TFAWS Paper Session

A passive thermal analysis of a small satellite

by **Wyatt Hurlbut**

Presented By
Wyatt Hurlbut, EIT, Graduate Student

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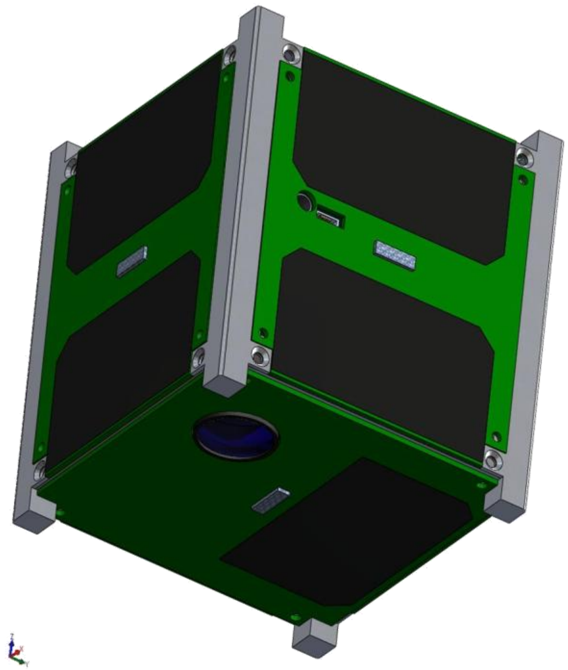
Introduction

- CubeSat Design Specifications, www.cubesat.org
  - Begun as a collaboration in 1999 between Stanford University and California Polytechnic State University (CalPoly)
  - 1U CubeSat: 1.33 kg,10x10x10 cm^3
  - 2U is 2.66 kg, 20x10x10 cm^3; 3U is 4.00 kg, 30x10x10 cm^3
  - Center of Mass: 2 cm from Geometric Center
  - Secondary payload for launch vehicles
- Unique design challenges
  - Very short build time, low budgets
  - Student-run development teams
  - Existing power limitations
  - Extreme thermal environments
- "Failure **is** an option."
  - *Professor Jordi Puig-Suari*

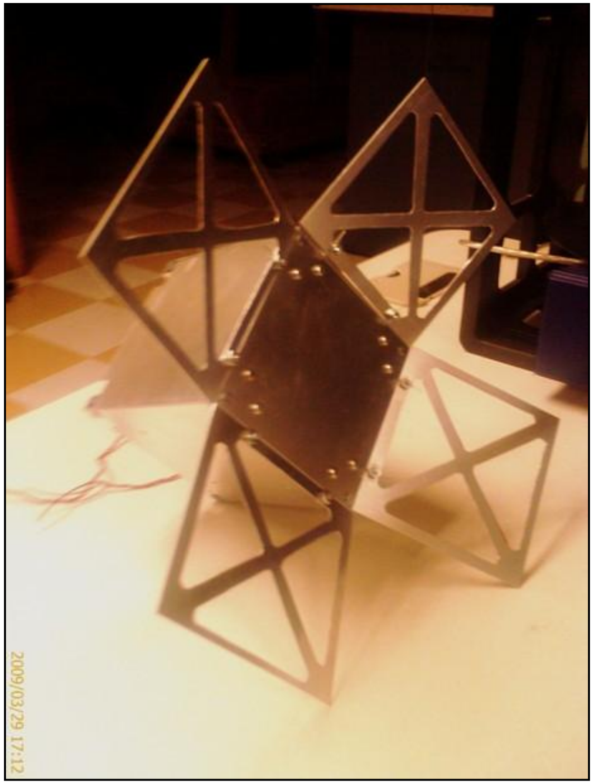


CubeSat Mission Objectives

- Educational hands-on design process
  - Mostly students and volunteers
  - Highlights student research and interests
  - Conception to completion: two to three years
- Launch vehicle requirements
  - Cannot impact primary payload
  - Compliant with ITAR, FCC, CubeSat specs, et cetera
  - Launch costs $40-80k, not inclusive of testing
- University budget **$500k-$1000k**
  - No space-hardened equipment
  - Commercial off-the-shelf components
  - Machining and fabrication costs prohibitive
  - Power constraints impact potential

Solar Power Constraints

- Approximate average solar power: www.spectrolab.com
  - Two space-rated panels per face, ~1 W per cell
  - Transmission needs: 500-2000 mW
- Design considerations
  - Location; Quantity
  - Deployment angle; Orientation
  - Total # axis stabilization
  - Orbital launch parameters
- Requires attitude control system
  - Considerable technical knowledge
  - Machining / fabrication challenges
  - Nontrivial mass cost
  - Average case: 5 degrees accuracy

