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Thermal Modeling and Testing of the Edison Demonstration of Smallsat Networks Project

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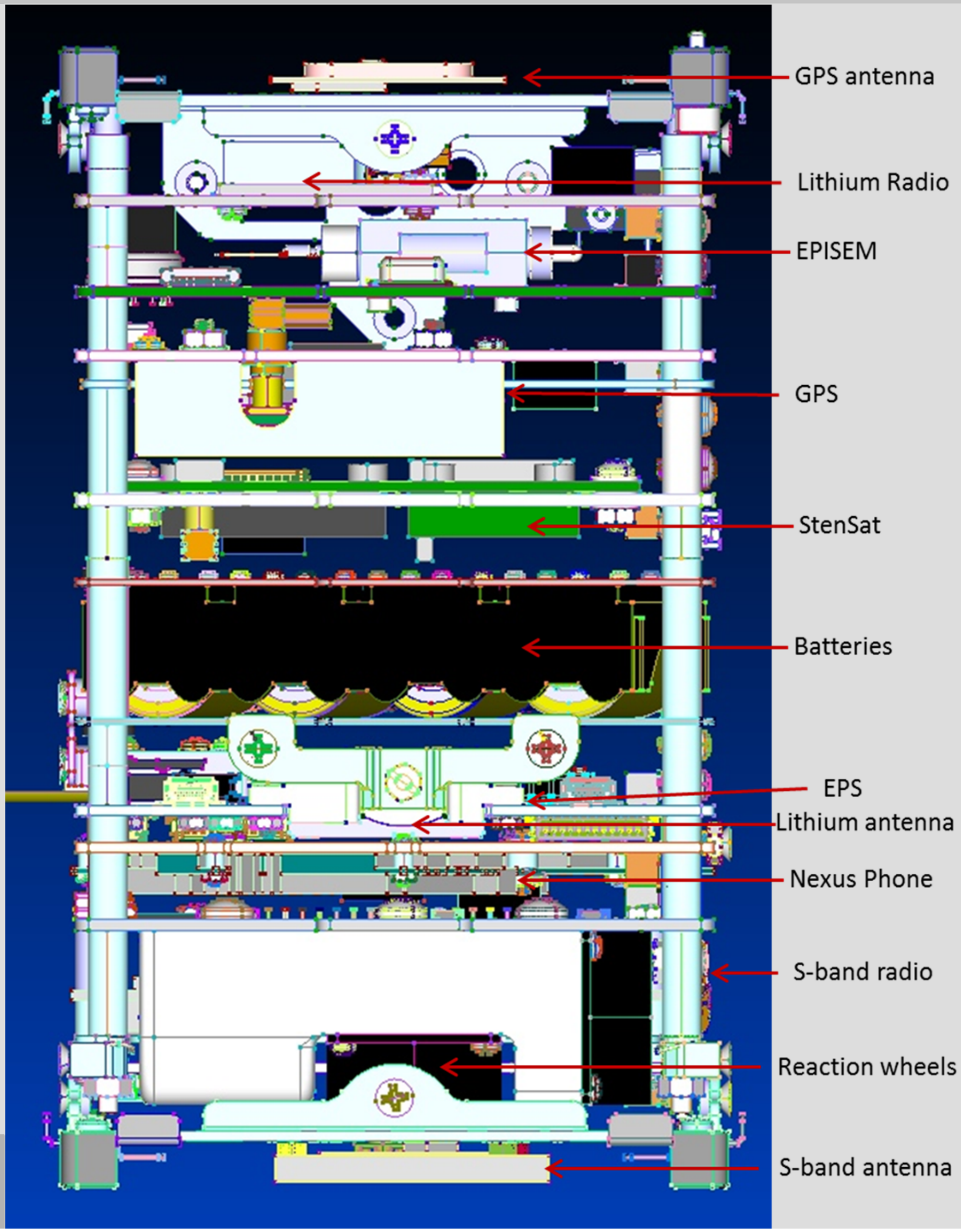
Introduction to EDSN

- NASA will be launching a swarm of 8 1.5U 2kg cubesats (EDSN) similar to the PhoneSats (launched over the last two years)
- Launching on new Super Strypi vehicle in November 2014 as the secondary payload
- Nominally into a circular near-polar ~500 km orbit
- Primary mission is to demonstrate intra-swarm communications
- Multi-point in-situ data acquisition (EPISEM)

