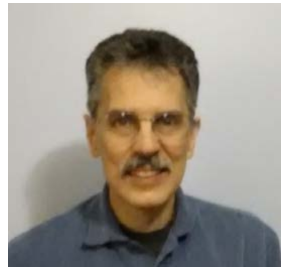
Team Miles: a CubeQuest deep space mission by citizen inventors

Abstract

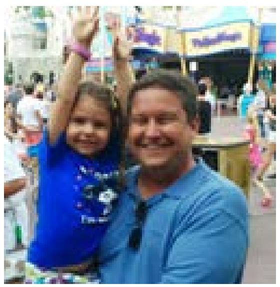
- Team Miles is a team of citizen inventors competing in the NASA CubeQuest Challenge. Our 6U cubesat's trajectory passes near Mars using new Iodine thrusters, reaching nearly 100 million km from Earth. This presents a number of technical challenges for propulsion, navigation, attitude control, thermal management, communications, and autonomy plus more mundane, yet critical, challenges with a distributed team and documentation management as we design to man-rated mission standards. Our solutions are born of the maker movement first and classic aerospace second. The risks and rewards of this team structure will be highlighted as we discuss the latest mission design and its evolution, including feedback from NASA and our responses. We share these lessons hoping for collaboration and to accelerate the pace of other daring projects.

Team Members (GT4, partial)





