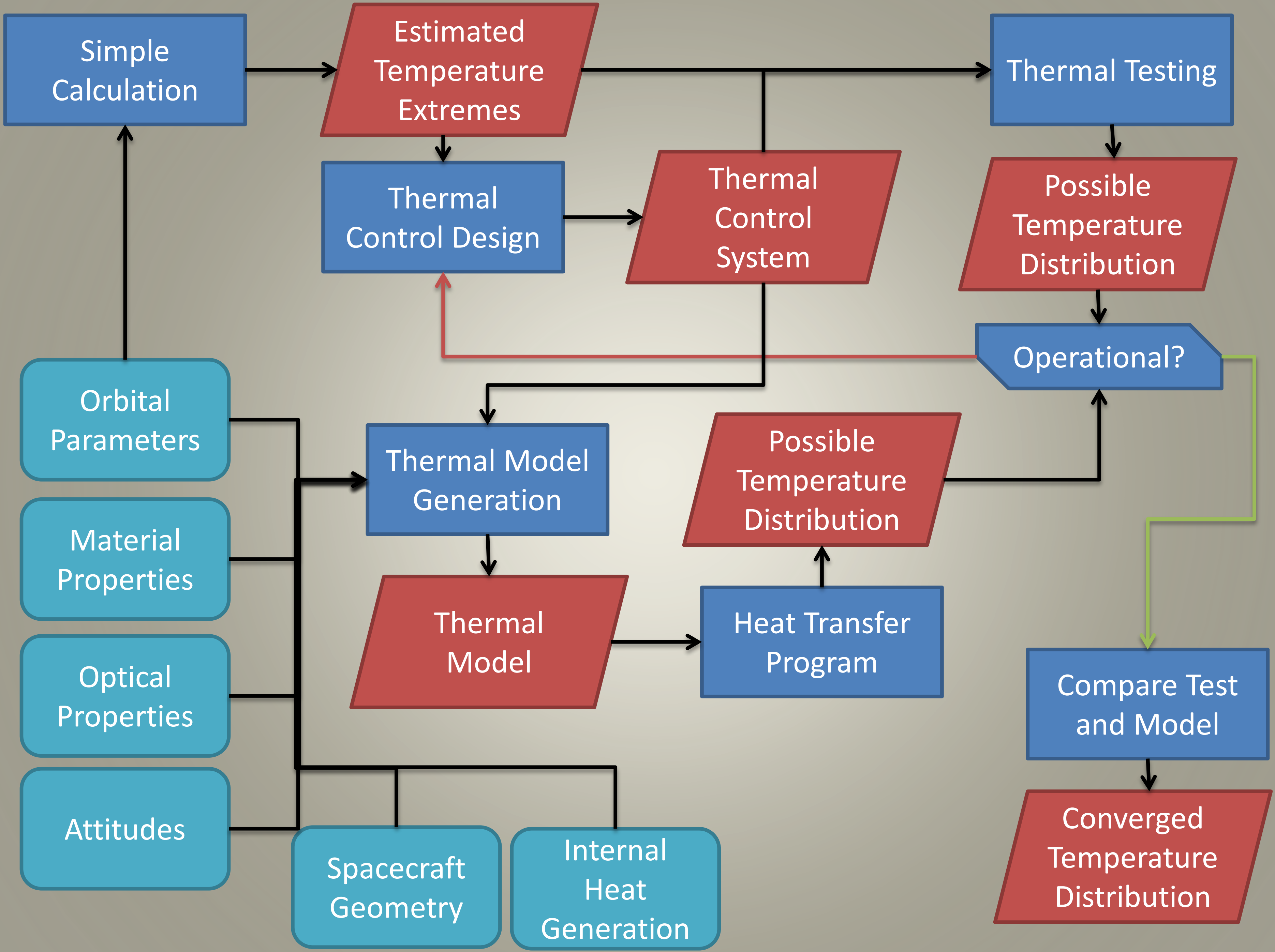
- Battery on both PharmaSat and FASTRAC limits temperature bounds (0°C to 45°C)
- Avionics and communications also critical on FASTRAC (5°C to 65°C)
- PharmaSat uses industrial grade components (−40°C to 85°C)
- PharmaSat biological experiment requirements (around room temperature)

Thermal Control Methods

- Passive: no resources required from the spacecraft after installation
  - MLI
  - Thermal coatings
  - Conductance-regulated materials
- Active: requires power, sensors, data handling
  - Heaters/coolers
  - Thermal switches
  - Dewars
- Small spacecraft have minimal space for heaters and solar panels to power active controls

