2017 Spacecraft Thermal Control Workshop

Thermal Testing of a Planetary Roller Screw for the Mars 2020 Rover Sample Caching System

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Mission Overview

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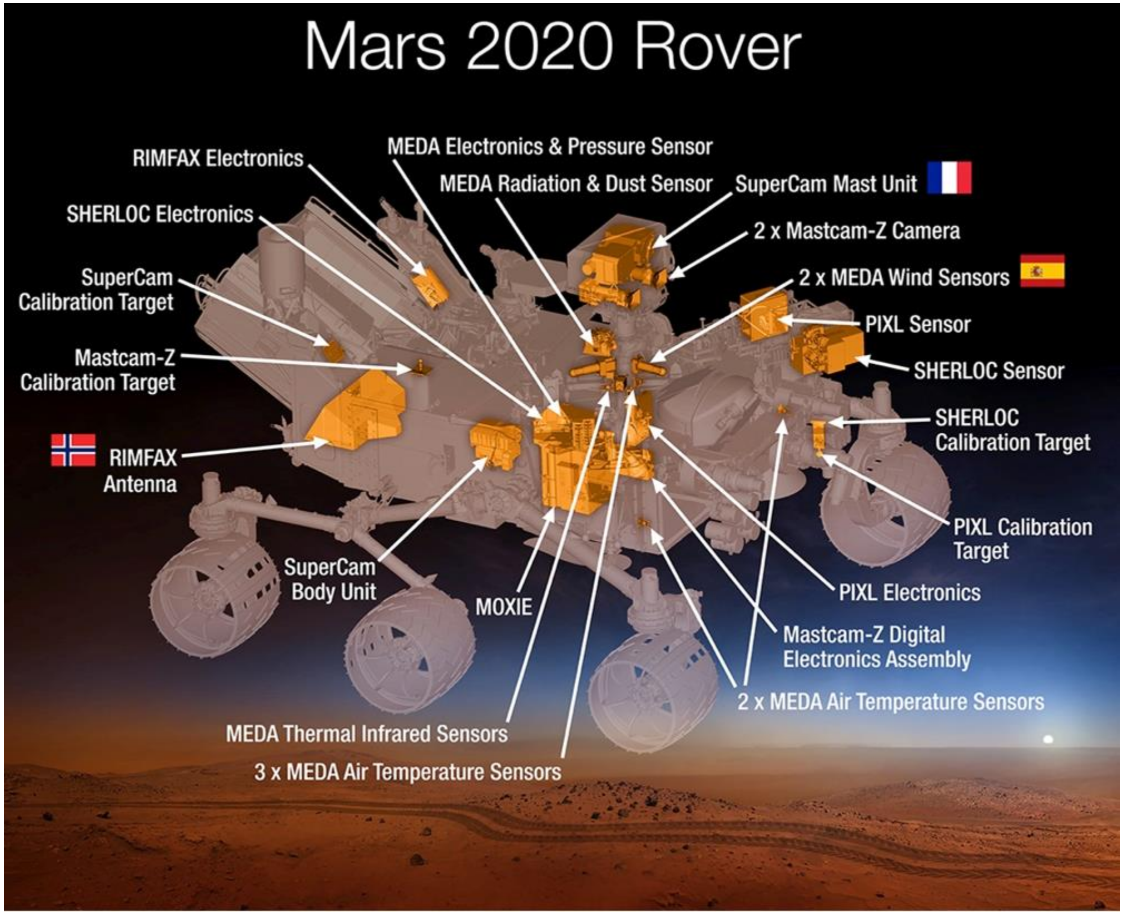
- The Mars 2020 Rover is planned for launch in 2020, and will carry a suite of instruments as well as a Sample Caching System (SCS) [1].

Instrument Suite:

1. **Mastcam-Z** - stereo zoom camera
2. **Supercam** - remote elemental chemistry and mineralogy
3. **SHERLOC** - fine-scale organic geochemistry and mineralogy (mapping)
4. **PIXL** - fine-scale elemental chemistry (mapping)
5. **RIMFAX** - subsurface structure - ground penetrating radar (Norway)
6. **MEDA** - weather and atmospheric dust monitoring (Spain)
7. **MOXIE** - ISRU - conversion of atmospheric CO_2 to O_2



[1] Farley, K., "Mars 2020 Project Update," Committee on Astrobiology and Planetary Science, September 17, 2015. Accessed from http://sites.nationalacademies.org/cs/groups/ssbsite/documents/webpage/ssb_169425.pdf on 12/9/2016.