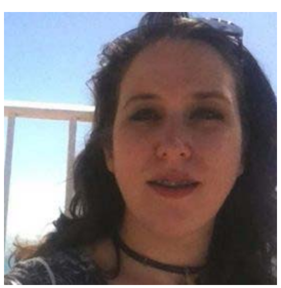

Wes Faler
Bill Shaw
Don Smith
Frank Fomby




Alex Wingeier
Sydnie Nugent Pierce
Jarrod "J" Kent
Seth Dennis

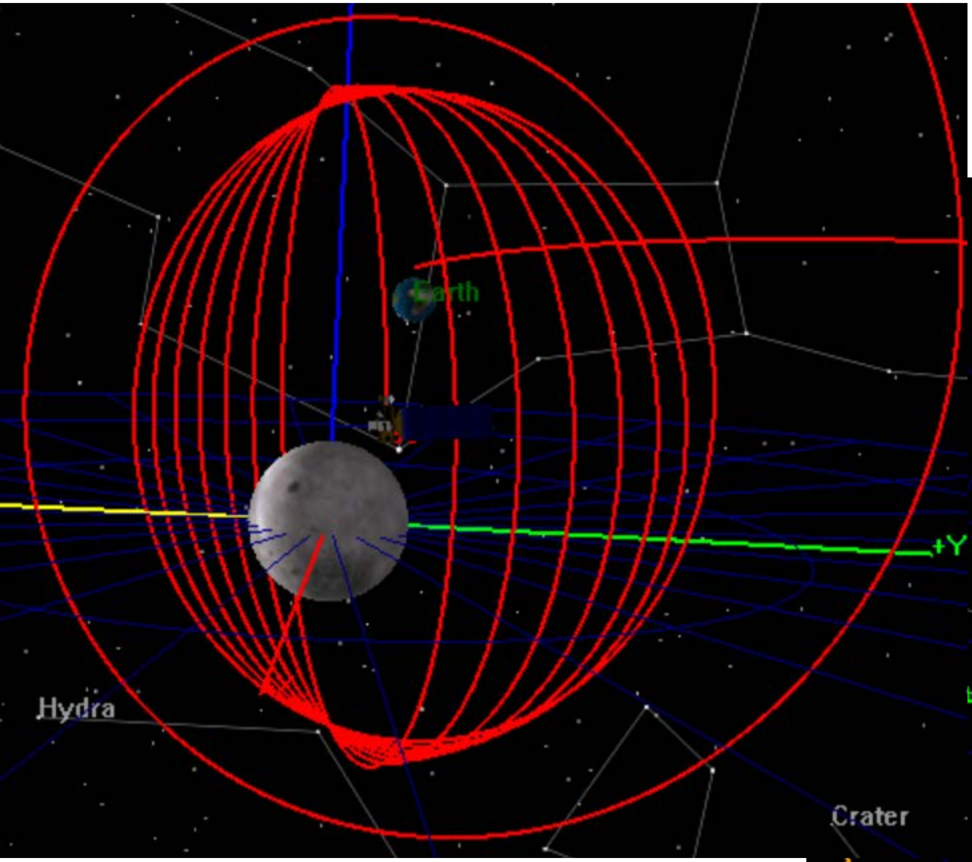



Charles Bucher
Humna Khan
Tim DeBenedictus
Jan McKenna



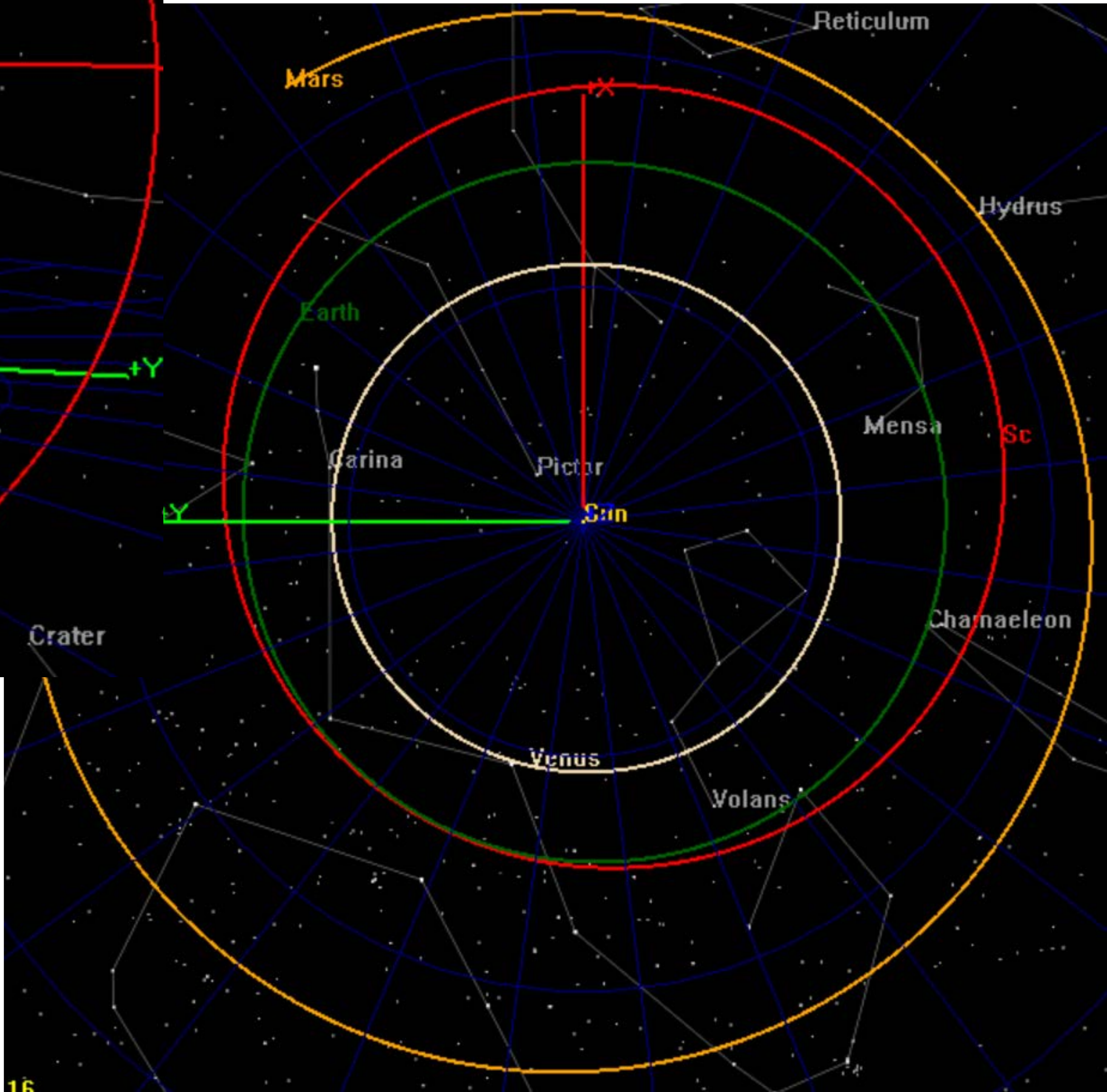

Heather Bradford
Tracy Ingram
George Papabeis
Denise Oates

GT1 – Vision of Lunar Orbit

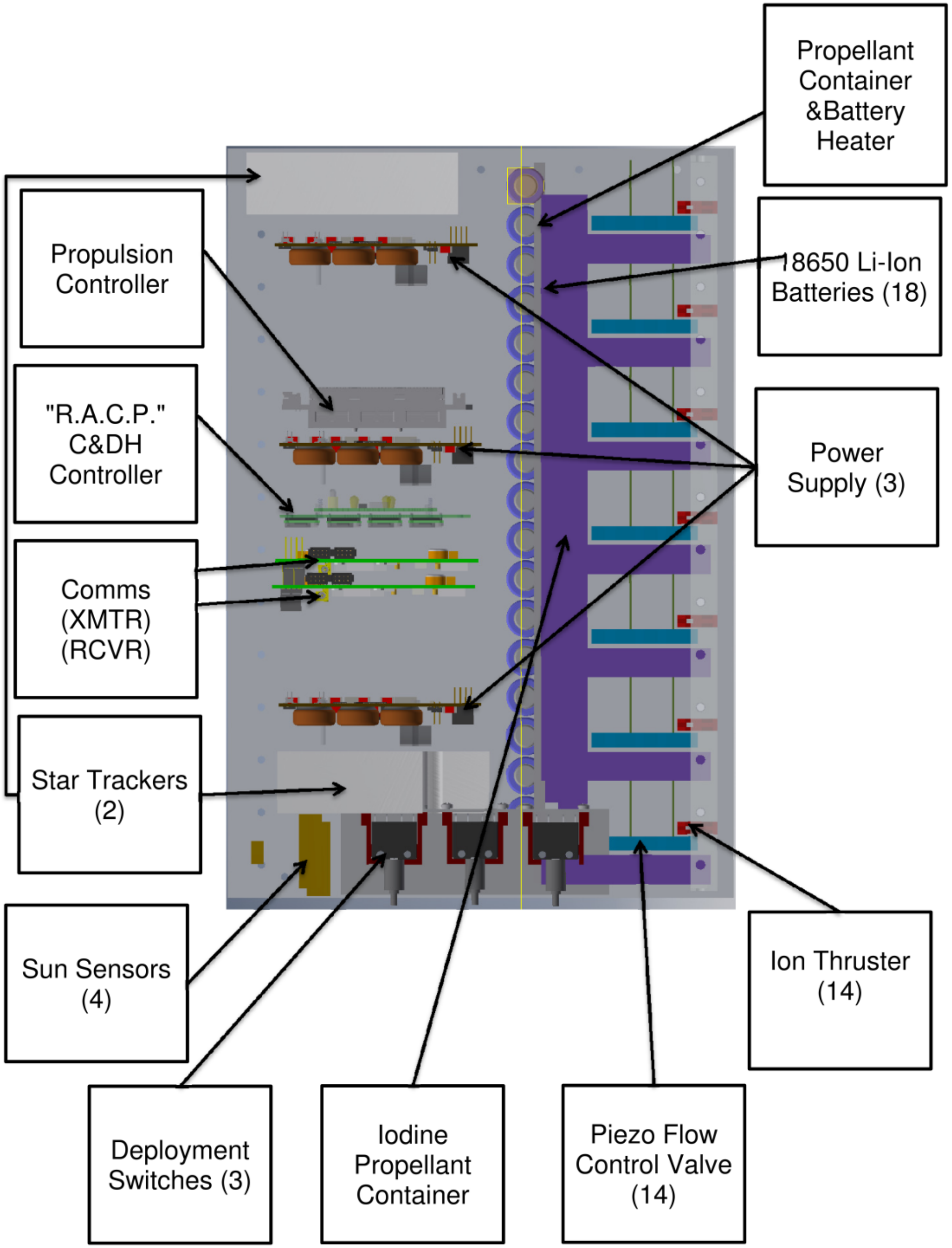


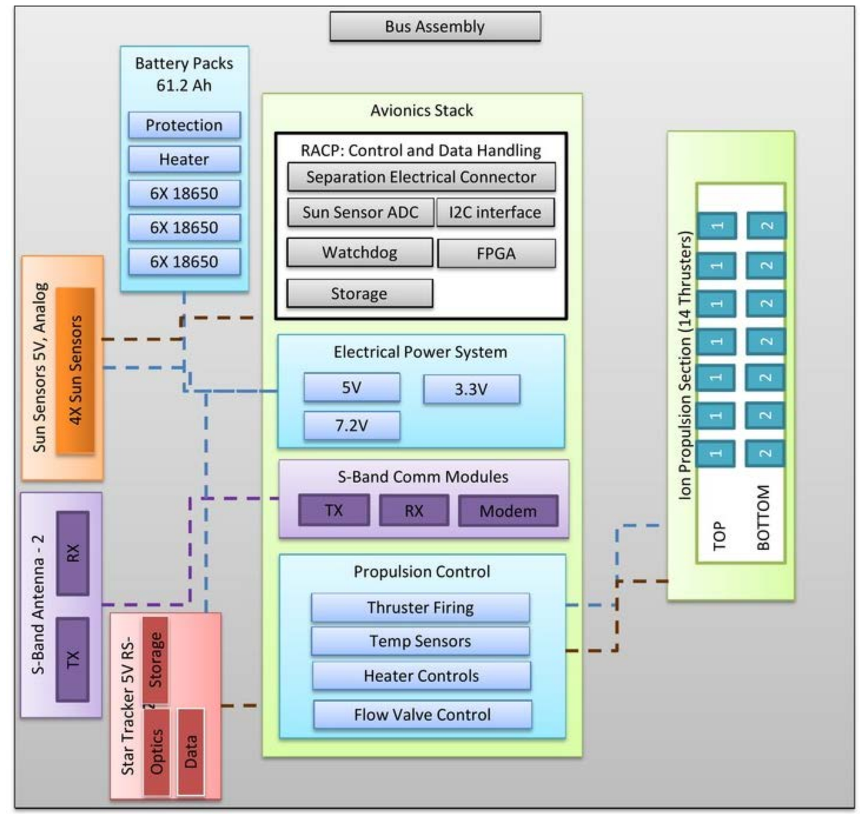
Elliptical polar lunar orbit

Disposal in storage orbit between Earth and Mars



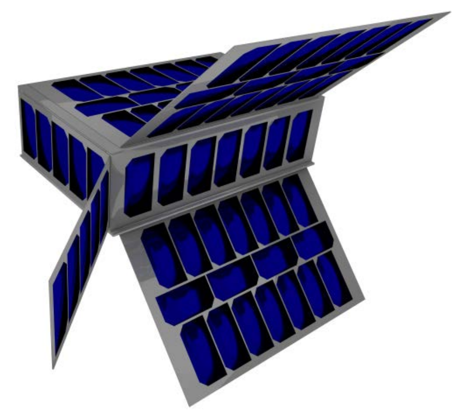
GT1 – Hardware Decisions





8.3 kg Dry Mass
11.3 kg Total Mass
2.7 kg Remaining

7,546 cm^3 Used
2,601 cm^3 Remaining



GT1 – Why?

Strategy: The lunar orbit judging criteria is used repeatedly in scoring, making it the most critical component of the Lunar Derby. Thus, we focus on successful lunar orbit first.

Communication
- **Use proven NASA link-budget for LADEE mission with DSN**
  - **Increased spacecraft transmitter power to assure tracking success**
- **Eliminate C&C uplink need through significant autonomy**
  - **Improve autonomous accuracy with redundant sensors and fusion algorithm**
  - **Robust autonomy through continuous simulation with an evolving attacker**
- **Reduce cost by using only the free tracking services provided by DSN for CubeQuest**
- **Polar lunar orbit with great views of the earth – frequent communication opportunities**

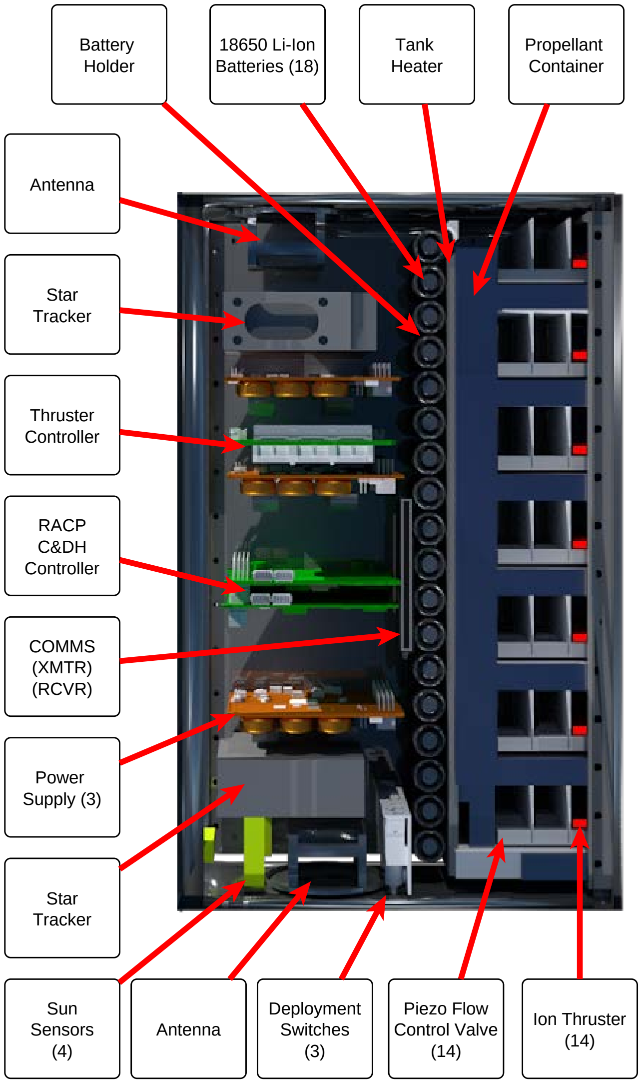
Radiation resistance
- **1.5mm solid skin Aluminum with 3mm total shielding on electronics**
  - **Not a skeletonized design commonly used for CubeSats**
- **Large radiation margin on COTS components**
- **Redundant computing resources and health monitoring**
