NEA Scout Thermal Control

ICES Paper 2019-94

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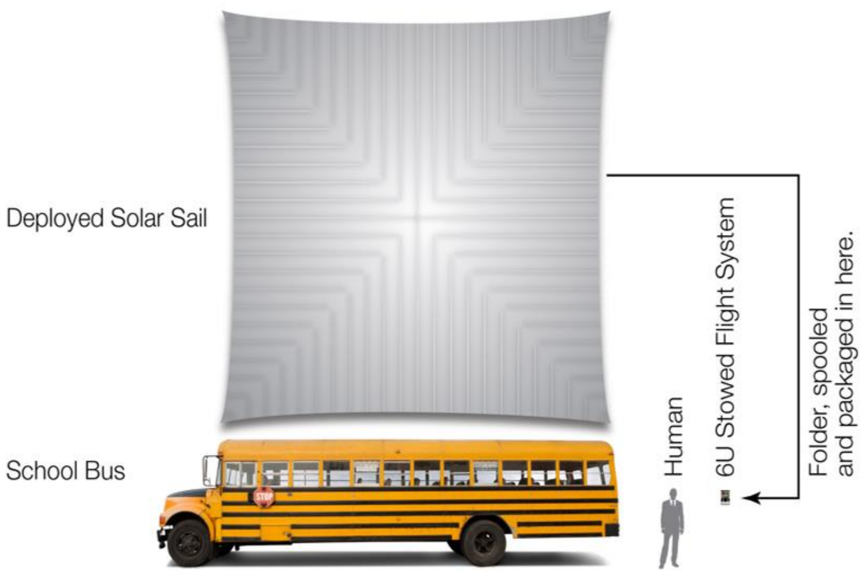
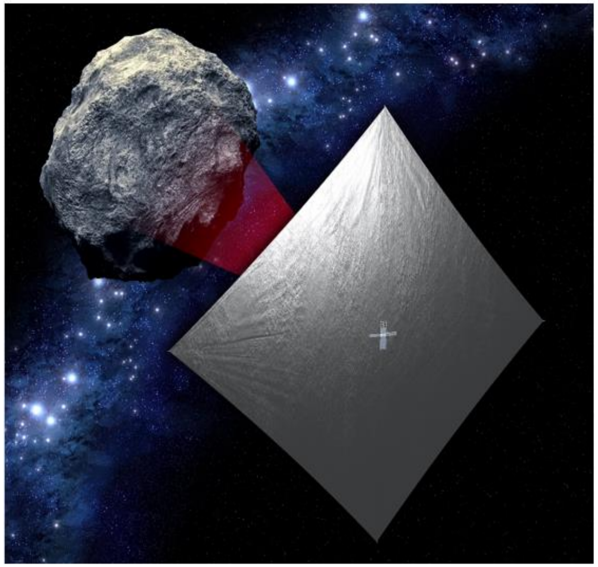
NEA Scout Overview

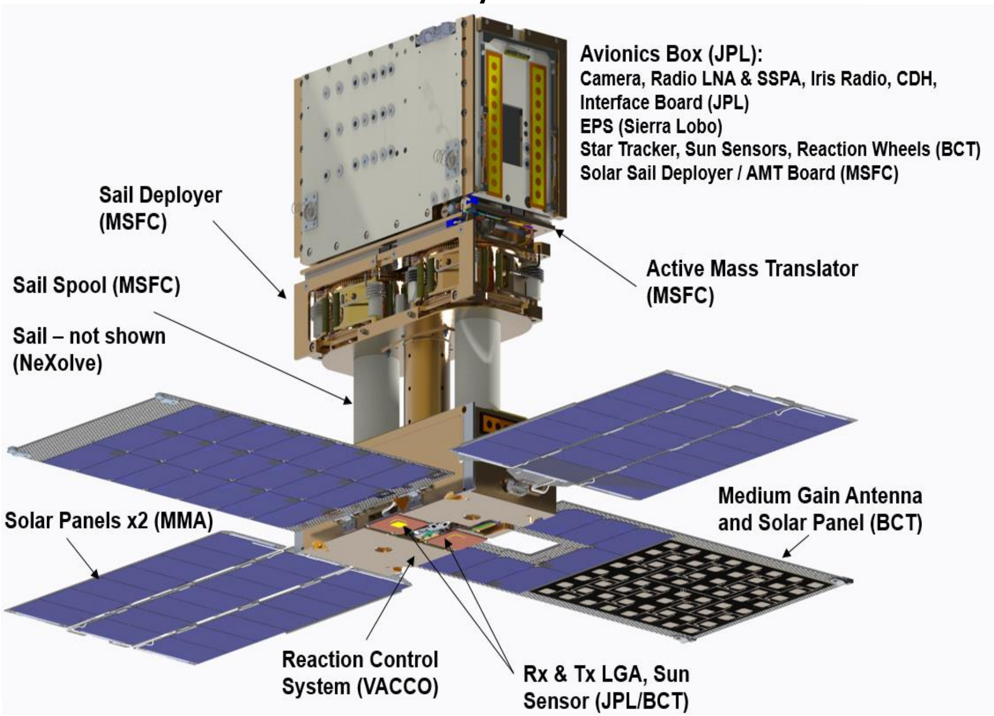
- 6U CubeSat
- Secondary payload on SLS EM-1
- Utilizes aluminized polyimide solar sail for main propulsion element
- Navigate to a Near Earth Asteroid and photograph using onboard camera
- Mission life expected to be 2.5 years





NEA Scout Team

- Jet Propulsion Laboratory (JPL) – Avionics
- Marshall Space Flight Center (MSFC) – AMT, Sail Deployer, Spacecraft Integration
- VACCO – Reaction Control System
- Blue Canyon Technologies (BCT) – Attitude control systems, 2x3U solar panels
- Mountain Man Aerospace (MMA) – 1x3U HaWK solar arrays
- NeXolve – Solar sail