Sample Caching System (SCS)

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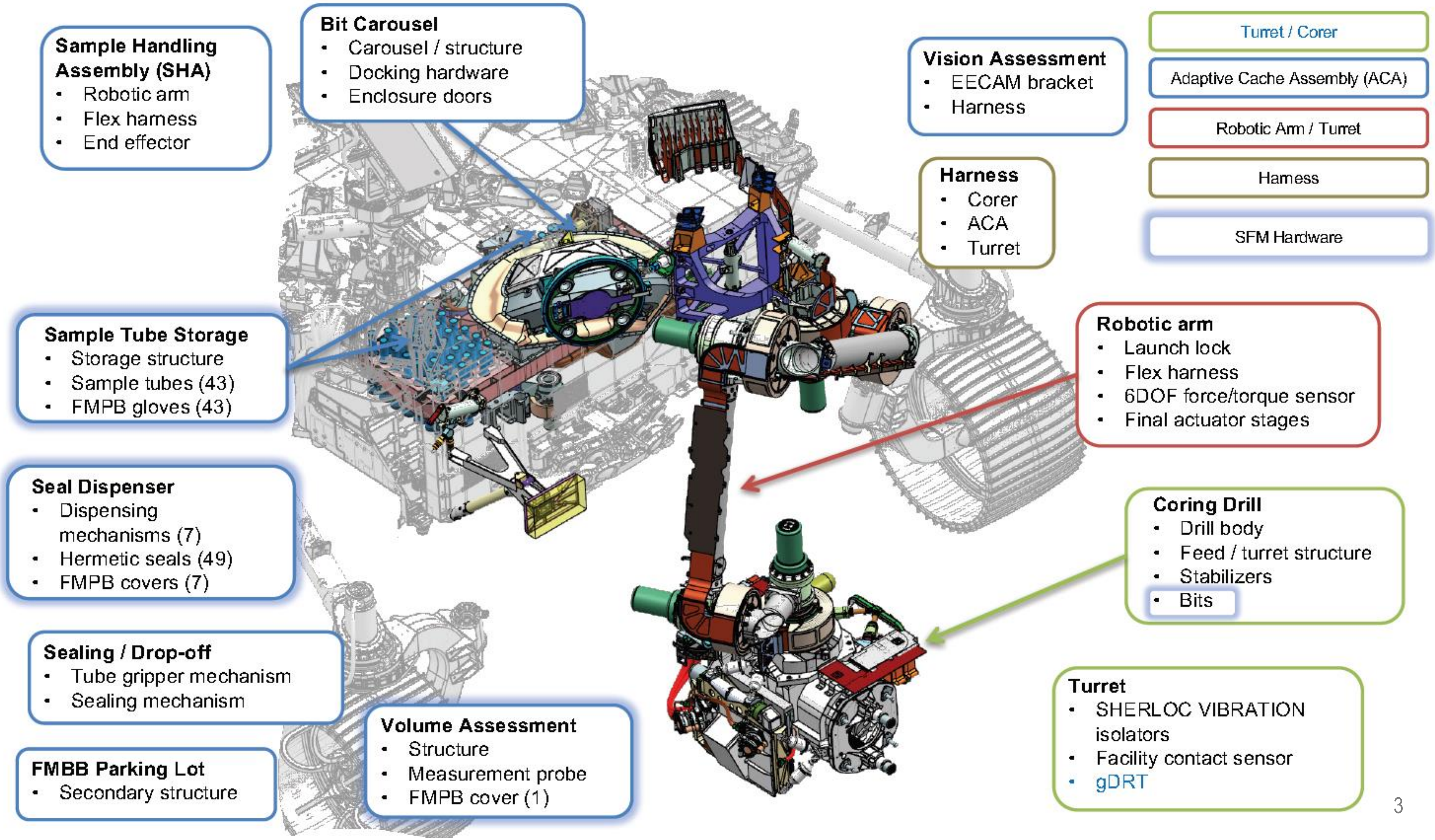
- **The SCS performs sample collection, manipulation, sealing, storage, and caching.**



Adaptive Caching Assembly (ACA)