- **Radiation tolerant CPUs proven in space**
- **Redundant power supply circuits – solar/battery, propulsion high voltage**
- **“Rolling-blackout” policy to reset electronics frequently – from $50Sat’s unshielded CPU**

Trajectory planning – GMAT’s solver cannot find our trajectory
- **750,000 trajectories considered so far**
- **Goal-centric algorithm (max comm. opportunities, min propellant consumption, stable orbit) finds novel trajectories with minimum human supervision**

GT2 – Still Lunar, with Changes

- **Spacecraft charging considerations**
  - **Added Faraday cage**
  - **Added grounding separation circuit**
- **Increase power margin for GT2 points**
  - **Reduced radio power usage while operating thrusters**
- **Increase mass margin for GT2 points, reduce prototyping cost**
  - **Changed from Teflon propellant tank to Nickel**
- **Increase radiation tolerance, lower development effort**
  - **Eliminated microprocessor from the thruster control board**
- **Lower development effort, pass safety review easier**
  - **Using COTS valves for propellant release safety**
- **Address GT1 judge's feedback**
  - **Added second antenna, clarified mounting locations**
  - **Using for-hire worldwide ground network for S-band transmissions**
- **Increase software reliability through simulation**
  - **Added high performance computing resources to ground system**

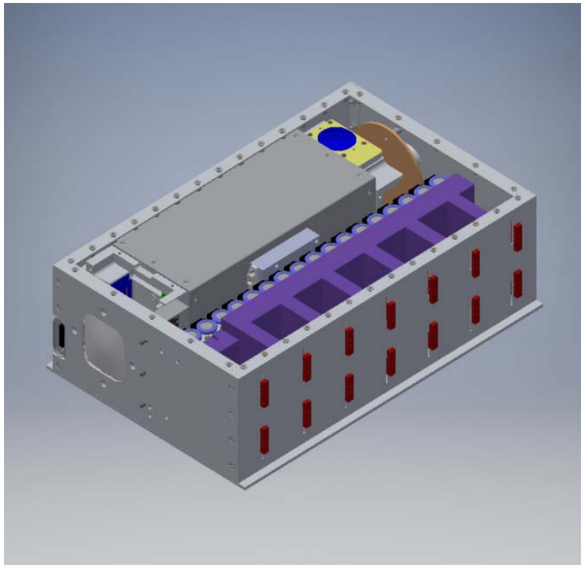
GT2 – Elaborating



- **Accomplished: TID radiation testing of COTS components and critical circuits**
- **Accomplished: thruster validated at 10^-6 Torr on inverted pendulum, commercial orders**
- **Setback: Venture-based funding plan did not occur due to internal management issues**
- **Setback: Flight software delayed due to transfer of vision ownership**