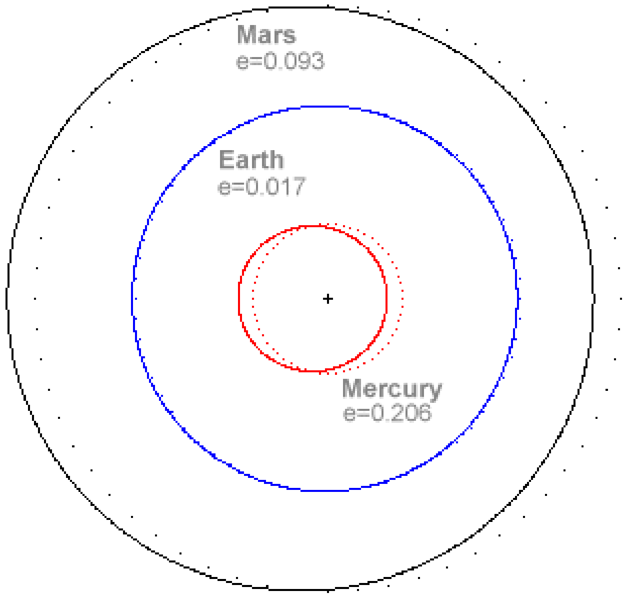


Extreme Thermal Environment

- Secondary payload
  - Launch vehicle often unknown
  - Average lifetime 6-60 months
- Low Earth Orbit (LEO)
  - Reduced radiation exposure from Van Allen belt
  - Allows amateur “ham” radio contact
  - Sun synchronous temperature – 295 K
  - Eclipsed temperature – 158 K

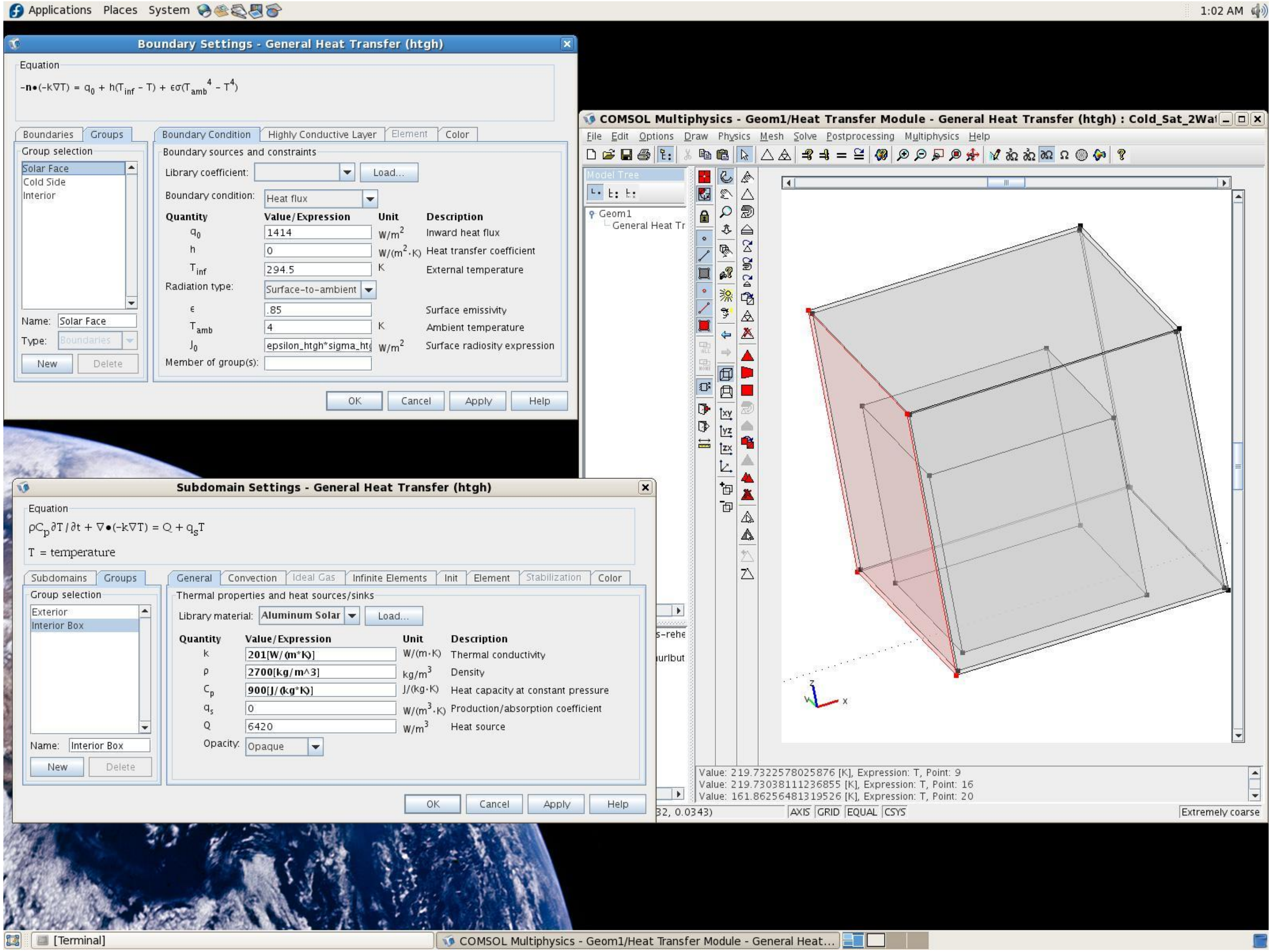
Altitude [km]	Velocity [km/s]	Orbit [min]	Sunlight [% Orbit]	Cooling [min]	Avg Temp [K]
300	7.73	90.37	59.58%	36.53	236.56
400	7.67	92.41	61.00%	36.05	238.40
500	7.62	94.47	62.22%	35.69	240.00
600	7.56	96.54	63.30%	35.43	241.41
700	7.51	98.62	64.28%	35.23	242.69
800	7.46	100.72	65.18%	35.07	243.86