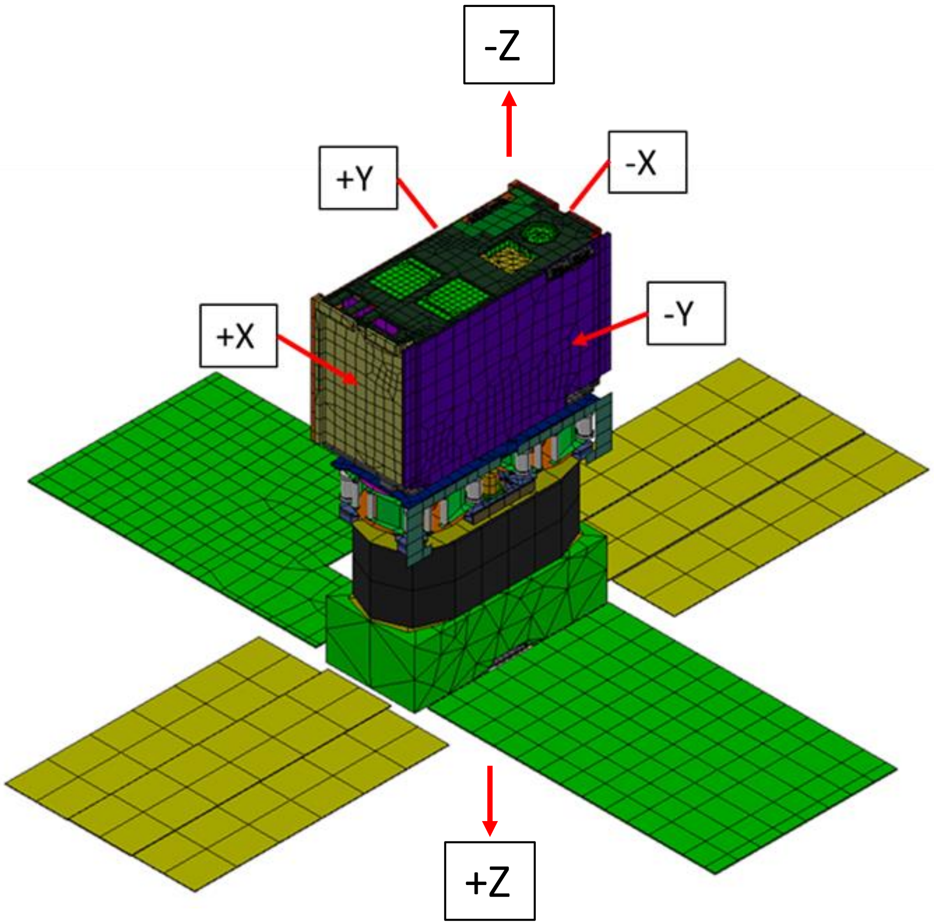


Mission Timeline

	Notes	Approximate Heat Loads	Sail Position	Solar Array's Angle to Sun
Post MSA Deployment	Deploy solar arrays, use RCS to detumble and orient spacecraft to sun facing. Allow batteries to recharge.	30W in RCS, 20W in avionics	Stowed	Unknown at first, then sun facing (0°)
Thrust Control Maneuver (TCM)	Use RCS to preform thrust control maneuver to get CubeSat on proper trajectory	30W in RCS, 40W in avionics	Stowed	Unknown
Sail Deploy	Deploy sail, while communicating with Earth	50W in avionics, 5W in sail mechanism	Deploying	0° to the Sun
Cruise	Spacecraft will spend most of life in this state	20W in avionics	Deployed	50° to the Sun (+/- 5°)
Comm	Communicating with Earth	45W in avionics	Deployed	70° to the Sun
Battery Recharge / Safe	Battery recharge if depleted and safe mode	20W in avionics	Deployed	0° to the Sun
Science	Camera operations while communicating with Earth	45W in avionics	Deployed	Assuming 50° to the Sun

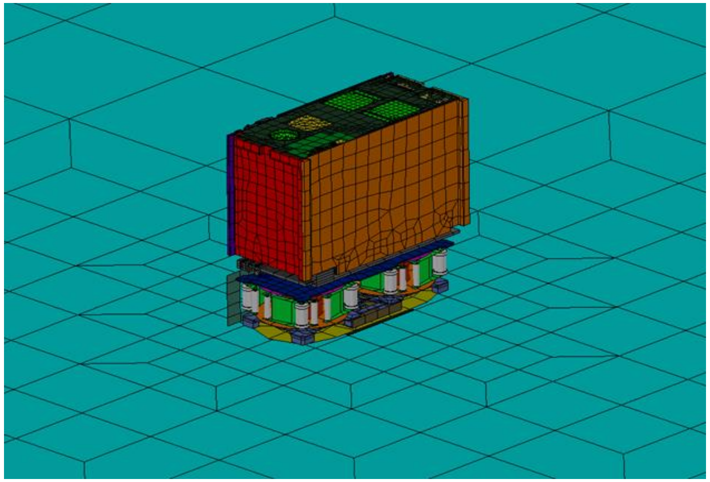
- Deployed from MSA at bus stop 1, approx. 4 hours after launch
- TCM will occur within the first 12 hours of deployment
- Comm is largest power draw on avionics
- 90% of mission life will be spent in Cruise and Comm