Thruster testing

Faraday Cage for radiation and EMI



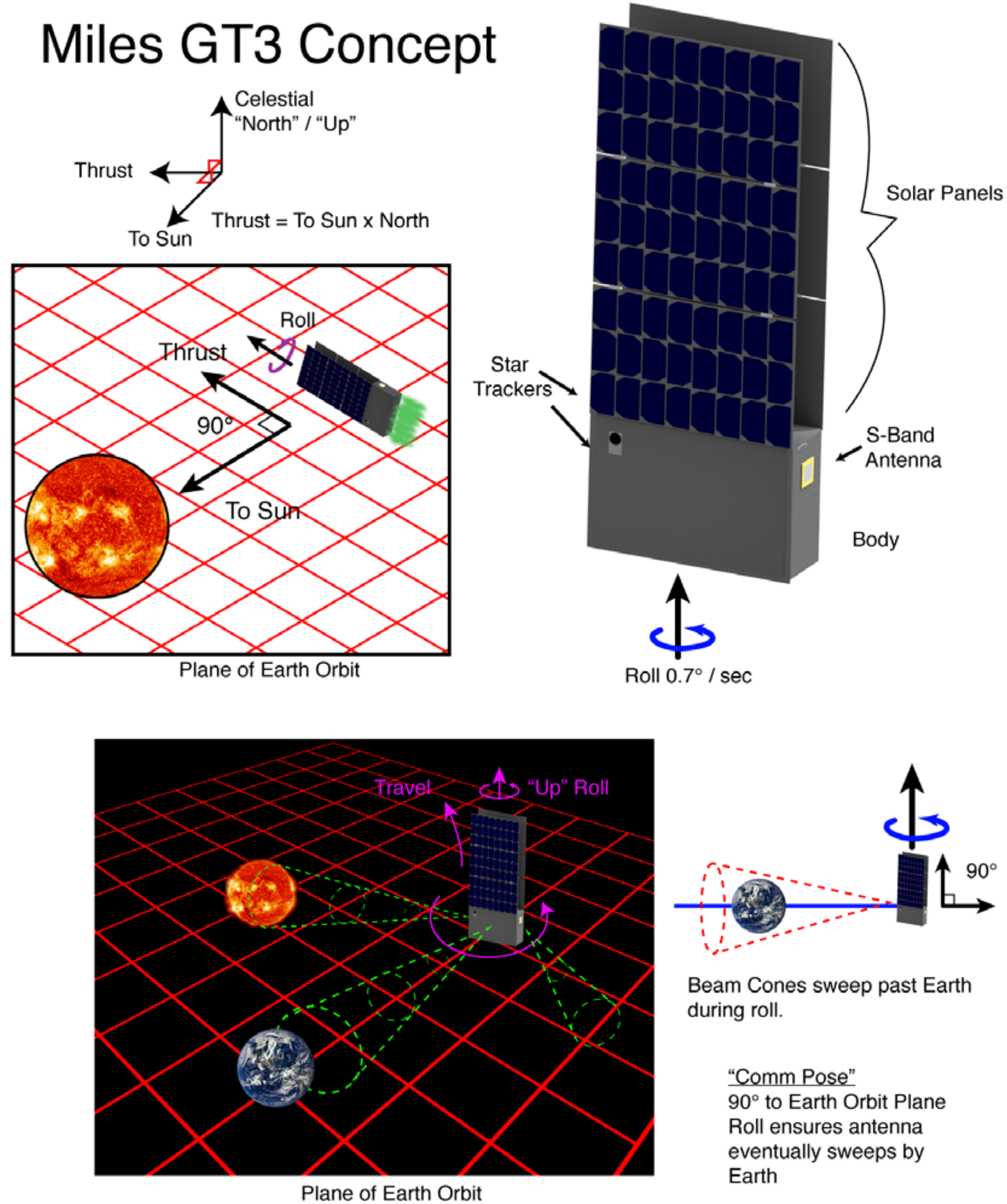
GT2 – The Feedback

Strengths:
• Overall, a good overview of the design with detailed mission steps and goals.
• Good use of detailed program schedule and associated tasks to manage program and fully understand effort needed.
• Provided detailed plan for milestone completion up to Ground Tournament #4 and beyond.
• Provided an extensive verification plan.
• Provided a complete Safety Data Package with hazards identified.

Weaknesses:
• Did not provide adequate substantiation of the autonomous software architecture and design in order to fully understand if it is sufficient to support the mission requirements. As a result, this high level of autonomy is seen as a risk to overall mission success.

GT3 – Pivot to Deep Space

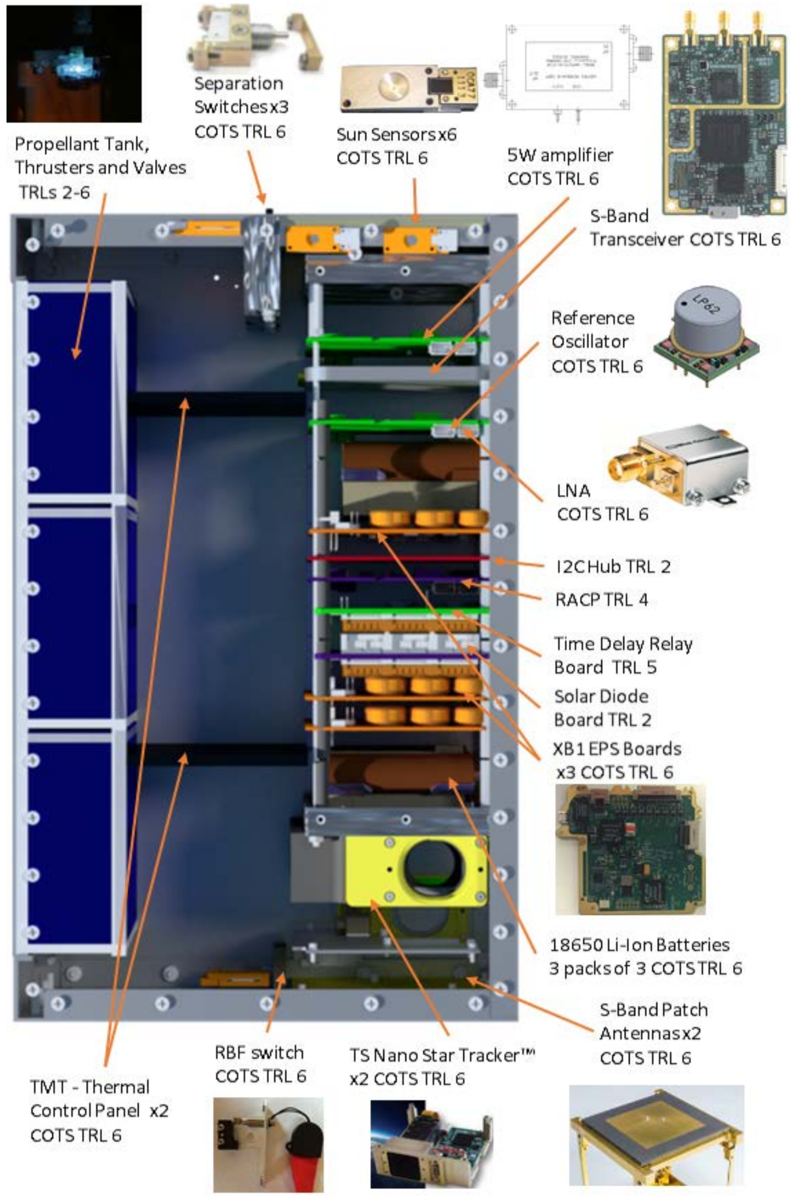
- Drastic software simplification.
  - Primary design driver!
  - Removed modules.
  - Open source comm software.
- Deep Space instead of Lunar Orbit.
- Added thermal challenges.
- Simple burn plan.
- Simplified antenna pointing.
- More COTS parts, fewer invented.
  - EPS
  - Batteries
- Mission success even with large attitude control error.