Worst Case Conditions

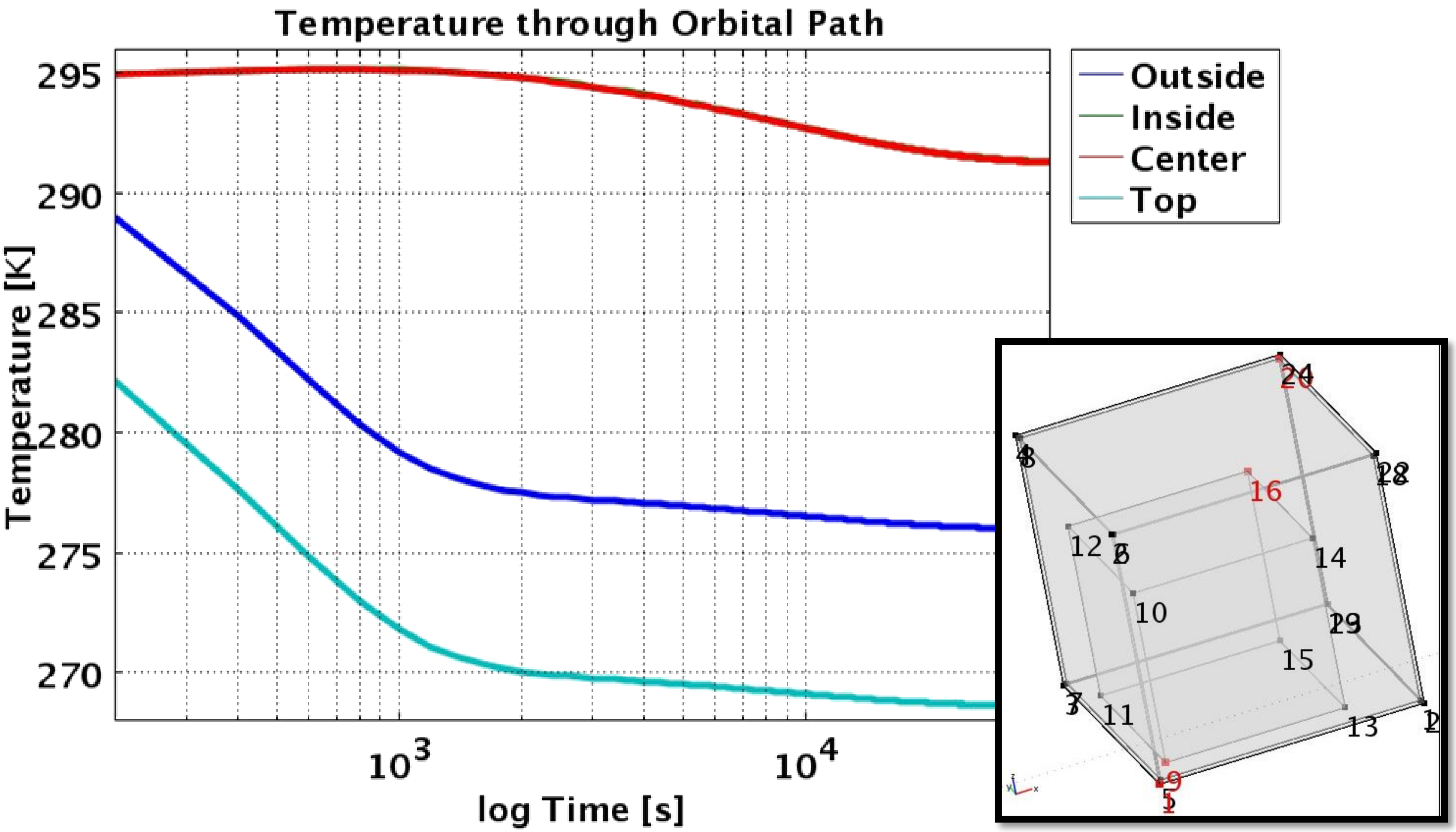


- Solar flux
  - Summer Season 1393 W/m^2
  - Winter Season 1305 W/m^2
- Hot condition
  - Sun-synchronous, summer orbit
- Cold condition
  - Sun-asynchronous, winter orbit
- Initial assumptions
  - Constant velocity, circular orbit, precise axis control
  - Altitude 300km, no atmosphere or atmospheric friction
  - Ambient temperature 4 K, No reflection from Earth or Moon
  - Material properties: 1 kg aluminum 6061-T6
  - Internal component block produces 2 watts