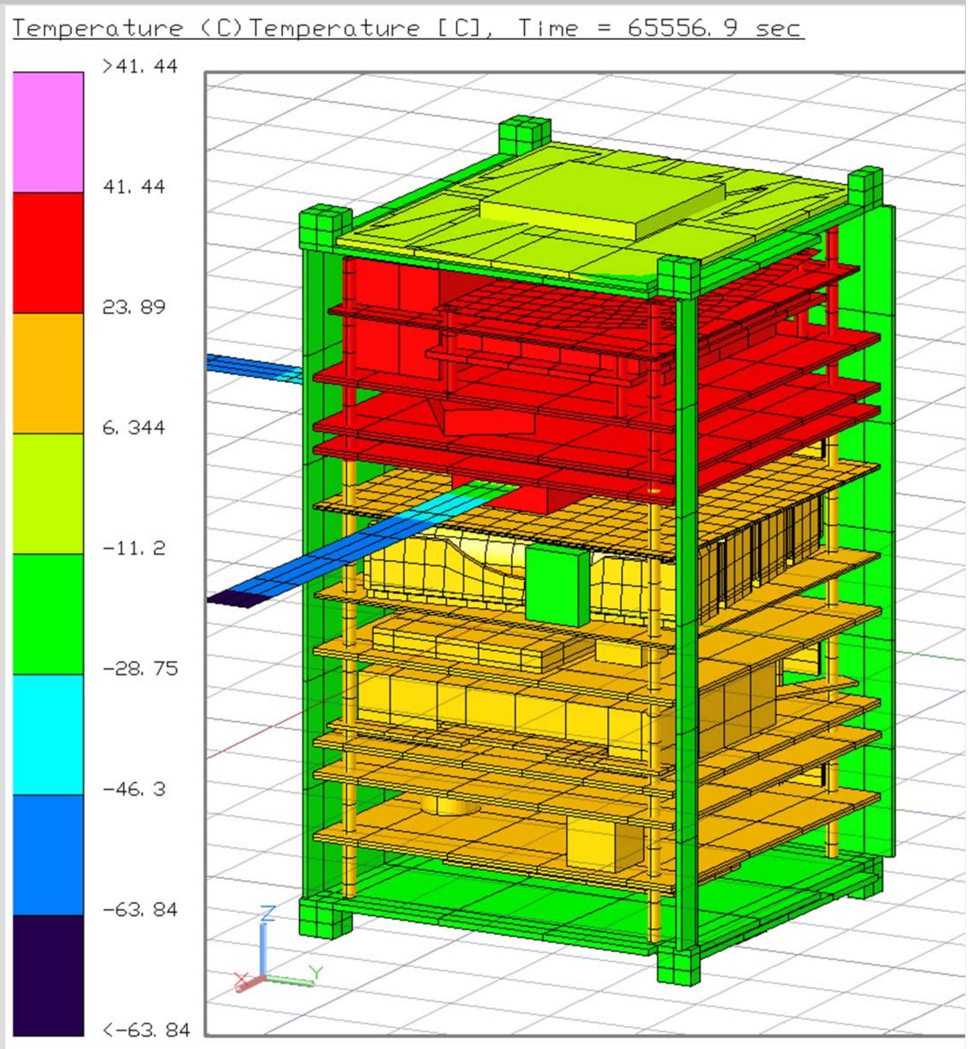
Thermal Issues

- Entirely passive
- Exterior covered in solar cells and magnetorquers
- Duty cycles highly variable
- Thermal analysis needed
  - Nominal not conservative
  - Unknown contacts
  - Uncharacterized materials
  - No subsystem TVAC testing
- Geometrically accurate thermal model constructed from CAD file



Thermal Model (1)

- Imported into and run in Thermal Desktop
- Accurate thermal mass
- Geometries simplified
- Some details (wires, screws, standoffs, etc.) ignored
- Only some thermal and optical properties known
- Only ~2 W of solar power
- Time-dependent heat loads for powered components and batteries (~20 Wh)