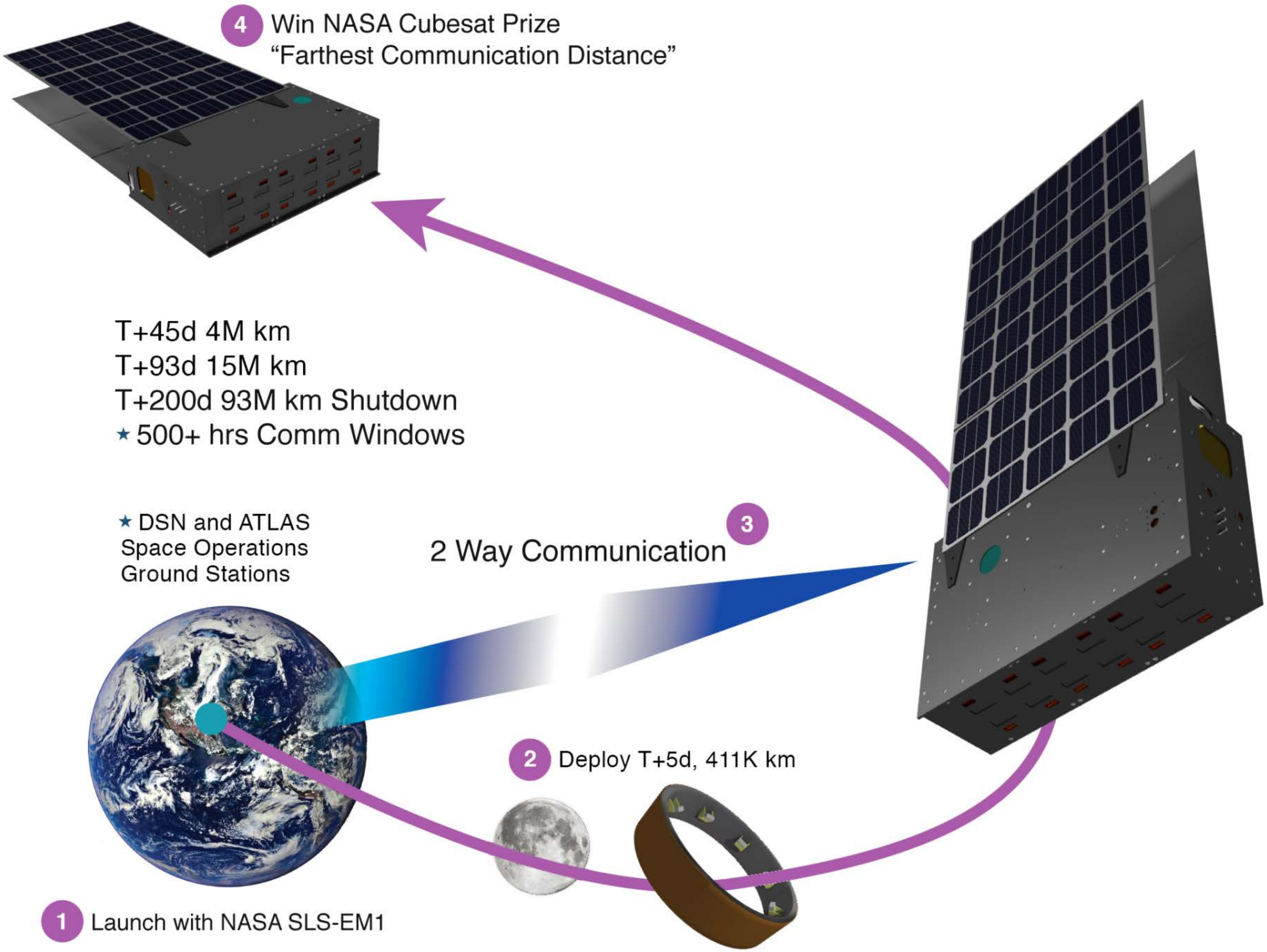
GT3 – Margin for Nav Error

Scenario	4.5M km Days	8.6M km Days	46M km Days	200-day Earth Dist. (km)	200-day Sun Dist. (km)
Baseline	51.3	74	149.6	9.233E+07	1.942E+08
No orbit change	60.4	89.8	203.4	4.368E+07	1.657E+08
45 deg sunward	61.4	95.6	182.7	5.714E+07	1.802E+08
45 deg antisunward	44.2	64.5	138.4	9.953E+07	1.916E+08
Burn Early by 2d	46.8	70.3	147.3	9.349E+07	1.944E+08
Burn Early by 1d	47.2	70.8	147.7	9.304E+07	1.944E+08
Burn Delayed by 1d	48.3	72.0	149.2	9.150E+07	1.940E+08
Burn Delayed by 10d	53.1	77.8	155.8	8.412E+07	1.920E+08
Burn Truncated to 30 days	47.9	73.7	158.4	7.416E+07	1.806E+08