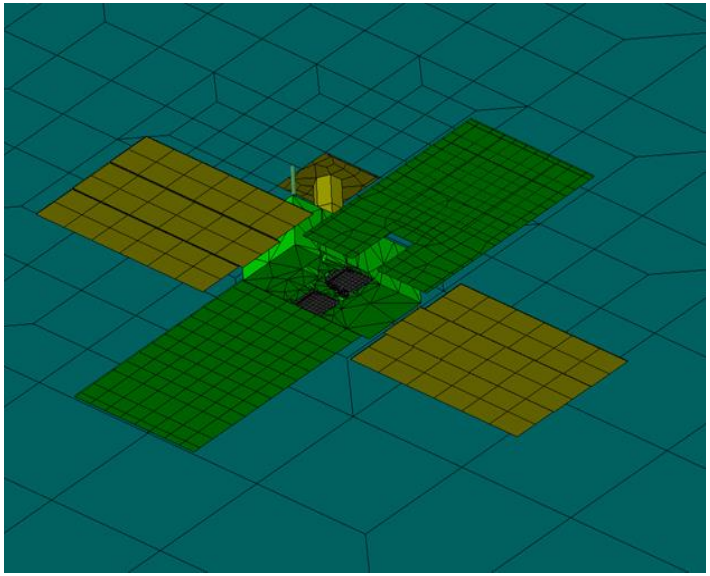
Thermal Model



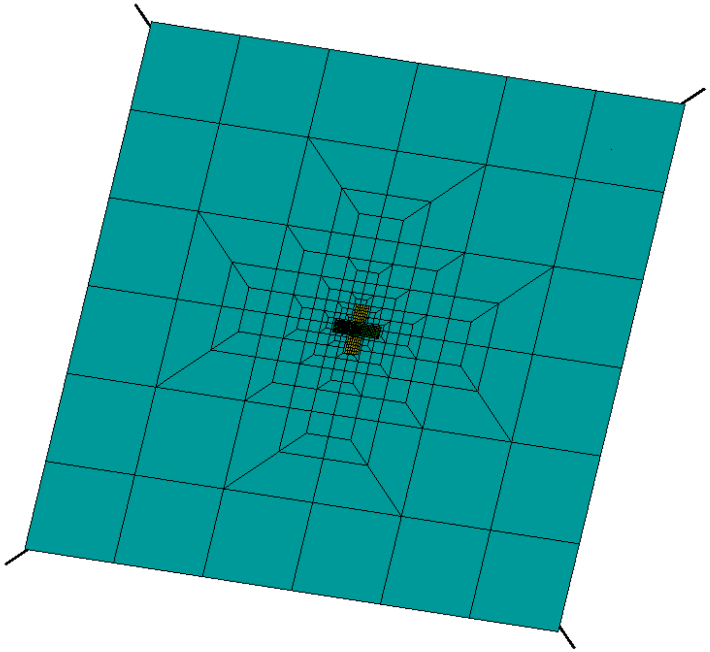
- Thermal Desktop was used and model was created from Thermal Desktop natives and finite element meshes from FEMAP
- Modeled in sail stowed and deployed configurations

Thermal Model



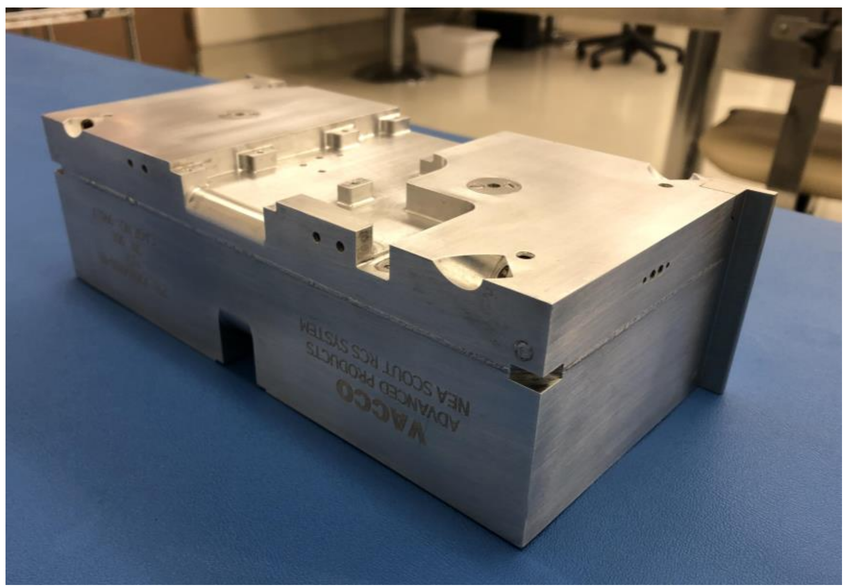


- Two different spacecraft environments due to the solar sail. Half the spacecraft is shaded and half is sun facing for the majority of the mission.



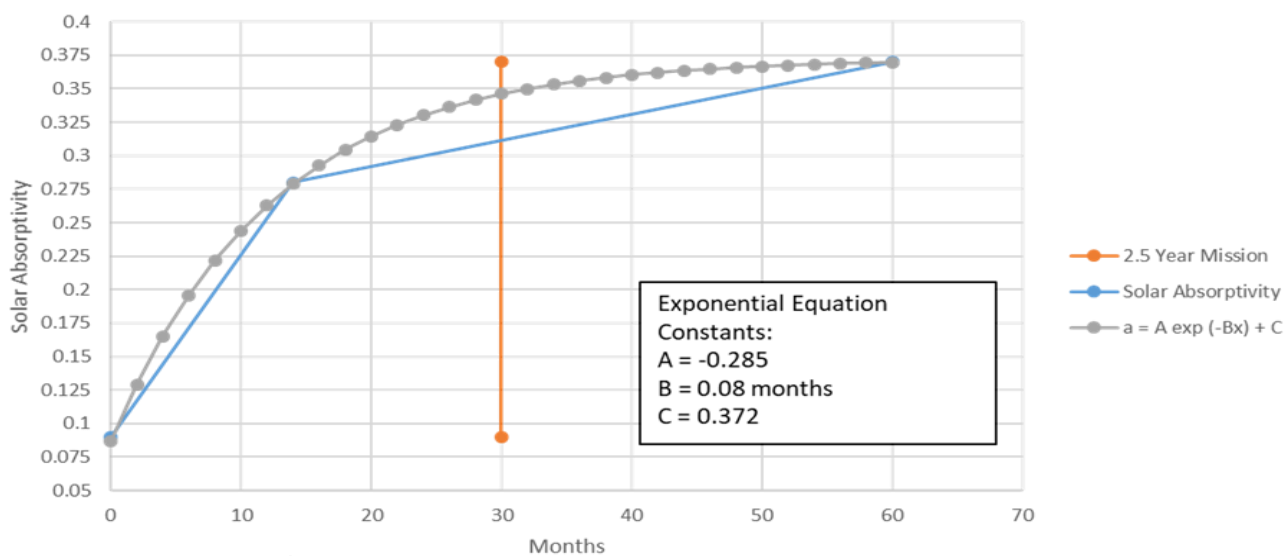
Thermal Challenges

- Deviations in as built configurations from the thermal design
  - Reaction Control System (RCS)
  - Medium Gain Antenna (MGA)
- Active Mass Translator motor operational capabilities
  - In recent TVAC tests, motors have been overheating and failing