Thermal Testing

- Thermal Vacuum and Power Management (TVPM)
  - Vacuum chamber at pressure of 10^{-5} torr
  - Thermal cycling between hot and cold, representative of orbit shadow
    - Hot case modeled with infrared lamps placed throughout the chamber (1000 W – 1600 W)
    - Cold case modeled with liquid nitrogen
  - Functional checks of system before and after cycling
- Thermal imaging also used to pinpoint hotspots



Simple Calculation

Estimated Temperature Extremes

Thermal Testing

Thermal Control Design

Thermal Control System

Possible Temperature Distribution

Operational?

Orbital Parameters

Thermal Model Generation

Possible Temperature Distribution

Material Properties

Thermal Model

Heat Transfer Program

Compare Test and Model

Optical Properties

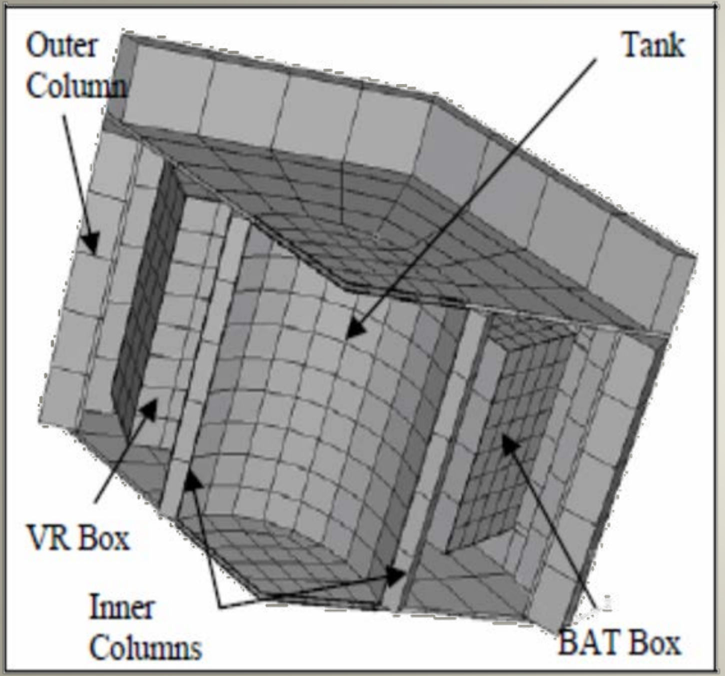
Attitudes

Spacecraft Geometry

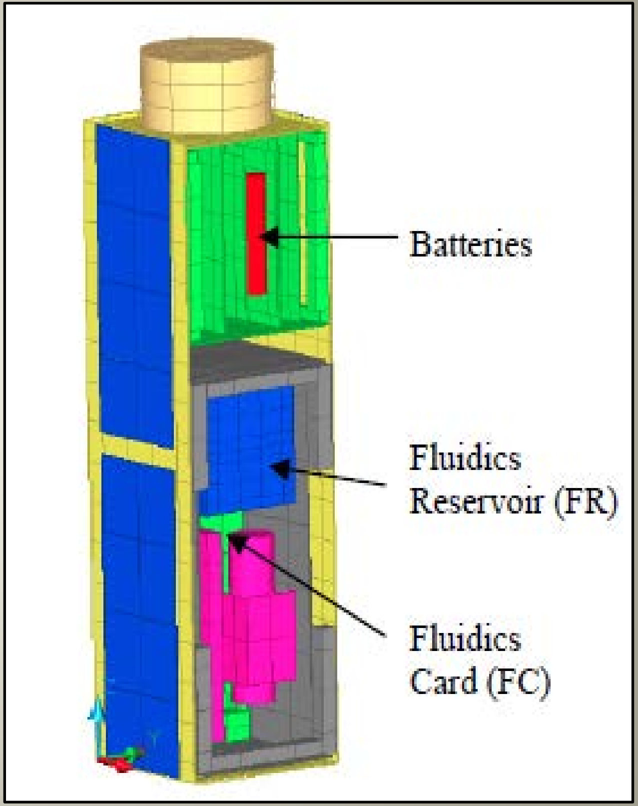
Internal Heat Generation

Converged Temperature Distribution

Level of Analysis

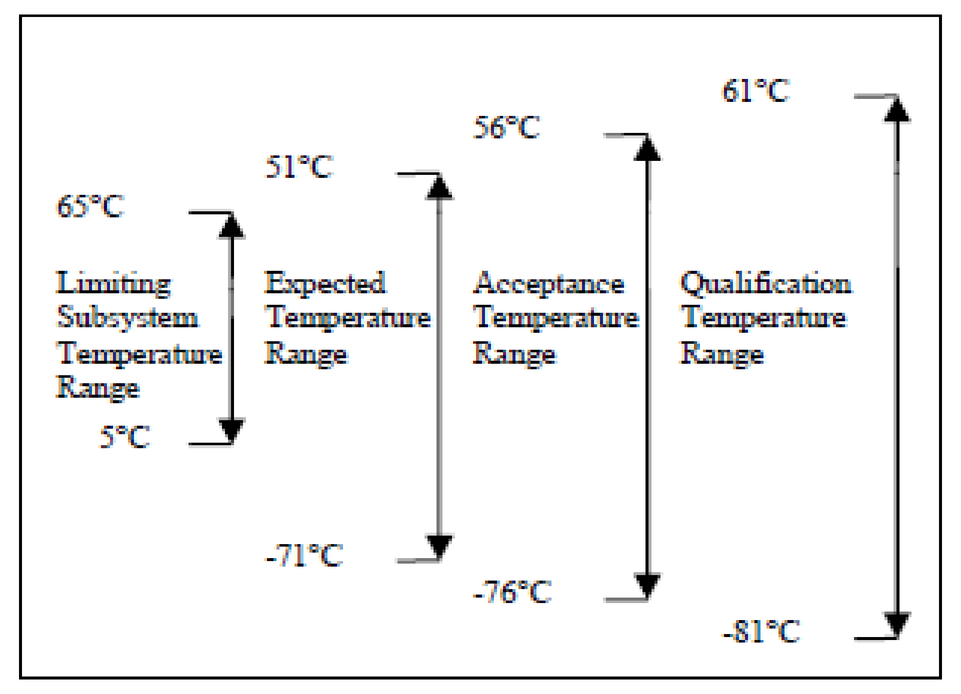


FASTRAC thermal model in Abaqus. Only 1/3 of the spacecraft was simulated.



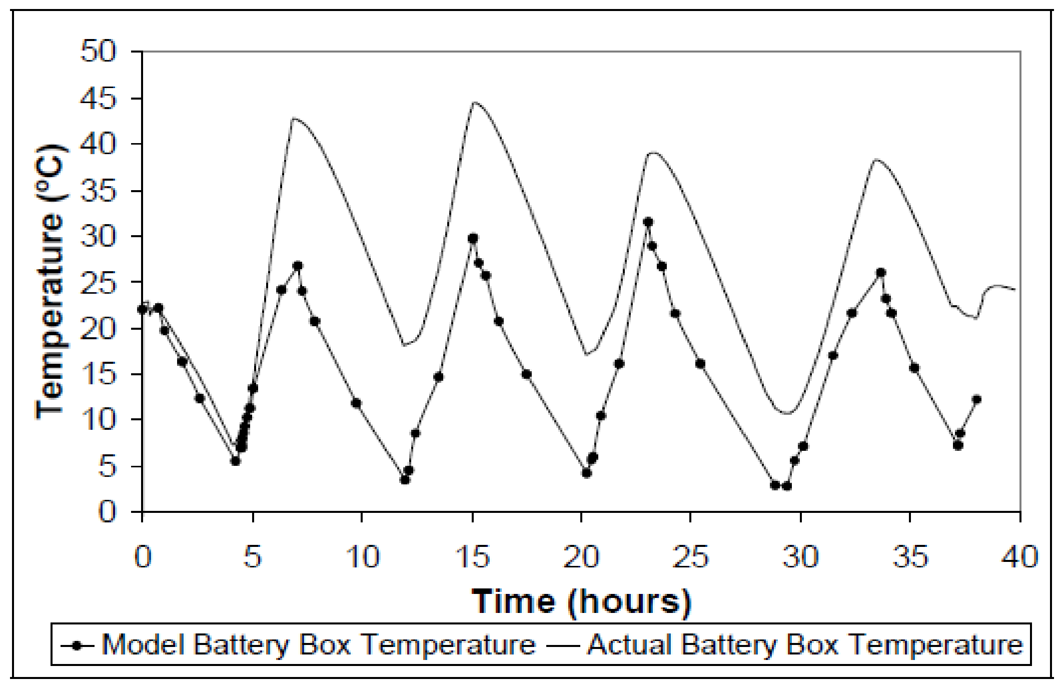
PharmaSat thermal model in Thermal Desktop