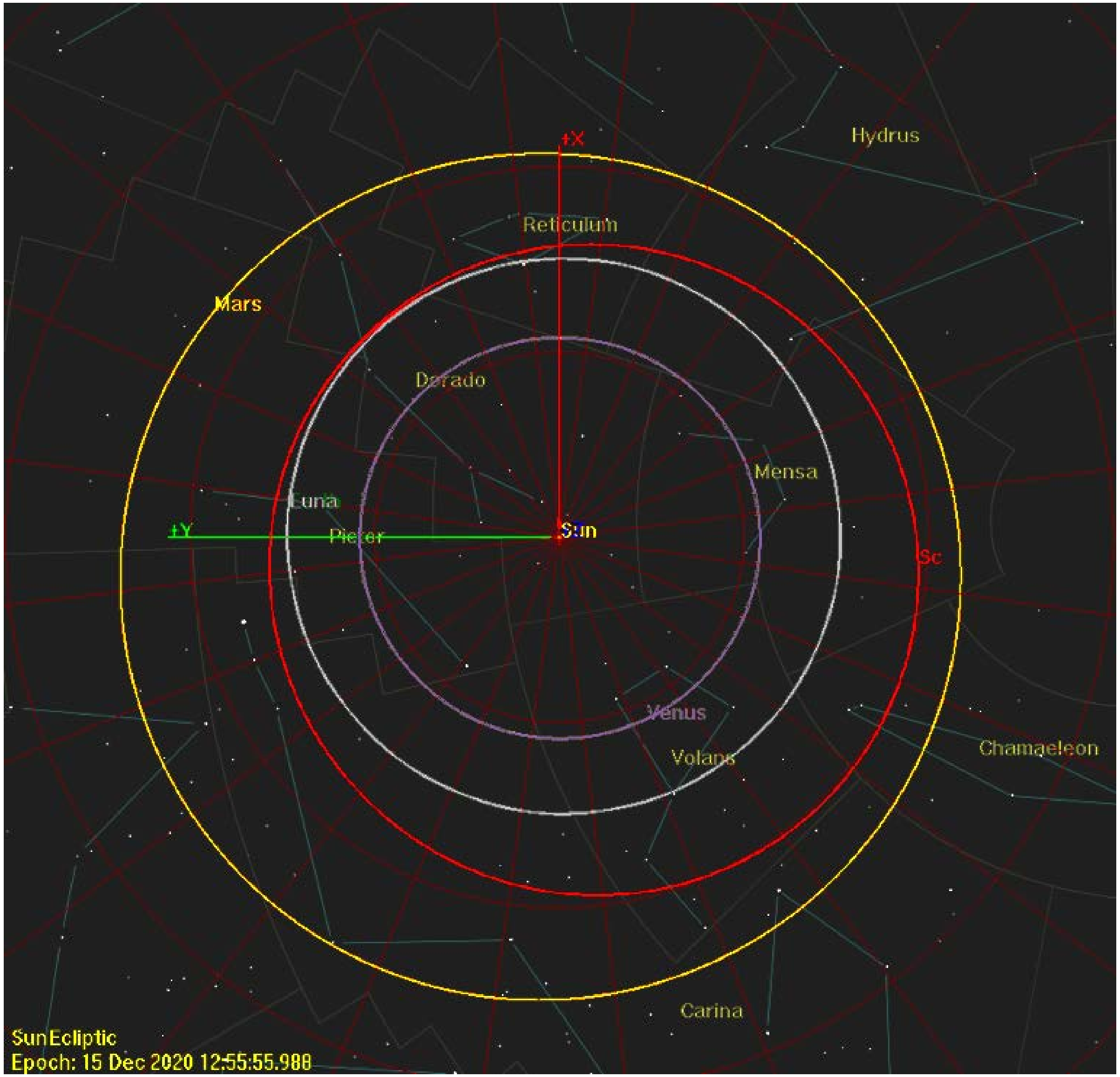
GT3 – Room to Spare



GT4 – Conops


4 Win NASA Cubesat Prize
"Farthest Communication Distance"
T+45d 4M km
T+93d 15M km
T+200d 93M km Shutdown
★ 500+ hrs Comm Windows
★ DSN and ATLAS
Space Operations
Ground Stations
2 Way Communication 3
2 Deploy T+5d, 411K km
1 Launch with NASA SLS-EM1

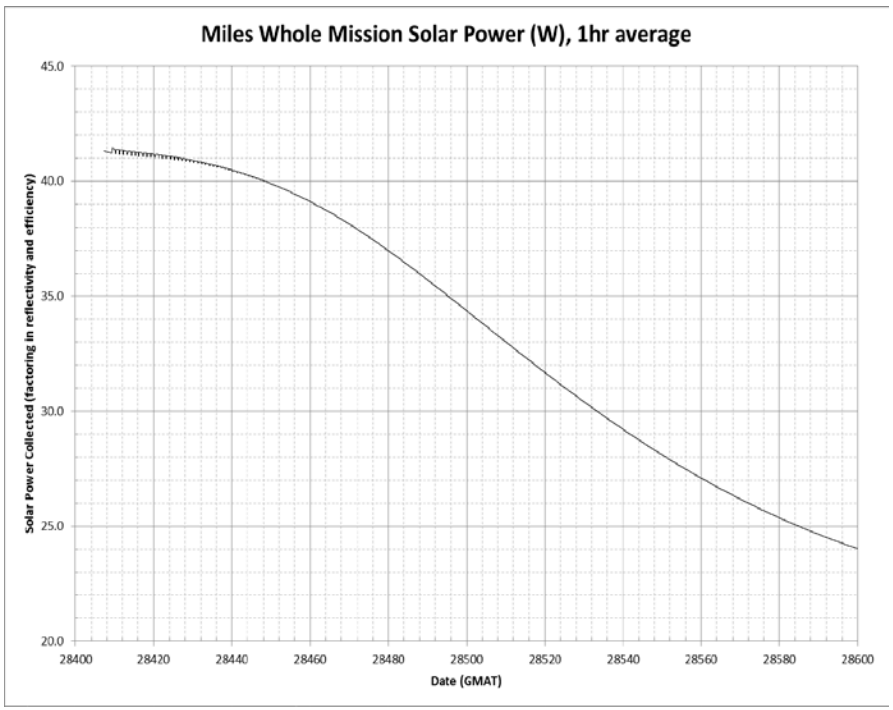
GT4 – Orbit

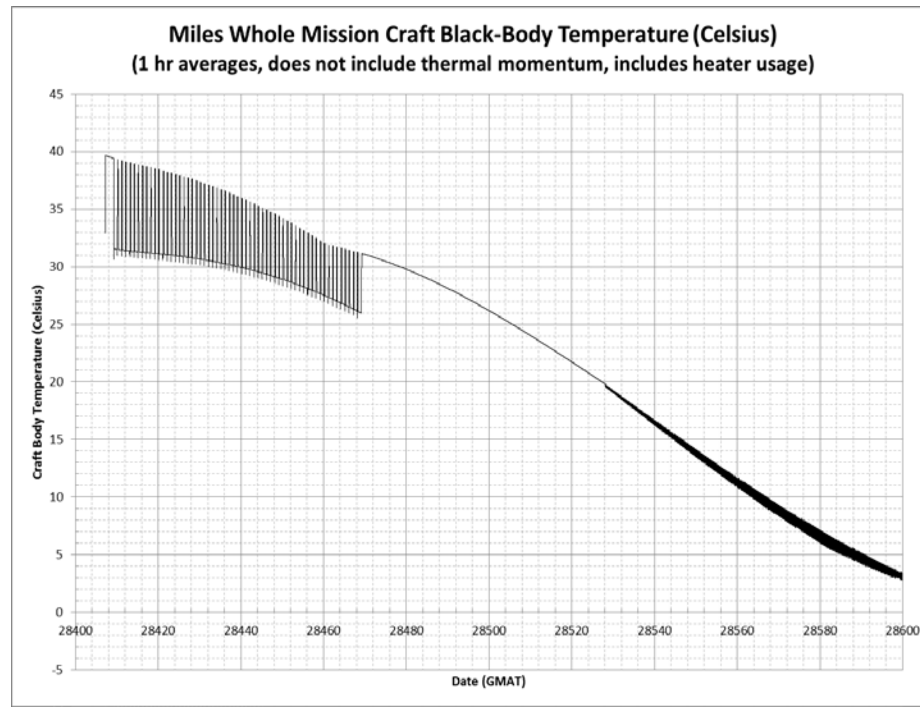


+X
Hydrus
Reticulum
Mars
Dorado
Mensa
Luna
+Y
Pieter
Sun
Sc
Venus
Volans
Chamaeleon
Carina
SunEcliptic
Epoch: 15 Dec 2020 12:55:55.988