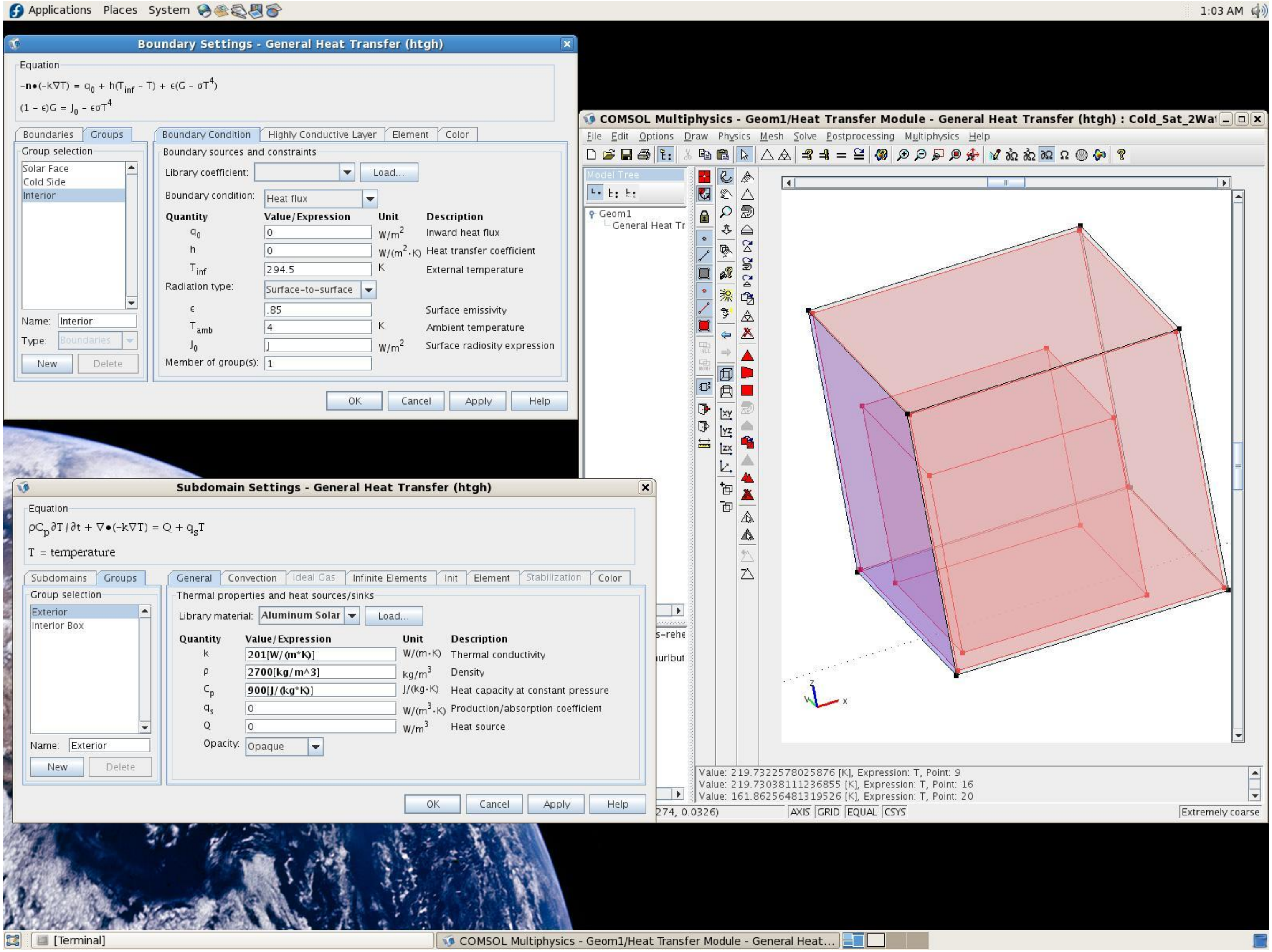
Hot Condition Model



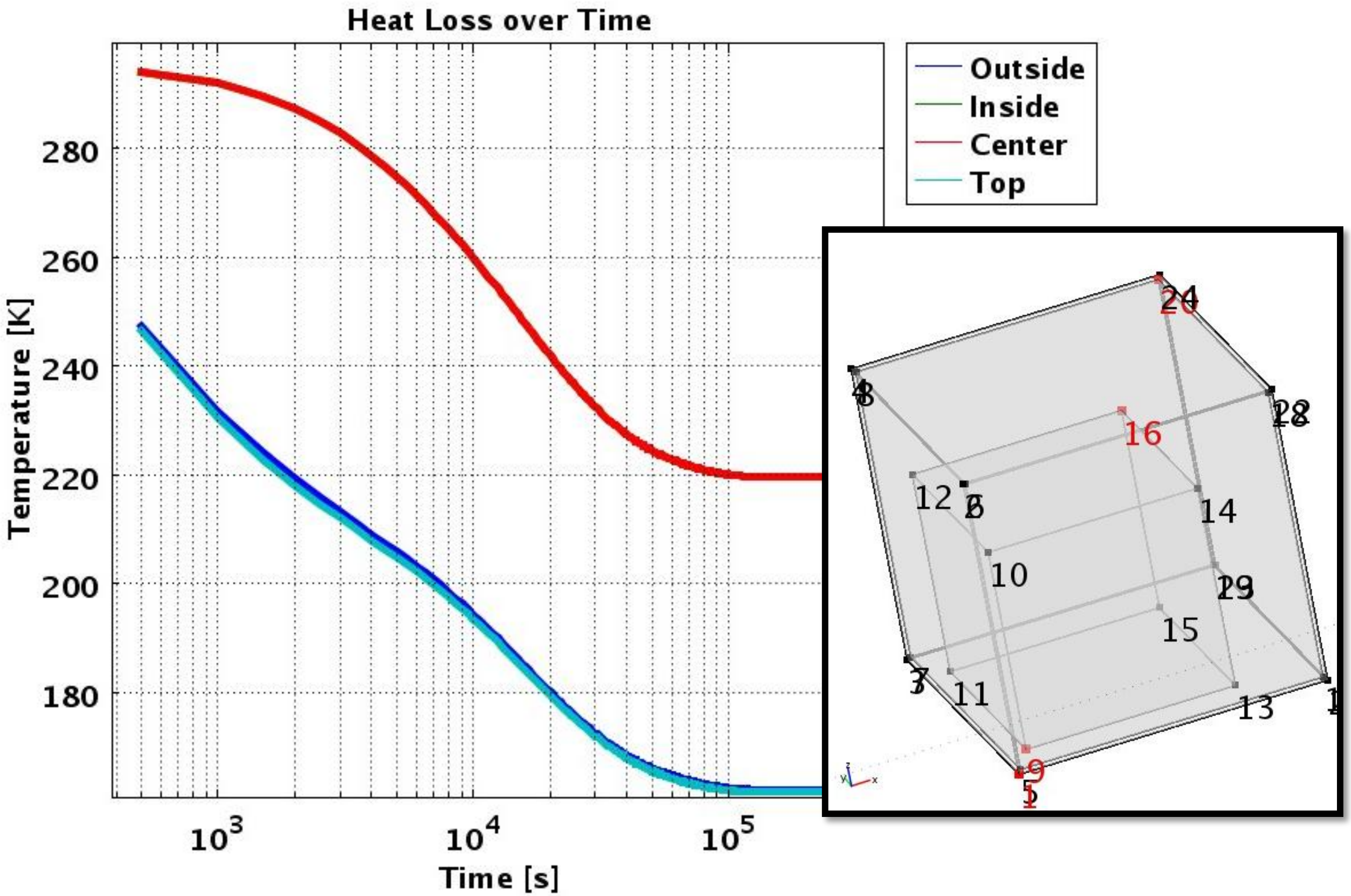