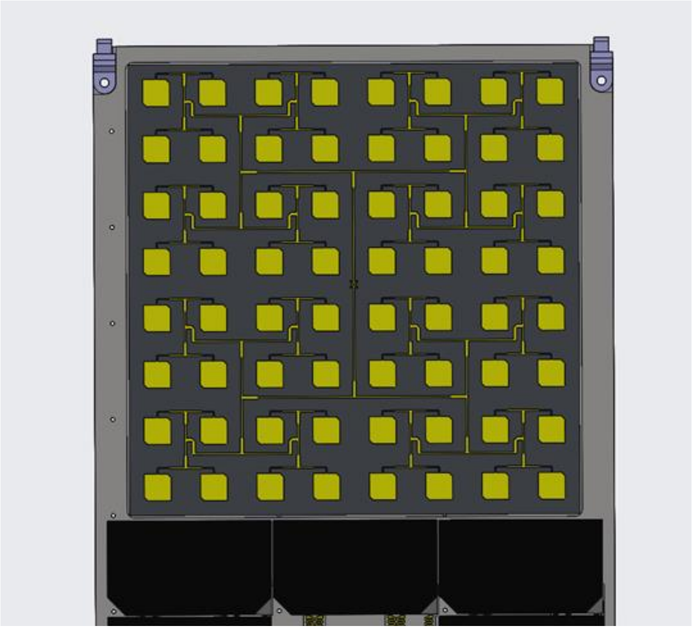
RCS Thermal Control

- Reaction Control System (RCS) has an alodine aluminum finish
    - As built optical properties varied from the assumed properties in the thermal model
    - Increased α/ε by a factor of 2
    - RCS was exceeding the maximum allowable flight temperature limit during cruise
- Silver Teflon tape will be used to improve optical properties of RCS surface
    - Concerned about potential for surface charging risk at deployment, looked at using ITO coated tape
    - Tape UV degradation throughout mission life and ITO has large difference between end of life and beginning of life - α/ε increases by a factor of 4
    - Chose to use non-ITO tape for better thermal performance and accept surface charging risk



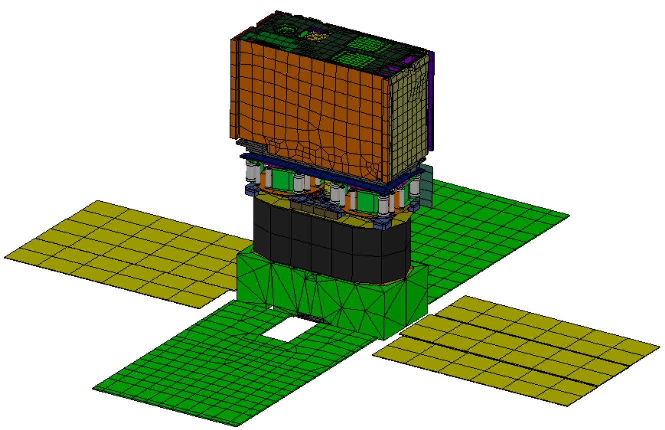
MGA Optical Properties

- Medium Gain Antenna (MGA) is mounted on the sun facing side of the BCT solar arrays
- During comm operations the MGA mounted solar array was exceeding the minimum allowable flight temperature limit
- MGA is roughly 55% of the surface area on the solar panel
- It was assumed to be Kapton, low α and high ε
- As built does not have kapton on the antenna due to performance improvements on the RF radiating surfaces
- New properties derived from material composition
    - Can be verified through measurement at a later date
- Increased α/ε from 0.136 to 0.636
    - Raised solar array temp to within allowable flight limits



Comm Pre-Sail Steady State

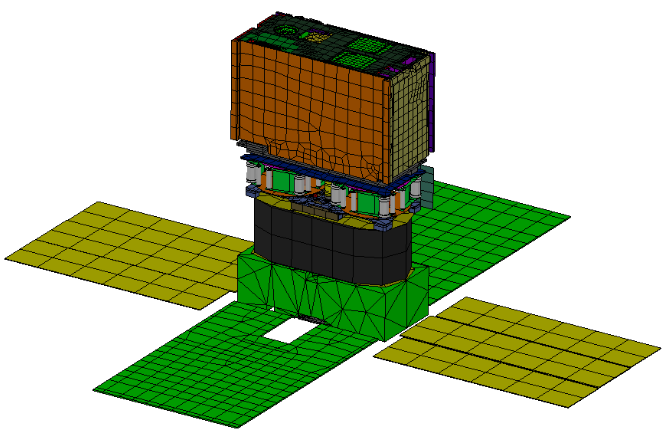
- 0° sun angle
- Avionics dissipating 45 W
- Operate avionics for 60 minutes before exceeding AFT limits
- Temperatures are in °C



	AFT (allowable flight temp)				Comm Run		Comm Margin	
	op		no op				op - margin	
	cold	hot	cold	hot	cold	hot	cold	hot
Telecom								
Iris Radio	-20	50	-20	50	51.1	57.7	71	-8
Low Gain Antenna	-50	80	-50	80	-7.4	50.7	43	29
Medium Gain Antenna	-50	80	-50	80	5.1	11.2	55	69
Propulsion								
Colorless Polymer 1 (Sail)	-200	250	-200	250	0.0	0.0	200	250
Eligiloy TRAC Booms	-215	250	-215	250	0.0	0.0	215	250
AMT Motors	-35	40	-35	40	0.8	5.9	36	34
Motor Controller Board	-40	55	-55	55	42.6	47.4	83	8
ADCS								
Cold Gas	-10	45	-24	45	-9.8	-9.2	0	54
RWA	-20	60	-20	60	49.2	53.9	69	6
Star Tracker	-20	60	-20	60	48.0	49.3	68	11
IMU	-40	85	-65	150	55.9	56.5	96	28
Power								
Solar Arrays	-25	90	-45	90	5.0	56.6	30	33
EPS	-20	50	-20	50	55.4	68.8	75	-19
Batteries	0	30	-10	30	41.7	42.5	42	-13
NEA Scout Instrument								
Camera	-25	50	-35	70	40.3	41.5	65	8
Additional Stuff								
Flight Computer Board	-40	50	-40	50	54.8	58.3	95	-8
Common Interface Board	-55	100	-65	110	55.8	59.6	111	40
Course Sun Sensor	-25	75	-40	85	-1.1	44.2	24	31
Receiver	-20	50	-20	50	51.5	55.2	71	-5
Exciter	-20	50	-20	50	52.3	58.6	72	-9
Radix	-20	50	-20	50	54.2	63.1	74	-13
PSB	-20	50	-20	50	53.2	58.1	73	-8
LNA	-20	50	-20	50	58.4	61.0	78	-11
SSPA	-20	50	-20	50	63.7	83.0	84	-33