GT4 – Power & Thermal

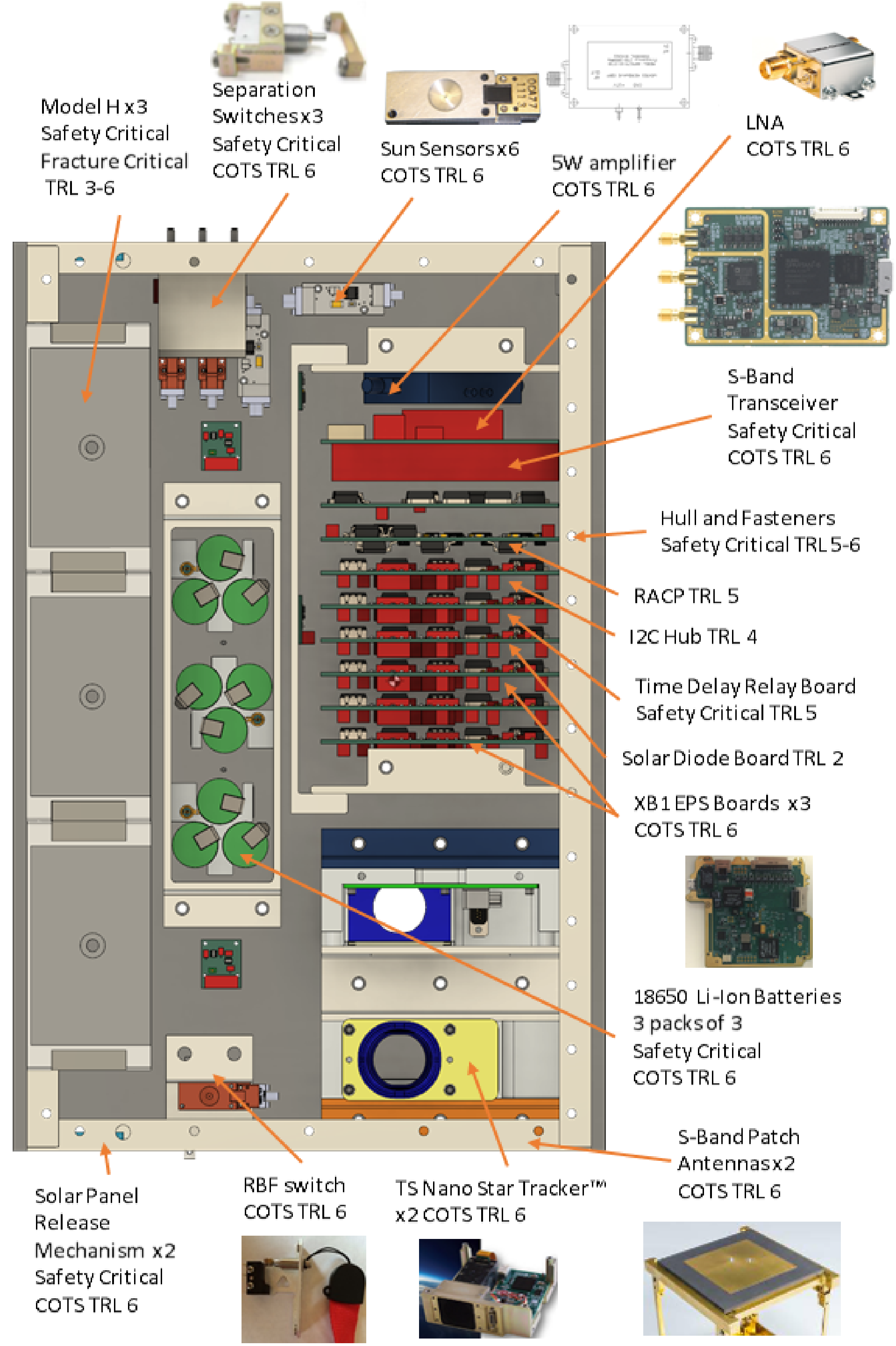
The dips in temperature on the craft black body chart are due to the thruster being used for the first portion of the burn plan. Energy leaves the craft as kinetic energy in the exhaust rather than being retained as thermal energy. Towards the end of the mission, the battery recharge cycles extend with diminishing solar power. Heaters are used briefly at the beginning of the mission while the batteries are charging, then more extensively near mission end.