Hot Condition Results



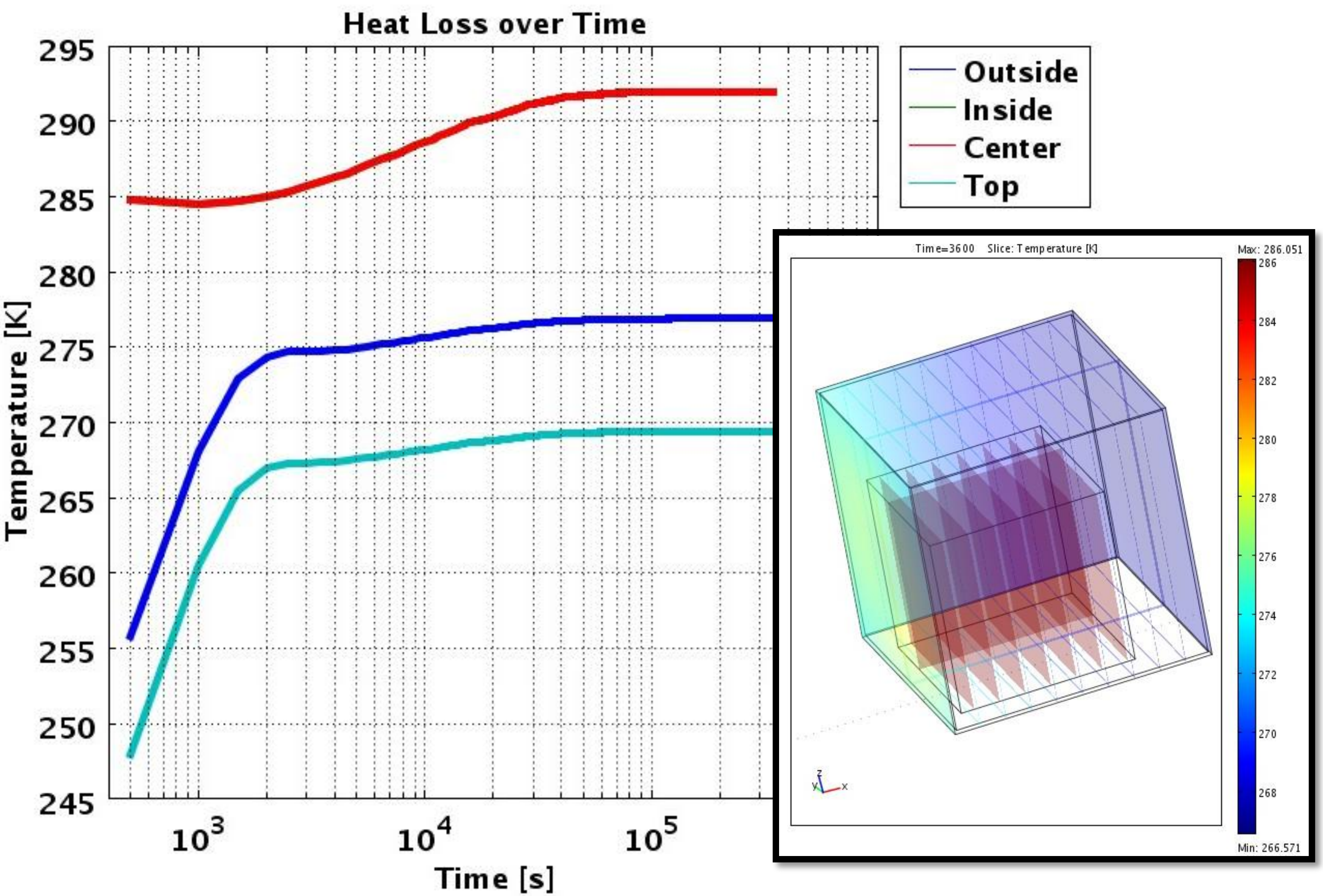
Cold Condition Model