Selected Analysis Results
FASTRAC



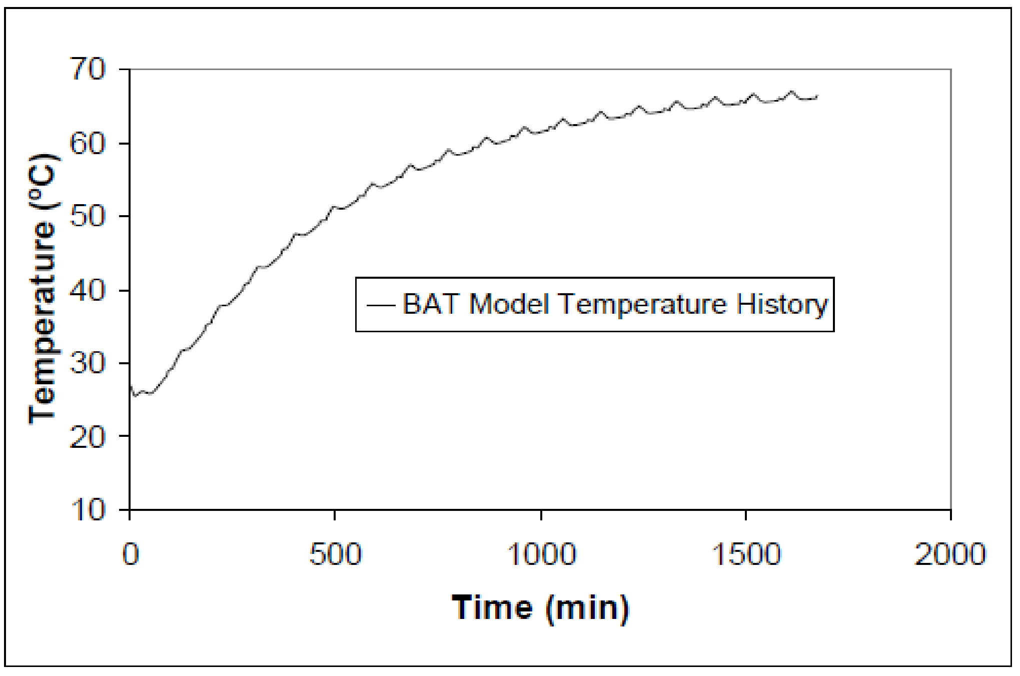
Expected temperature ranges as computed by simple calculations (spherical body). Limiting subsystem is avionics.

Selected Analysis Results FASTRAC



Thermal vacuum test vs. Abaqus model results show discrepancy of 10°C when subject to same boundary conditions.

Selected Analysis Results FASTRAC

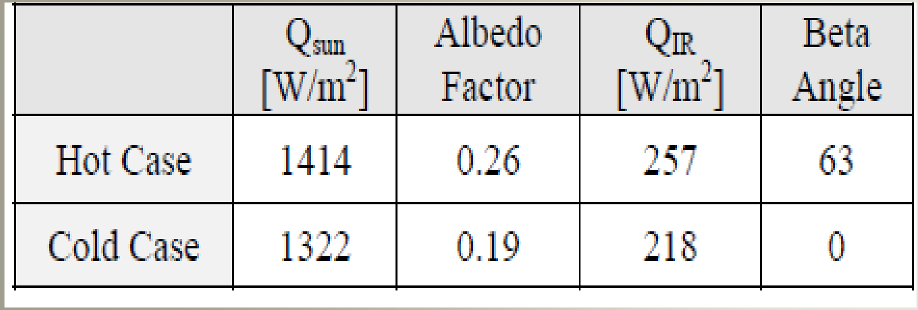


Abaqus model subject to environment conditions with 10°C correction shows inoperable temperatures endured by battery.