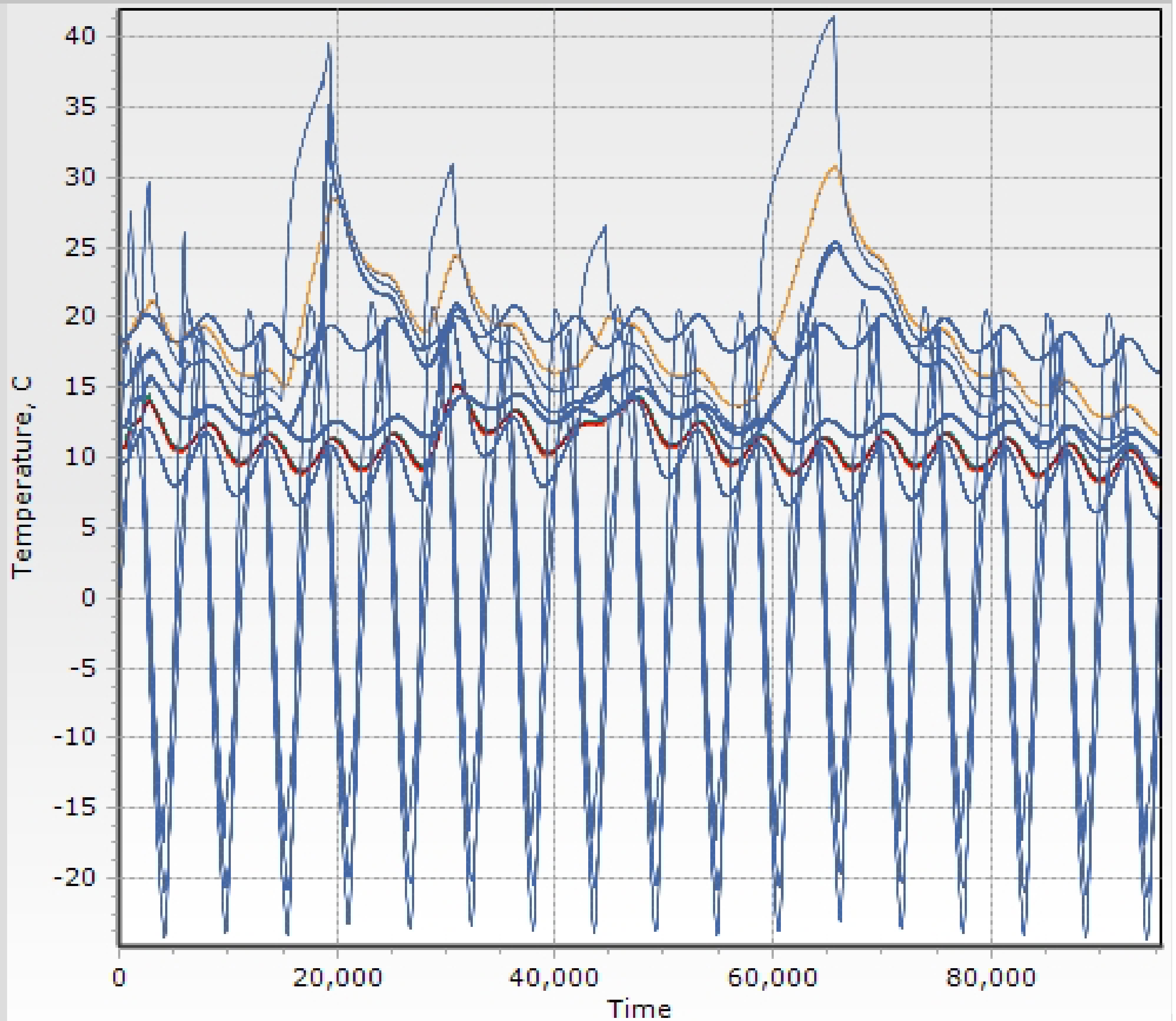
Thermal Model (2)

- Each model ran seventeen 94 minute nominal orbits
  - maximum (30°) and minimum (0°) beta angle
  - Eclipses: 36% to 38% of orbit
- Orbit-averaged albedo (30% and 25%)
- Solar (1414/1322) and earth IR (240/218) maximum and minimum flux values
- Different spacecraft orientations (magnetic field aligned)
  - Stabilized (S-band antenna towards earth)
  - Rapidly spinning in all 3 axes (reduces extremes by ~ +5/-2°C)
- Different heat load duty cycles (many potential combinations during operations due to downlink)