Cruise Pre-Sail Steady State

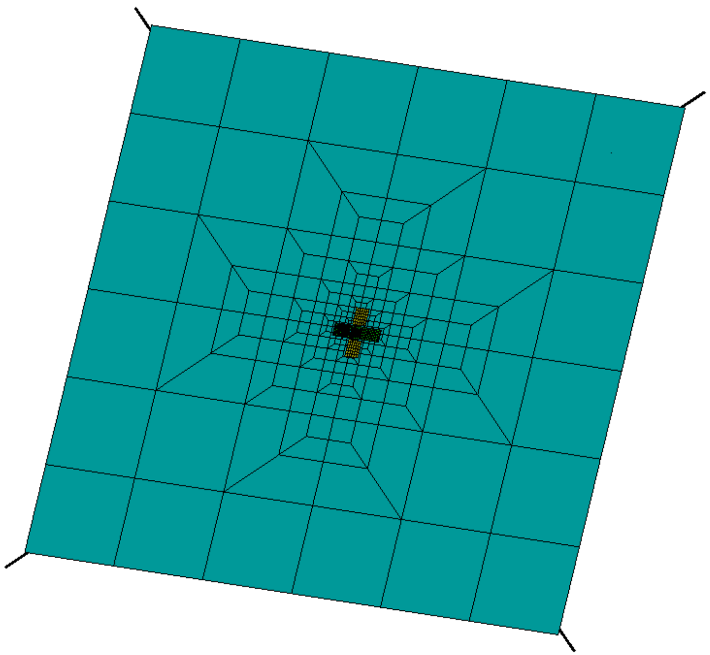
- 0° sun angle
- Avionics dissipating 20 W
- Temperatures are in °C
- Results with Internal RCS heaters 0 W



	AFT (allowable flight temp)						Cruise Margin	
	op		no op		Cruise Run		op - margin	
	cold	hot	cold	hot	cold	hot	cold	hot
Telecom								
Iris Radio	-20	50	-20	50	7.5	11.9	28	38
Low Gain Antenna	-50	80	-50	80	-5.4	50.2	45	30
Medium Gain Antenna	-50	80	-50	80	29.8	37.1	80	43
Propulsion								
Colorless Polymer 1 (Sail)	-200	250	-200	250	-46.8	141.0	153	109
Eligiloy TRAC Booms	-215	250	-215	250	-86.2	201.2	129	49
AMT Motors	-35	40	-35	40	-2.7	0.5	32	40
Motor Controller Board	-40	55	-55	55	4.1	8.2	44	47
ADCS								
Cold Gas	-10	45	-24	45	-10.3	-9.7	0	55
RWA	-20	60	-20	60	7.8	10.1	28	50
Star Tracker	-20	60	-20	60	6.0	7.2	26	53
IMU	-40	85	-65	150	9.1	10.0	49	75
Power								
Solar Arrays	-25	90	-45	90	29.8	86.1	55	4
EPS	-20	50	-20	50	9.0	16.5	29	33
Batteries	0	30	-10	30	3.0	4.0	3	26
NEA Scout Instrument								
Camera	-25	50	-35	70	2.8	4.3	28	46
Bus Electronics								
Flight Computer Board	-40	50	-40	50	9.0	12.6	49	37
Common Interface Board	-55	100	-65	110	9.0	13.1	64	87
Course Sun Sensor	-25	75	-40	85	2.8	51.4	28	24
Receiver	-20	50	-20	50	7.7	11.5	28	38
Exciter	-20	50	-20	50	8.0	11.6	28	38
Radix	-20	50	-20	50	8.9	16.5	29	33
PSB	-20	50	-20	50	8.4	10.8	28	39
LNA	-20	50	-20	50	7.0	7.8	27	42
SSPA	-20	50	-20	50	6.9	7.6	27	42

Cruise Post-Sail Deploy Steady State

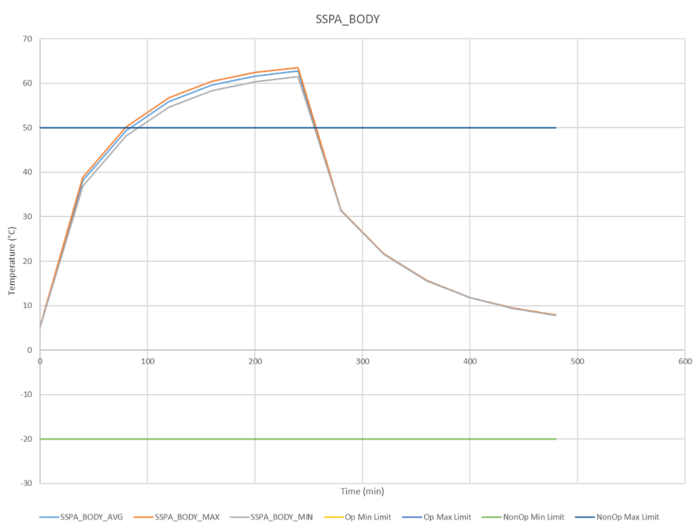
- 50° nominal sun angle
  - 45° hot case
  - 55° cold case
- Avionics dissipating 20 W
- 5 W battery heater
  - Results are with 0 W
- Temperatures are in °C