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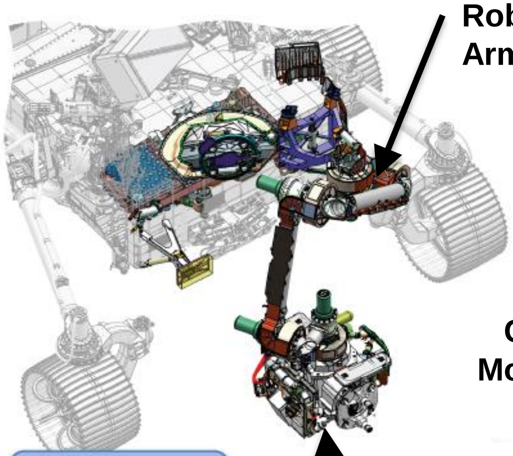
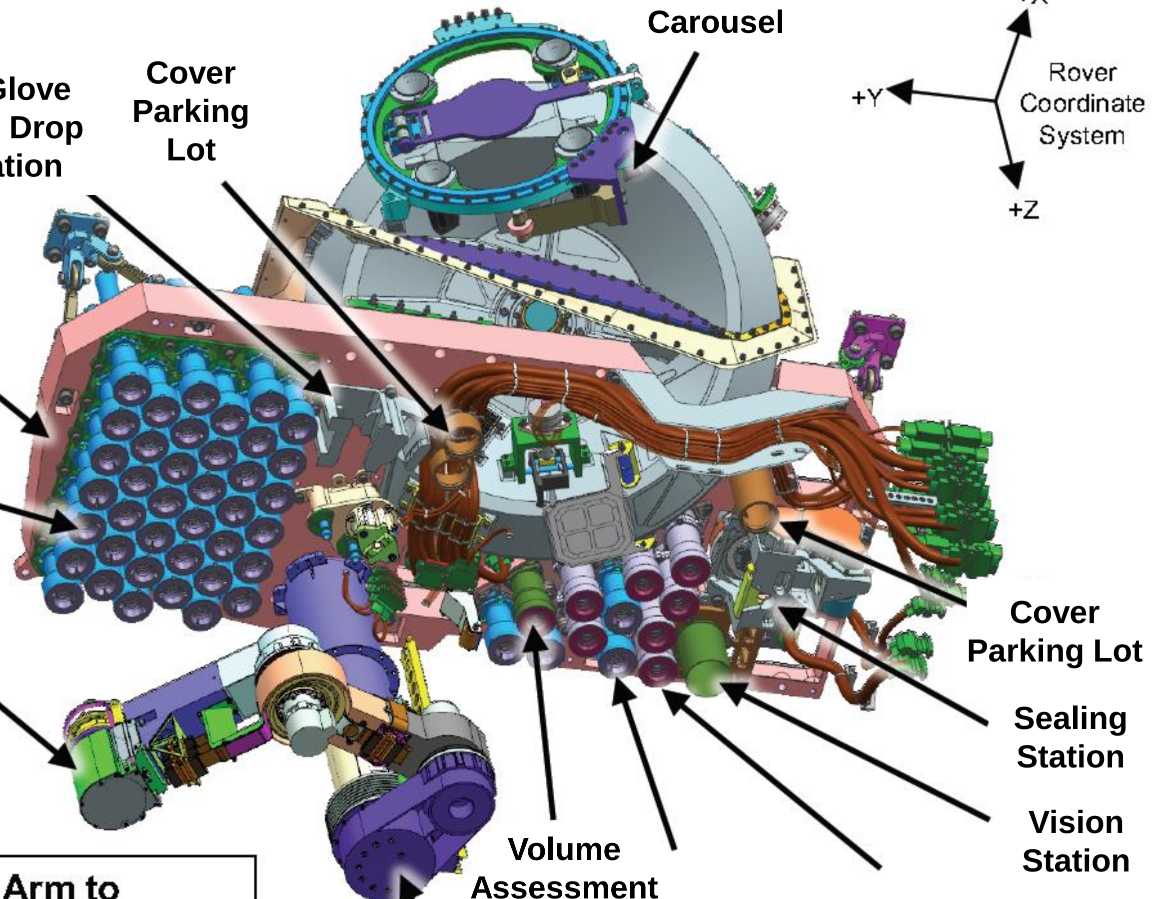