→Determined bounding temperatures for components

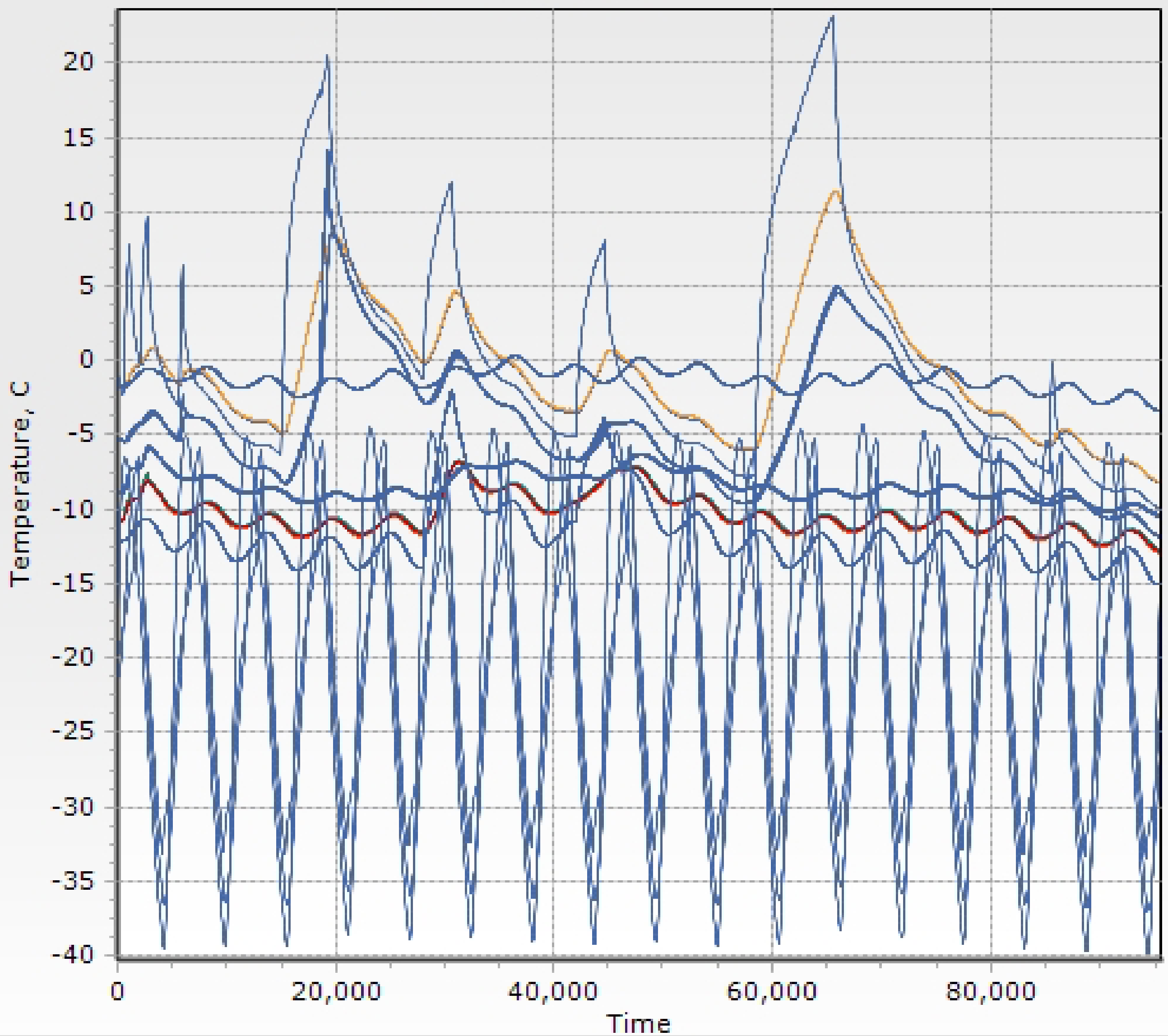
Results (hot case)

- Stabilized orientation
- Maximum orbital environments
- Chassis, MTs, SPs not included in plot
- Patch antennas have ~50°C thermal cycle
- Phone & S-band transceiver reach ~40°C
  - Worse if extended detumble or alignment downlink needed



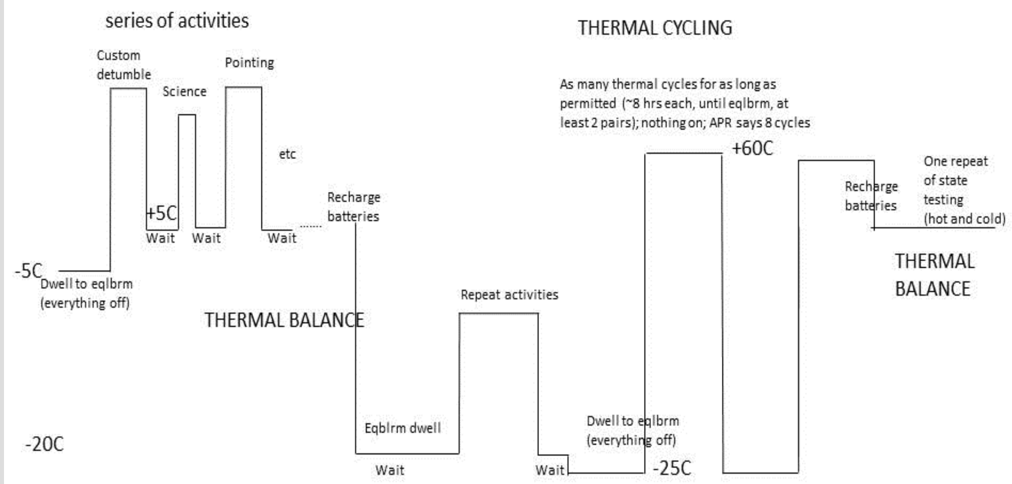
Results (cold case)