	AFT (allowable flight temp)				Cruise Run		Cruise Margin	
	op		no op				op - margin	
	cold	hot	cold	hot	cold	hot	cold	hot
Telecom								
Iris Radio	-20	50	-20	50	4.3	9.5	24	41
Low Gain Antenna	-50	80	-50	80	-8.1	35.7	42	44
Medium Gain Antenna	-50	80	-50	80	-3.7	15.2	46	65
Propulsion								
Colorless Polymer 1 (Sail)	-200	250	-200	250	-134.1	126.3	66	124
Eligiloy TRAC Booms	-215	250	-215	250	-115.4	185.9	100	64
AMT Motors	-35	40	-35	40	-22.4	-11.1	13	51
Motor Controller Board	-40	55	-55	55	0.8	5.7	41	49
ADCS								
Cold Gas	-10	45	-24	45	15.5	35.9	26	9
RWA	-20	60	-20	60	4.5	7.6	24	52
Star Tracker	-20	60	-20	60	2.7	4.7	23	55
IMU	-40	85	-65	150	5.8	7.6	46	77
Power								
Solar Arrays	-25	90	-45	90	-3.7	58.3	21	32
EPS	-20	50	-20	50	5.7	14.0	26	36
Batteries	0	30	-10	30	-0.2	1.5	0	28
NEA Scout Instrument								
Camera	-25	50	-35	70	-0.5	1.8	25	48
Additional Components								
Flight Computer Board	-40	50	-40	50	5.7	10.1	46	40
Common Interface Board	-55	100	-65	110	5.7	10.6	61	89
Course Sun Sensor	-25	75	-40	85	-0.5	36.4	25	39
Receiver	-20	50	-20	50	4.4	9.1	24	41
Exciter	-20	50	-20	50	4.8	9.1	25	41
Radix	-20	50	-20	50	5.6	14.1	26	36
PSB	-20	50	-20	50	5.2	8.3	25	42
LNA	-20	50	-20	50	3.7	5.4	24	45
SSPA	-20	50	-20	50	3.6	5.1	24	45

Comm Post-Sail Deploy Steady State

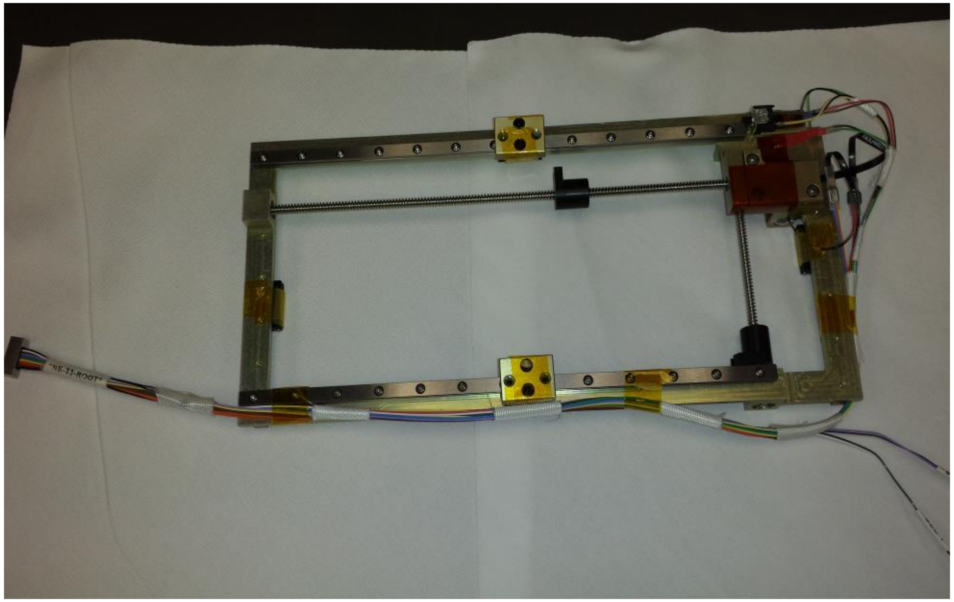
- 70° nominal sun angle
- Avionics dissipating 45 W
- Limited to 80 minutes of comm operation before SSPA exceeds AFT limits
- Temperatures are in °C



	AFT (allowable flight temp)						Comm Margin	
	op		no op		Comm Run		op - margin	
	cold	hot	cold	hot	cold	hot	cold	hot
Telecom								
Iris Radio	-20	50	-20	50	50.3	56.6	70	-7
Low Gain Antenna	-50	80	-50	80	-15.9	49.6	34	30
Medium Gain Antenna	-50	80	-50	80	-35.7	-31.0	14	111
Propulsion								
Colorless Polymer 1 (Sail)	-200	250	-200	250	-168.6	101.9	31	148
Eligiloy TRAC Booms	-215	250	-215	250	-134.2	162.0	81	88
AMT Motors	-35	40	-35	40	-31.6	-28.2	3	68
Motor Controller Board	-40	55	-55	55	41.5	46.2	81	9
ADCS								
Cold Gas	-10	45	-24	45	-8.9	-3.5	1	48
RWA	-20	60	-20	60	48.3	52.9	68	7
Star Tracker	-20	60	-20	60	47.1	48.2	67	12
IMU	-40	85	-65	150	54.9	55.4	95	30
Power								
Solar Arrays	-25	90	-45	90	-6.8	0.0	18	90
EPS	-20	50	-20	50	54.6	67.8	75	-18
Batteries	0	30	-10	30	40.9	41.6	41	-12
NEA Scout Instrument								
Camera	-25	50	-35	70	39.3	40.4	64	10
Bus Electronics								
Flight Computer Board	-40	50	-40	50	54.0	57.3	94	-7
Common Interface Board	-55	100	-65	110	54.9	58.5	110	41
Course Sun Sensor	-25	75	-40	85	-8.6	42.8	16	32
Receiver	-20	50	-20	50	50.7	54.2	71	-4
Exciter	-20	50	-20	50	51.4	57.6	71	-8
Radix	-20	50	-20	50	53.3	62.1	73	-12
PSB	-20	50	-20	50	52.3	57.1	72	-7
LNA	-20	50	-20	50	57.4	59.8	77	-10
SSPA	-20	50	-20	50	62.7	81.8	83	-32