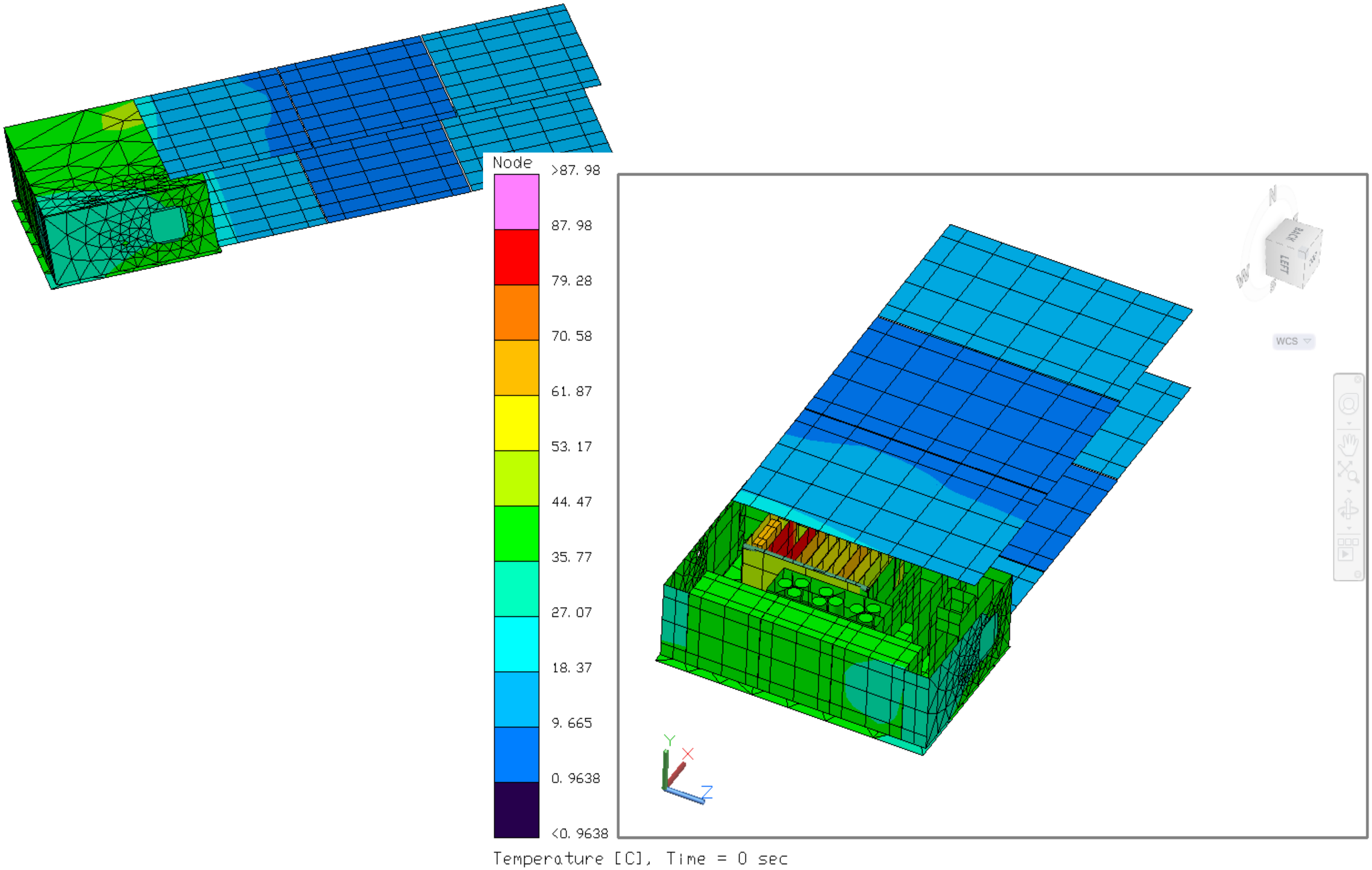


GT4 – Refinements

- Batteries moved
  - Safety mandate
  - Attitude control benefit
- Thermal management of RF parts
- Streamline thruster controls
  - Removed I/O burden on CPU
  - Tested new control circuits
- Reducing manufacturing costs

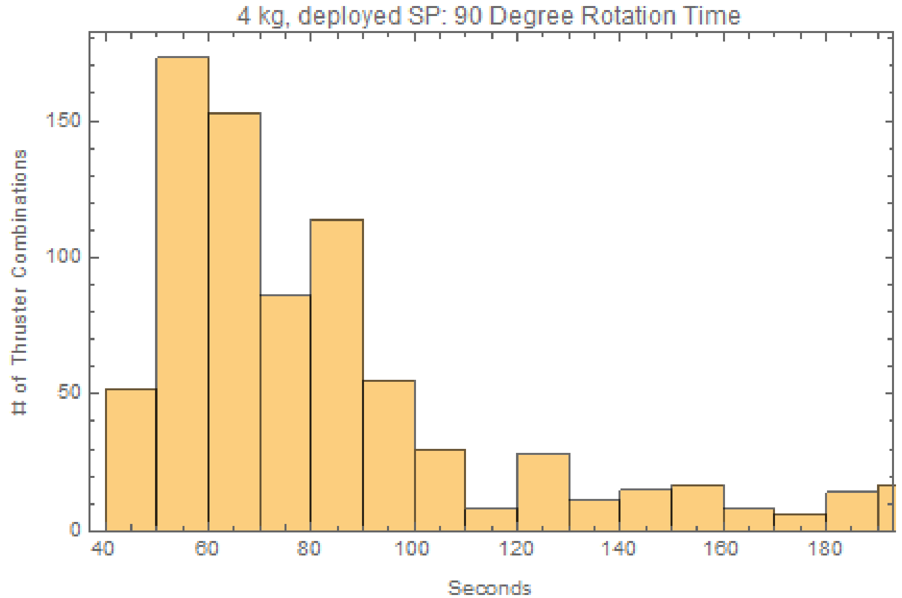


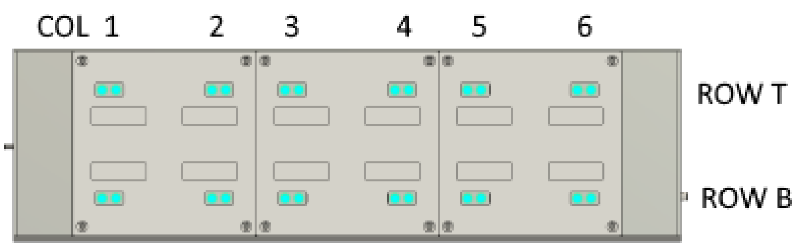
GT4 –Thermal


Node
>87. 98
87. 98
79. 28
70. 58
61. 87
53. 17
44. 47
35. 77
27. 07
18. 37
9. 665
0. 9638
<0. 9638
Temperature [C], Time = 0 sec
WCS
Y
X
Z

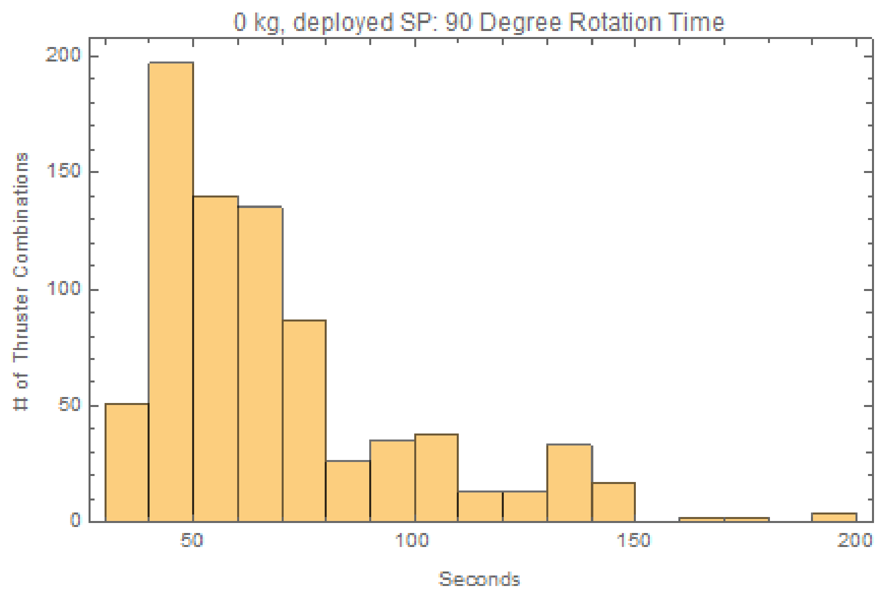
GT4 – Attitude Control

For the initial mission configuration of 4 kg of propellant and deployed solar panels, there are hundreds of thruster combinations that accomplish a 90 degree rotation within 100 seconds:





After consuming all propellant with the moving center of mass, the situation changes, causing most combinations to complete within 100 seconds:



Thank you from Team Miles!

"Promises to keep, miles to go."

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