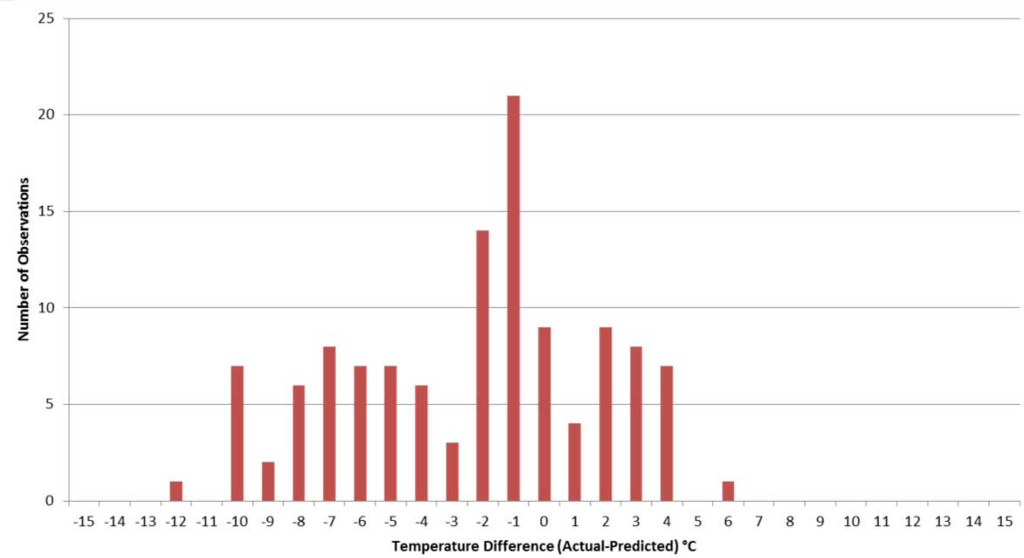
- Stabilized orientation
- No internal components colder than -15°C
  - All cold operation limits < -20°C
  - Except batteries…
- External surfaces get to ~-40°C
  - Potential SP TC cycling issues
- TMs (not shown) have ~120°C thermal cycle



TVAC

- Could not 'test as fly'
  - Limited resources
  - No radio transmissions
  - Simple chamber thermal controls
- Power dissipation determined from TVAC results
  - Total average 4.6W dissipation (>25% drop)
- Nominal 0+/-5°C non-op environment
- TVAC results showed major issue with thermal models: PCB grounding planes
- Chassis cutouts not in model, so tape added





Summary (hot)

- Copper grounding planes:
  - 10x higher conductivity in PCBs so heat carried away
- With ~10°C margin, no overheating issues
- Caveats:
  - Orbit change of beta (not launching at local noon)
  - Substantial conops changes

Summary (cold)

- May have degraded oscillator behavior
- Likely have degraded battery behavior
  - At ~-10°C off nominal cold case, deemed acceptable
- Patch antennas near cold op limit
  - But just not tested to those limits
- TM antennas cycle from -80 to +50 °C
- Otherwise, have ~20°C margin
- Caveats:
  - Extended non-op periods

Conclusions

- Thermal Desktop modeling of the EDSN spacecraft shows no significant thermal concerns
- Some components are 'near' their temperature limits in extreme cases, but the risk is deemed minimal and acceptable
- Loss of battery efficiency due to low (<0C) temperatures deemed acceptable

Lessons Learned for Cubesats

1) Communication is key – always ask for confirmation of even the most obvious thing
2) You never know your orbit until launch since you are the secondary payload
3) Pictures are not as good as seeing the hardware for yourself
4) Thermal imaging though helpful, easy, and cheap, can be very misleading
5) Things – almost *every* thing – will change
6) Inspection of ‘good’ results are minimal while ‘bad’ results result in more work
7) Do not assume others read what you write
8) Nomenclature is important so state terms, do not assume
9) No subsystem testing means uncertainty in inputs before testing of the ‘final’ SC
10) Beware ‘instincts’: One thermal analyst’s ‘meh’ is another’s ‘eep’
11) A limit may not mean a limit, but, rather, ignorance
12) But most importantly…..

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Trust no one