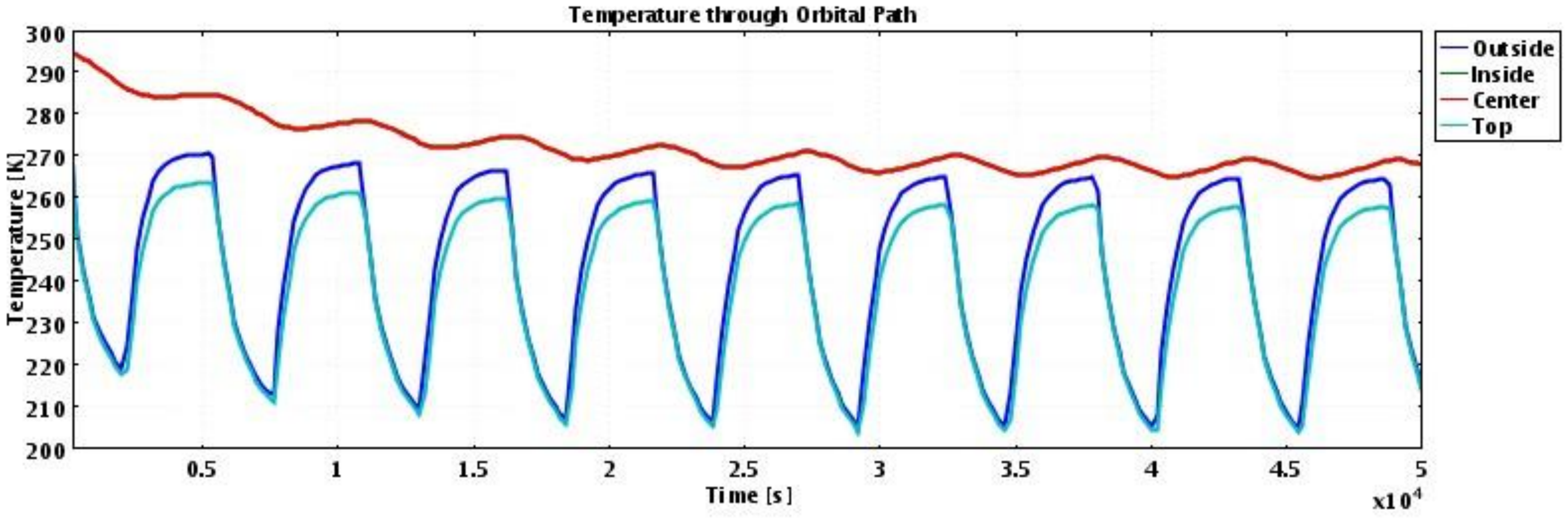
Results of First Orbit

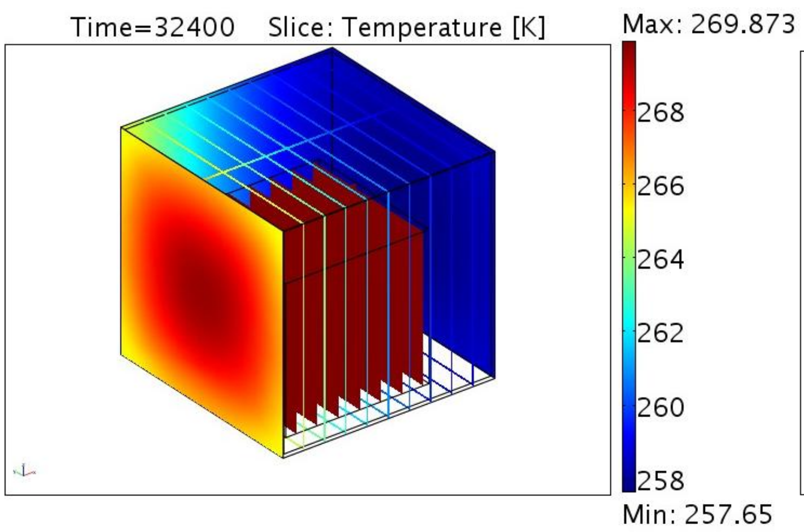