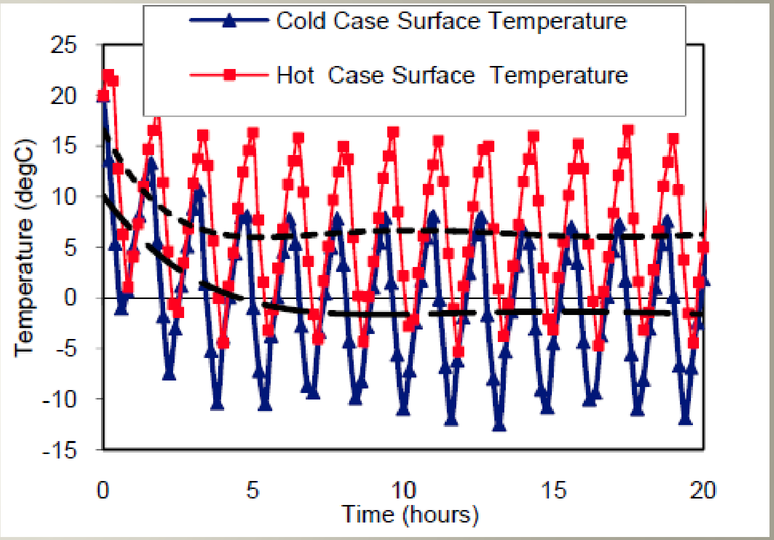
Selected Analysis Results
FASTRAC

- Added maximum rotation to spacecraft as allowed by GPS signal to mitigate temperatures (10 rev/orbit)
- Still required 39% shadow time, achievable with maximum altitude of 360 km.

Selected Analysis Results
PharmaSat

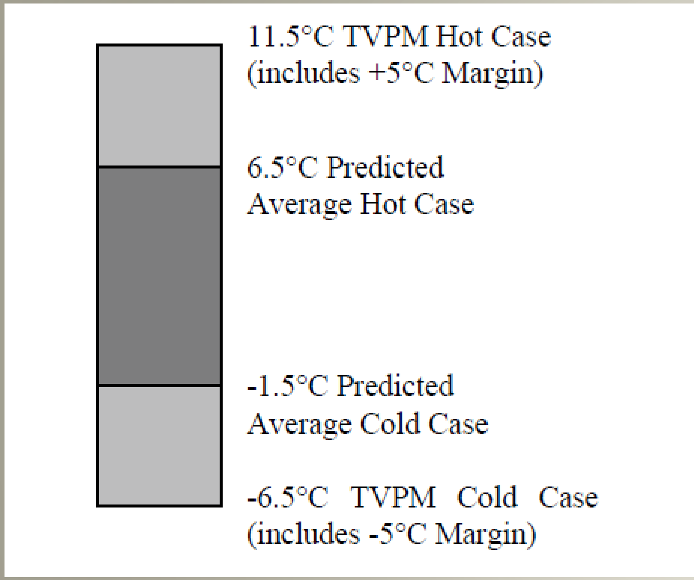


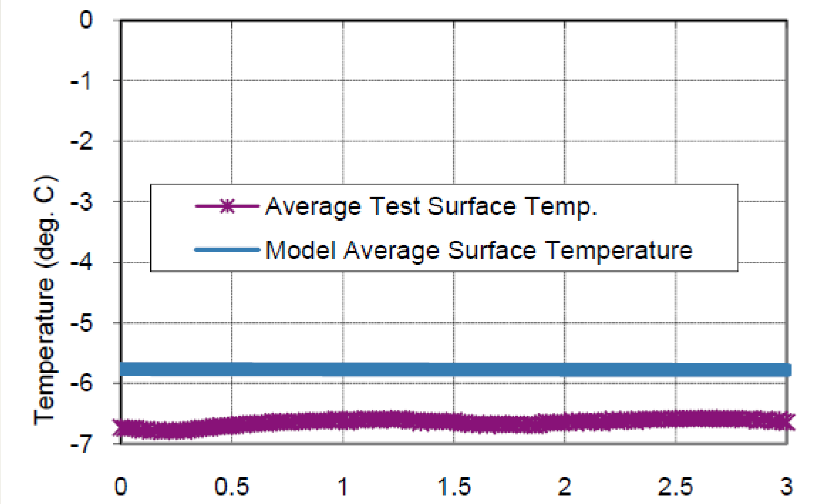
	Q_{sun} [W/m^2]	Albedo Factor	Q_{IR} [W/m^2]	Beta Angle
Hot Case	1414	0.26	257	63
Cold Case	1322	0.19	218	0



Since orbit is known, hot and cold case determined by time of year (beta angle). Surface temperatures computed in Thermal Desktop.

Selected Analysis Results PharmaSat





5°C margin added to average equilibrium surface temperatures from model to establish test conditions. Testing results compared to model results show 1°C discrepancy. All component temperatures within bounds.

Conclusions

- Thermal analysis enables design of adequate thermal control system and ensures mission success
- Thermal model must be validated with testing
- Small satellites require creative applications of passive control systems to reduce resources