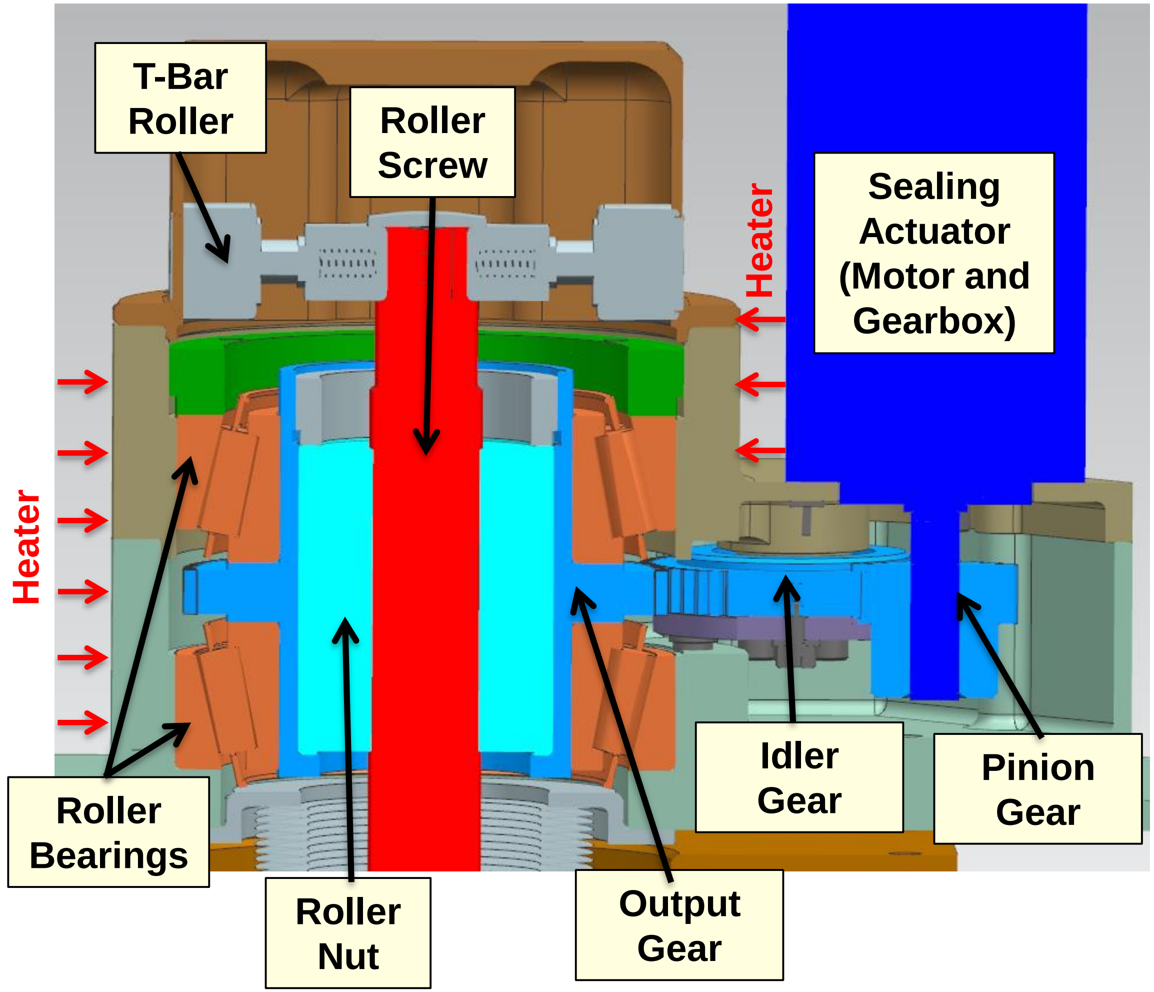
- Store Bits
- Manipulate Tubes
- Assess Sample
- Seal Sample
- Store Sample
- Drop-off Sample

Single Sample Handling Arm to access individual stations:

Bit carousel, tube storage, hermetic seal dispensers, vision assessment, volume assessment, cover parking lot, sealing, passive drop-off

Sealing Station Cross Section

- The Sealing Station is a part of the Mars 2020 Rover that is used to force a cup and plug into the open end of a Mars sample tube, creating a hermetic seal.
- Thermal Conductance of Planetary Roller Screw is very uncertain.
  - Conservative estimates of 0.023 W/K correspond to a 3 hour warm up.
- A less conservative estimate of > 0.15 W/K would significantly reduce the warm up time.