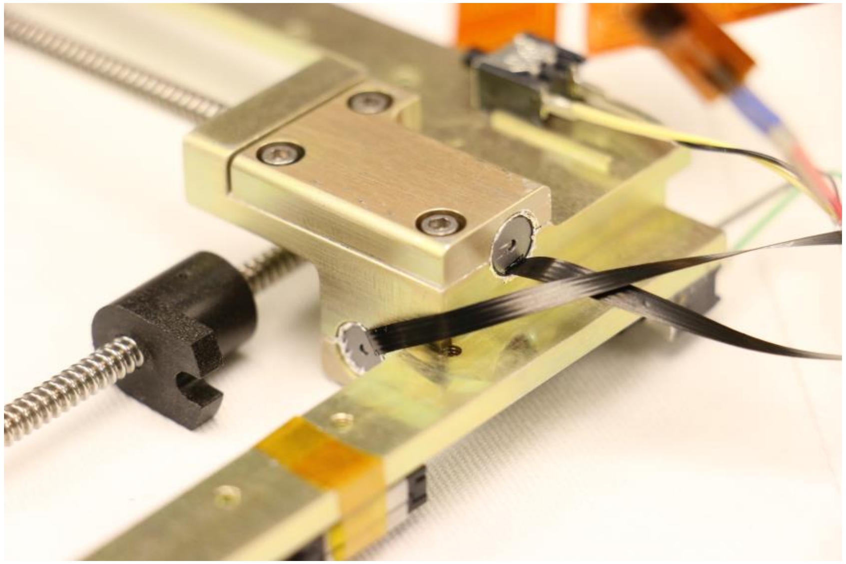
AMT Motor Failure

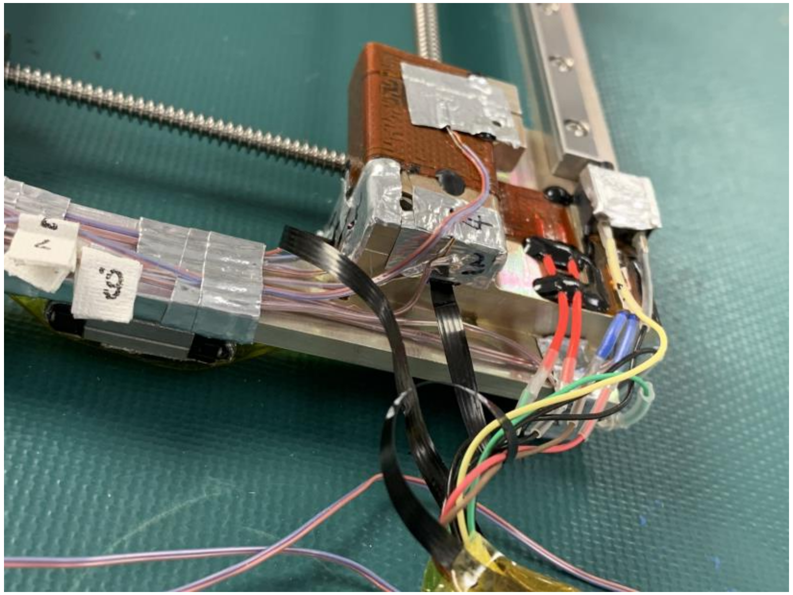
- AMT motor failure during TVAC testing
  - Coils overheated leading to electrical short
- AMT is used to adjust center of mass of the spacecraft
  - De-saturates the reaction wheels
  - Motor selection based on volume constraints
    - 6mm diameter motors
    - Not space rated