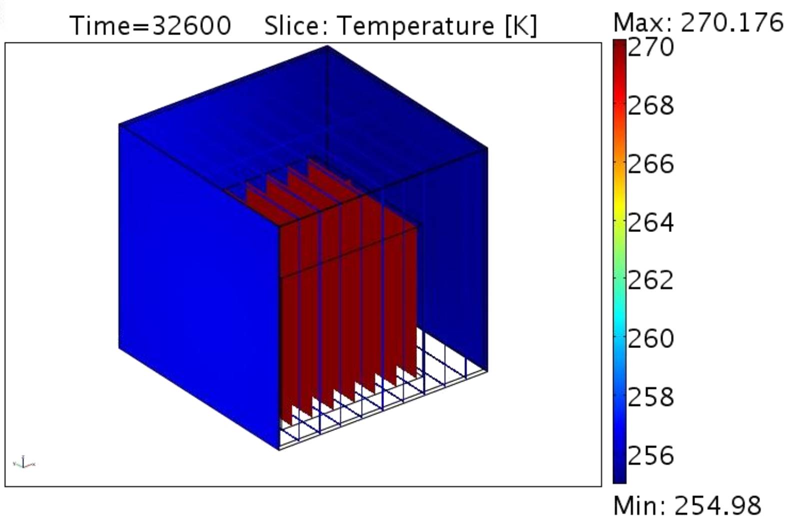
Results of First Orbit, Cont.



Orbit Comparison, cont.