Test Objective

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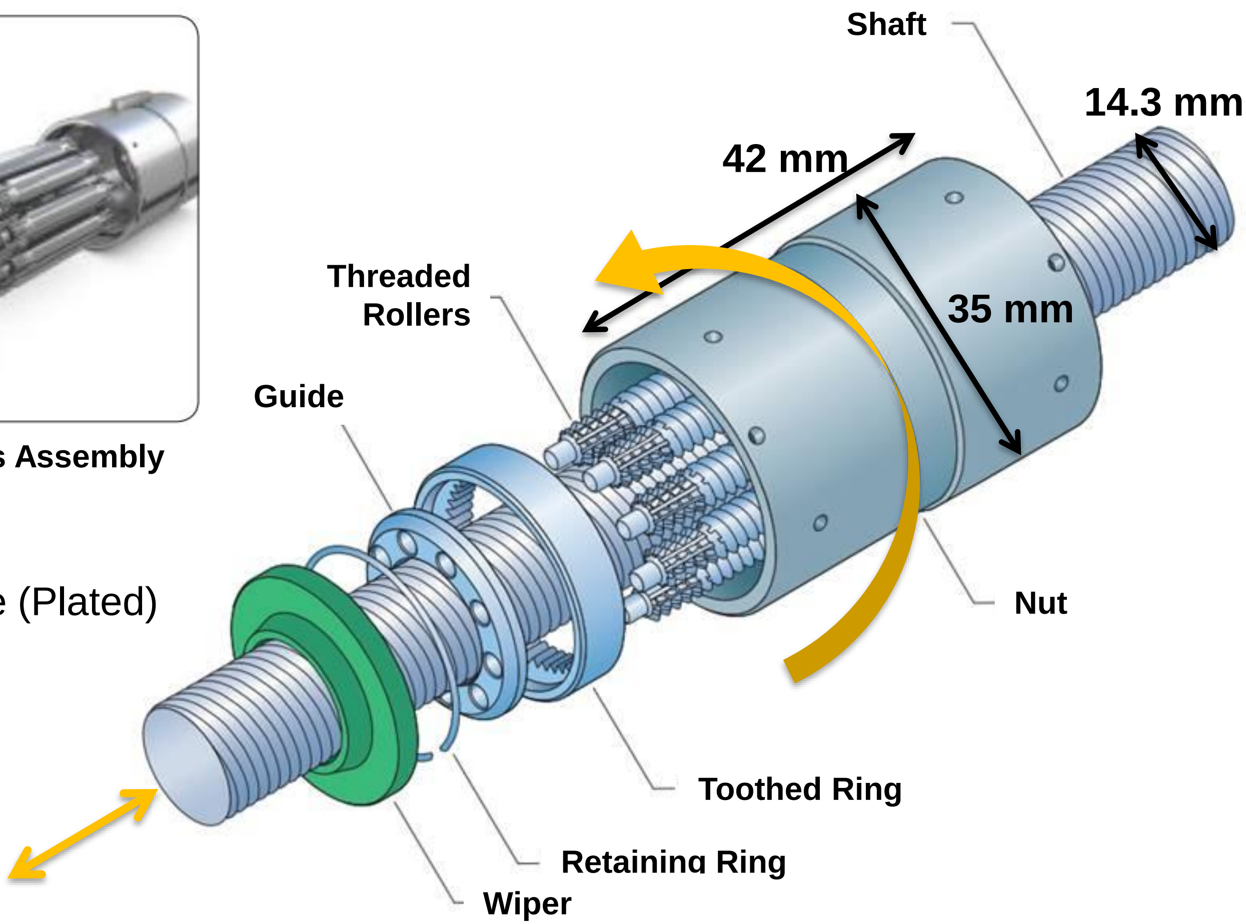
Objective: Gather transient and steady state warm up data for a flight like planetary gear screw and measure the Nut-Screw thermal conductance.