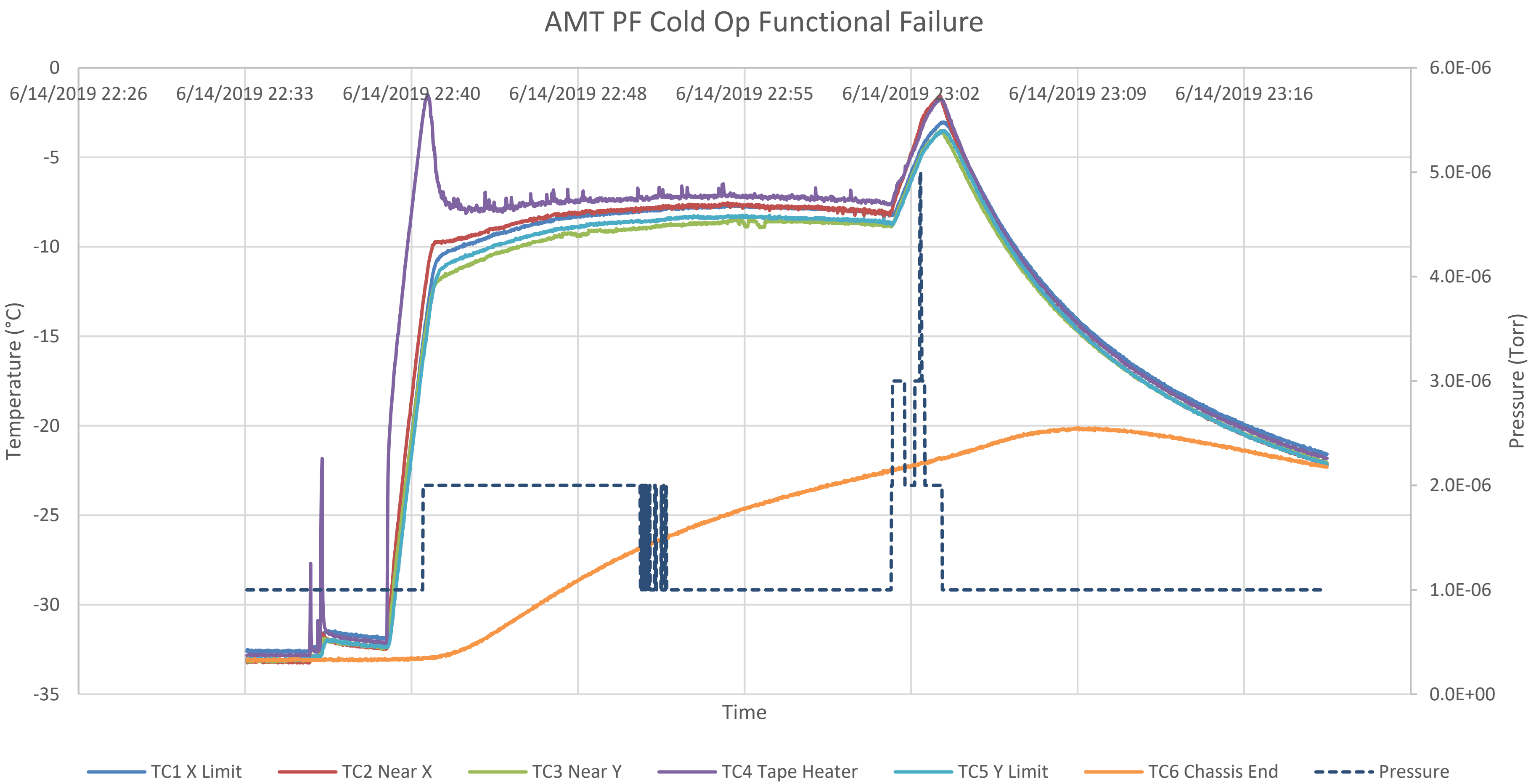
AMT Motor Failure

- Referred to SME at MSFC and believed to have potentially caused Paschen Discharge (PD) based on test data
  - Data shows temperature, pressure, and current spike at moment of failure
  - No vent path for gas to escape due to thermocouple location
- X-ray and destructive analysis confirmed coil failure due to overheating



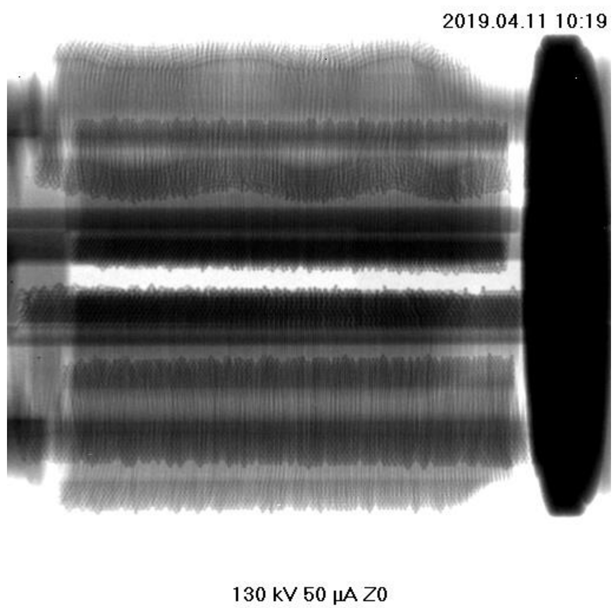


AMT Motor Failure



AMT Motor Failure

- Destructive analysis showed no signs of Paschen discharge, and believed motor failed due to high current draw
  - Both Paschen discharge and high current draw will lead to similar coil failures – exceeding coil temperature limits
  - Pressure spike due to off-gassing coil varnish
- Mitigations
  - Implementing duty cycle at all temperatures
  - Tightening current limits within motor controller board (MCB)



Thermal Testing

- Subsystem level testing held at vendor locations
- Fully integrated spacecraft testing held at MSFC
- TVAC testing requires hot box to regulate environment temp
- AMT still has to complete subsystem level TVAC

Reaction Control System (RCS)
Subsystem thermal cycle and TVAC at vendor

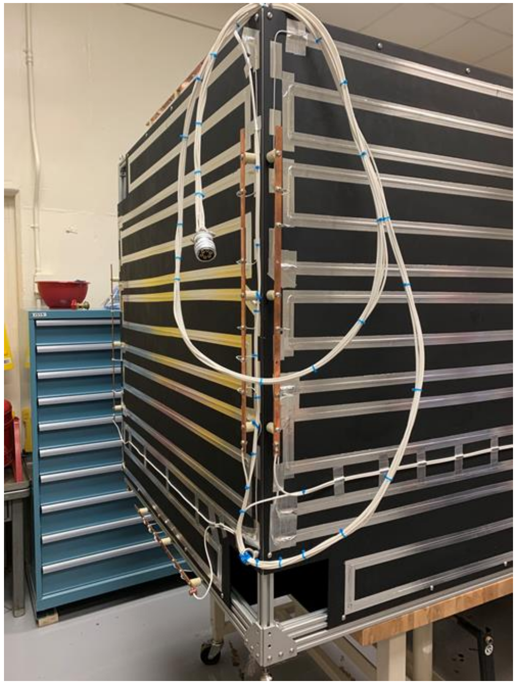
Solar Sail Deployer Mechanism
Subsystem bakeout, thermal cycle, TVAC operation at MSFC

Active Mass Translator (AMT)
Subsystem bakeout, thermal cycle, TVAC operation at MSFC

Avionics Box

Antenna/Solar Panel Arrays
Subsystem bakeout and thermal cycling at vendor

→ **Integrated Flight System**
System bakeout, thermal cycle, TVAC operation at MSFC



Lessons Learned

- Always double check assumed optical properties. The difference between what was assumed during design and the as built configurations can lead to large temperature changes.
- Take into consideration end of life and beginning of life optical properties. Do not assume properties stay constant. Common resources used to look up properties often do not have end of life/beginning of life so be sure to talk to a coatings expert about potential degradation.
- Changes to the thermal architecture after a Critical Design Review (CDR) are risky because they will not be reviewed to the same level that occurred at CDR.
- CubeSats are very sensitive to overall dimensions, be sure to claim part of the allowable envelop to place tapes and coatings early on in the design cycle. Adding 7 mils of tape late in the manufacturing process can be hard to accommodate. – *see paper for more detail*
- Include applications of thermal fillers (e.g. RTV's) early in discussions on assembly work flow. – *see paper for more detail*
- Ceramic based paints (e.g. Z93) are best applied to large acreage with minimal edges, and not to surfaces that have lots of penetrations or edges. – *see paper for more detail*

Acknowledgements

The NEA Scout team at MSFC including Tiffany Lockett, Alex Few, Rick Wilson, Joe Matus, Don McQueen, Miria Finckenor, and Matt Pruitt

The NEA Scout team at JPL including Duy Nguyen, and Annie Marinan.

Jon Sasson at Sierra Lobo for providing a seamless handoff of the thermal model and introducing the project including its challenges.

Heather Bradshaw at Goddard Space Flight Center for giving us advice on thermal interface materials and other thermal topics.