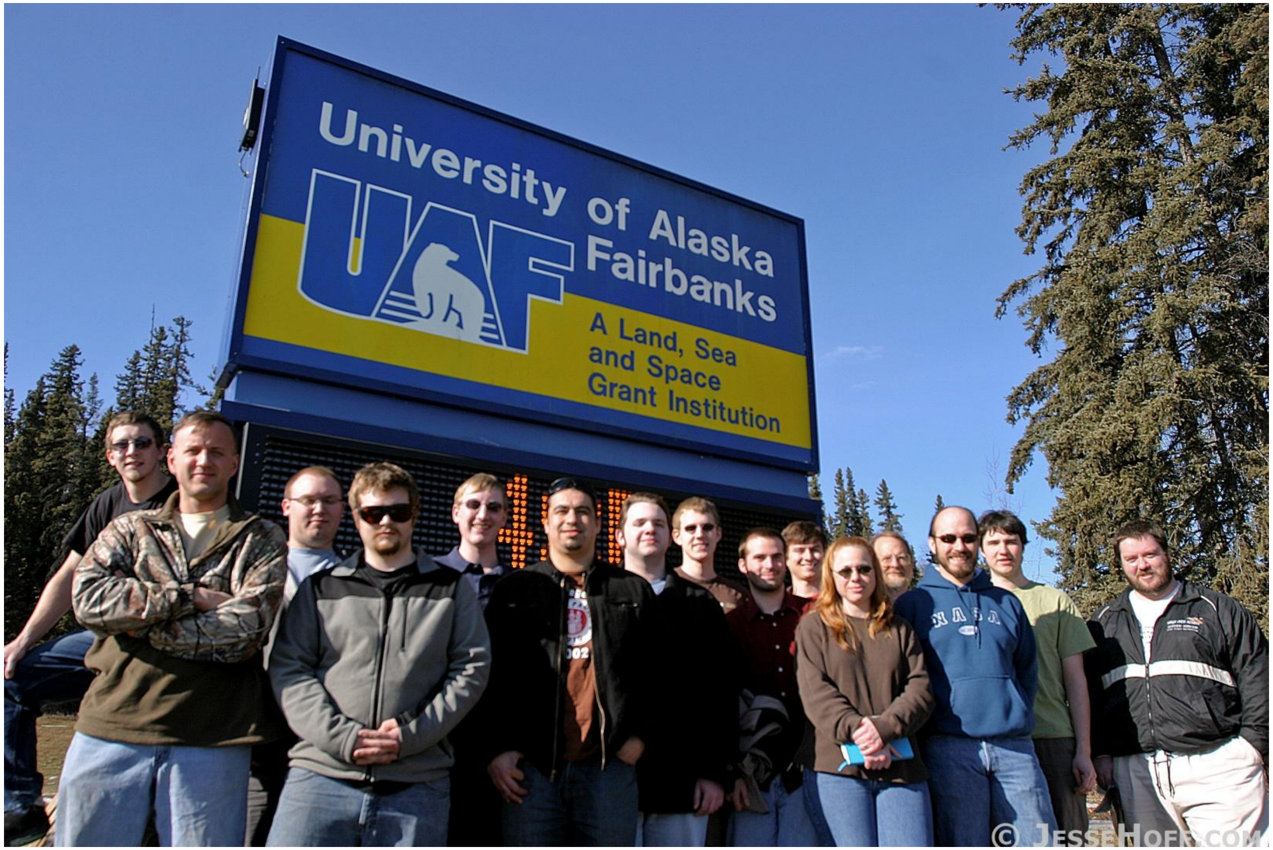
Summary

- Model results corroborate rough experimental data
  - Depends on ideal conditions
  - No knowledge of specific design
- Advantages to CubeSats:
  - Inexpensive, low-cost research
  - Excellent educational platform
- Disadvantages:
  - Challenging development environment
  - Continually reinventing ~~wheel~~ Sputnik
- Unanswered questions:
  - Thermal characteristics of CubeSats with deployed solar panels?
  - Overall accuracy of model that indicates thermal conditions?
  - Critical variables for deployable solar panel designs?
  - Should CubeSat teams consider this as a viable option at all?

Future Improvements

- Expand initial literature review
  - Designs often poorly documented
  - ITAR regulations prohibit releasing specific details
- Identify critical design constraint variables
  - Deployment angle; Orientation; Location; Quantity
  - Orbital launch parameters; Total # axis stabilization
- Determine thermal characteristics of detailed model
- Create detailed energy balance and thermal model
  - Used for the Alaskan Research CubeSat
  - Will be made available for future CubeSat teams
- Answer questions posed by CubeSat community
  - Are power issues best solved by simply increasing size?
  - How does each design variable impact a CubeSat?
  - Where do we start?

Acknowledgements



UAF CubeSat Team: Left to right: Samuel Vanderwaal , Donald 'Crank' Mentsch, Greg Geiger, Alex Arneson, Andrew Paxson, Marco Ulloa, Ben Montz, Wyatt Rehder, Dustin Olson, Robert Schnell, Heather Havel, Dr. Joseph Hawkins - Professor, Wyatt Hurlbut, Jesse Frey, and Steven Kibler.
Not pictured: Dr. Denise Thorsen – Director of ASGP, Dr. Rorik Peterson – Advisor, Gregg Christopher, Morgan Johnson, James Peters, and Scott Otterbacher.
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Thank you for your attention! Questions?