Threaded Rollers

Components Assembly

- 9 Threaded Rollers
- Lubricated with Braycote Grease (Plated)
- Screw Diameter: ~ **14.3 mm**
- Roller Diameter: ~ **7 mm**
- Nut Outer Diameter: ~ **35 mm**
- Nut Length: ~ **42 mm**



Test Hardware

- Test Articles (TA) are spares for the Sealing Station Engineering Development Unit (EDU).
  - Not JPL Critical Item (JCI) Hardware
  - No Quality Assurance (QA) Required

- There are 2 Test Articles:
  - Test Article 1: Same geometry, but increased tolerance compared to flight hardware.
  - Test Article 2: Same geometry and tolerances as the flight unit is expected to have.

- Both Test Articles are 4150 Steel, but the flight unit is expected to be made with 440 C stainless steel.

	4150 Steel	440 C Steel
Density	7850 to 7800 Kg/m^3	7800 Kg/m^3
Specific Heat	450 to 475 J/Kg-K	460 J/Kg-K
Thermal Conductivity	42 to 44.5 W/m-K	24.2 W/m-K
Modulus of Elasticity	210 GPa to 205 GPa	200 to 215 GPa
Rockwell B Hardness	99	97
Sources	MATWEB.com and makeitfrom.com	MATWEB.com, AZOM.com, and Gilmore's Spacecraft Thermal Control Handbook

- May introduce slight non-conservatism due to effect on contact resistance.
- Bulk effect can be accounted for using thermal model.
- Risk expected to be low, and predictions will ultimately be verified by testing on the flight unit.

Test Setup

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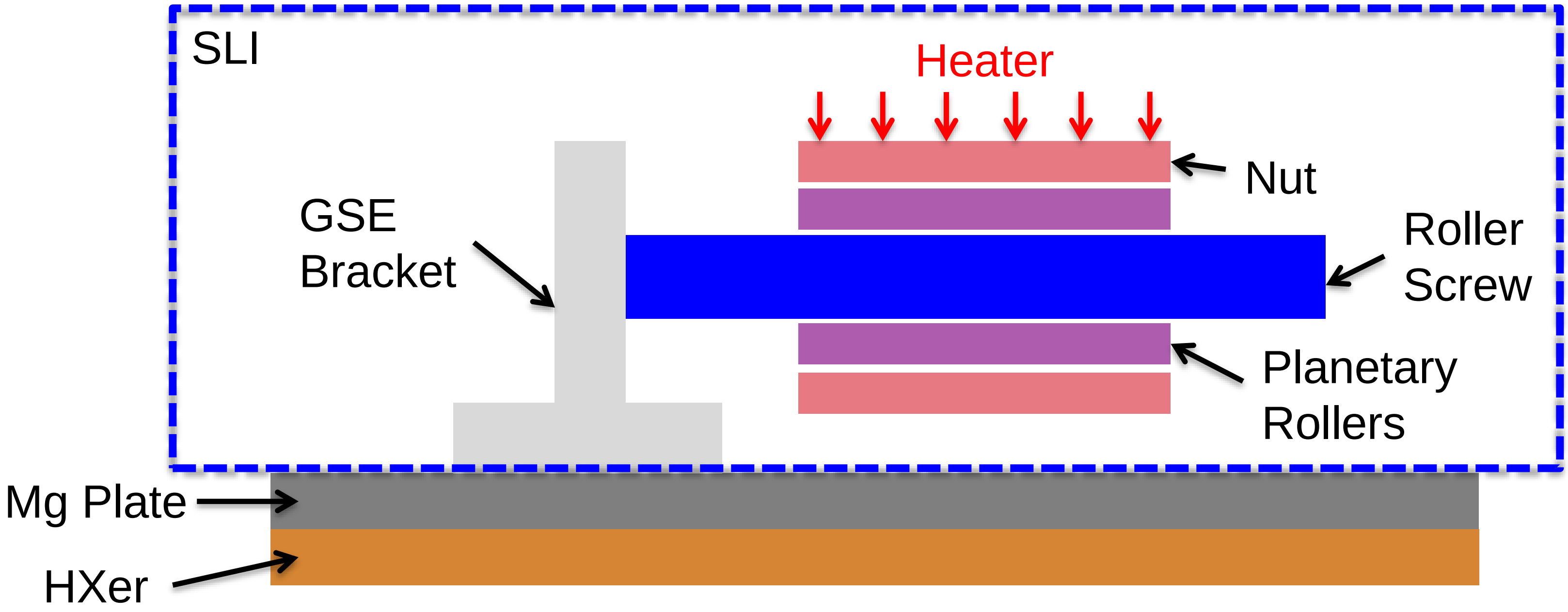
- Test articles horizontal during test.
- Test articles bolted to a GSE bracket using 1 x M8-1.0x35 mm bolts (20 N-m torque).
- GSE Bracket bolted to Mg Adapter Plate using 6 x M8-1.0x35 mm bolts (20 N-m torque).
- Test articles surrounded by double aluminized mylar single layer insulation (SLI) enclosure.



Test Conservatism

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- Conduct Testing at a cold range of temperatures
  - Thermal Conductivity at cold temperatures is reduced
- Conduct Testing in both Vacuum and 6 Torr N_2 atmosphere
  - Understand grease and gas contributions
- During testing, Nut should be warmed and screw should be cold.
  - Flight like gradient expected
  - Nut expands relative to screw
    - More tolerance between nut and screw
    - Conservative (lower) measured thermal conductance
- Planetary Roller Screw is un-loaded during test
  - Gravity load only during test
    - Conservative (lower) measured thermal conductance
  - In flight, a moderate level of preload is expected during warm up:
    - Warm Up (Stowed) Preload: ~ 2,900 N = 650 lb_f
    - Maximum Tube Sealing Force: ~ 8,200 N = 1850 lb_f
    - Mechanism Force Capability: ~ 28,000 N = 6300 lb_f

Test Matrix

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- Test was performed over a period of 3 Days, with only 2 days of temperature control.
  - Day 1: Set Up and Pump Down
  - Day 2: Vacuum Cycles
  - Day 3: GN_2 Cycles

- Total of 30 hours of chamber use and operation

Test Number	Test Day	Description	Duration	Pressure	Atmosphere	Shroud Temp (°C)	HXer Temp (°C)	Heater Power
1	Day 1	Pump Down	4 hours	760 to <1e-5 Torr	Air	N/A	N/A	0 W
2	Day 2	Vacuum Cool Down	6 hours	< 1e-5 Torr	Vacuum	-100	-100	0 W
3	Day 2	Vacuum Warm Up	6 hours	< 1e-5 Torr	Vacuum	-100	-100	3 W
4	Day 3	GN_2 Cool Down	4 hours	5 – 7 Torr	GN_2	-100	-100	0 W
5	Day 3	GN_2 Warm Up	4 hours	5 – 7 Torr	GN_2	-100	-100	3 W
6	Day 3	Chamber Warm Up	4 hours	5 – 7 Torr	GN_2	N/A	N/A	0 W

TC Location Schematic

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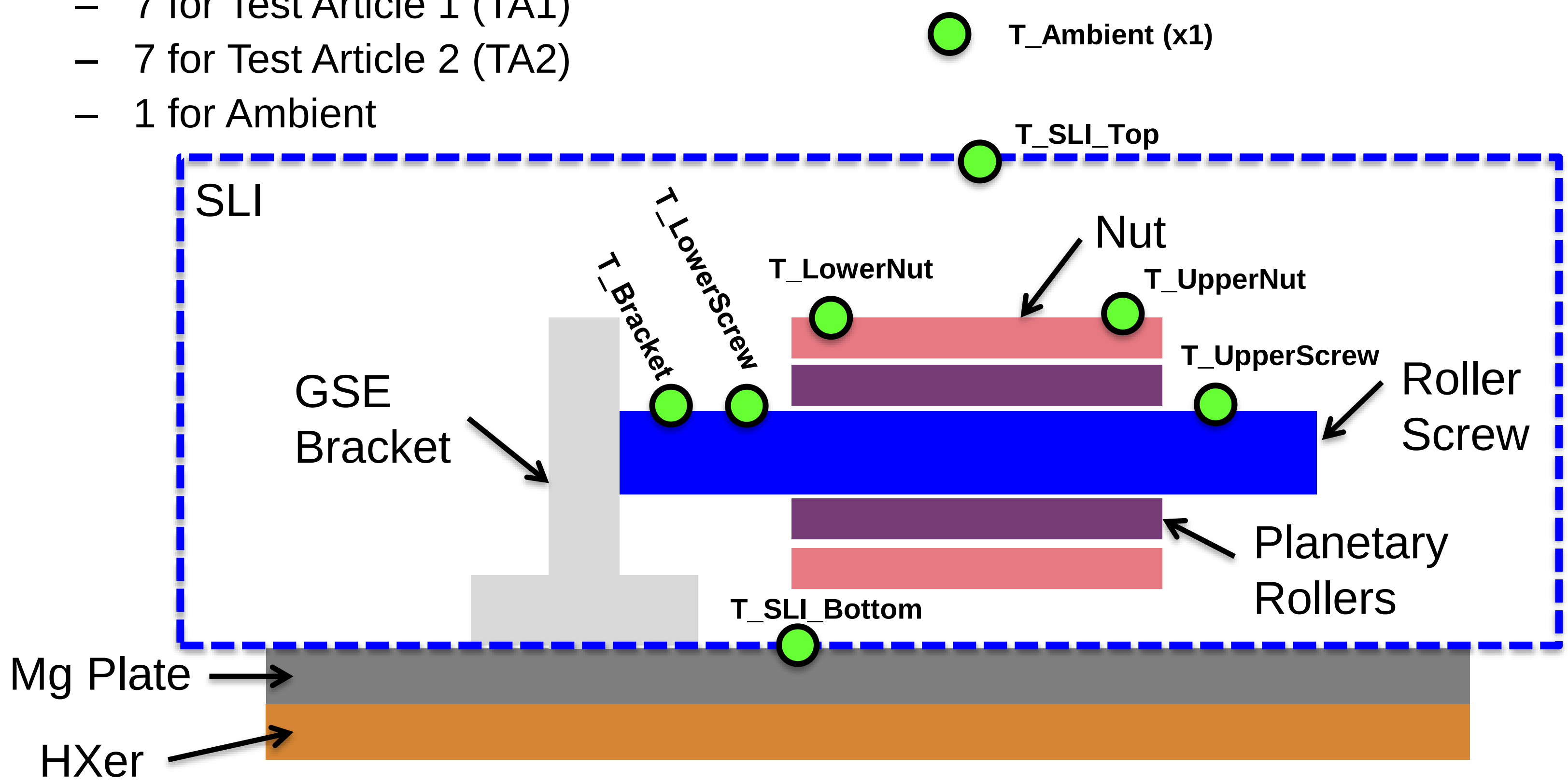
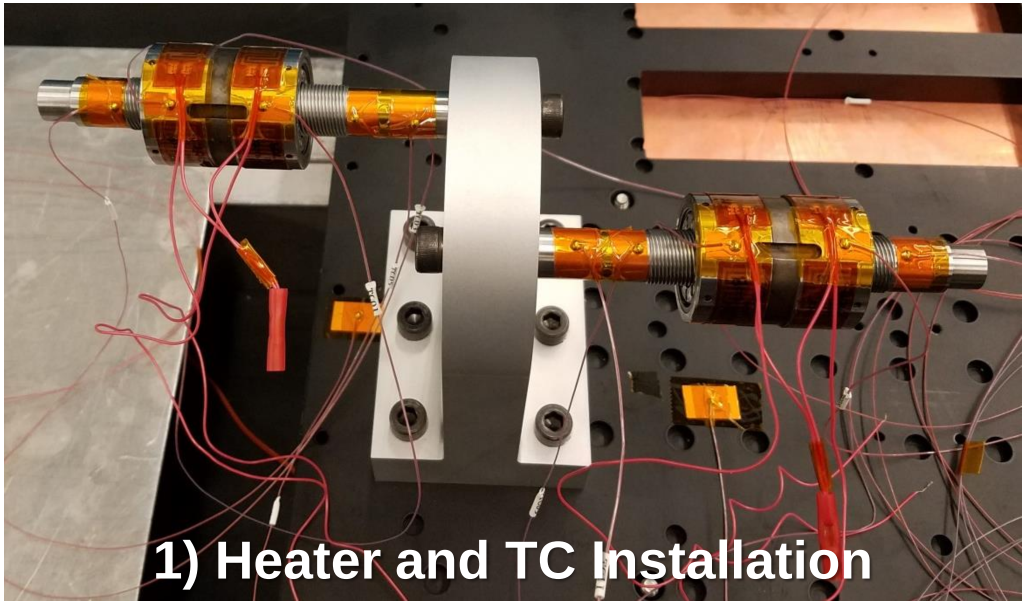
- Total of 15 TCs
  - 7 for Test Article 1 (TA1)
  - 7 for Test Article 2 (TA2)
  - 1 for Ambient

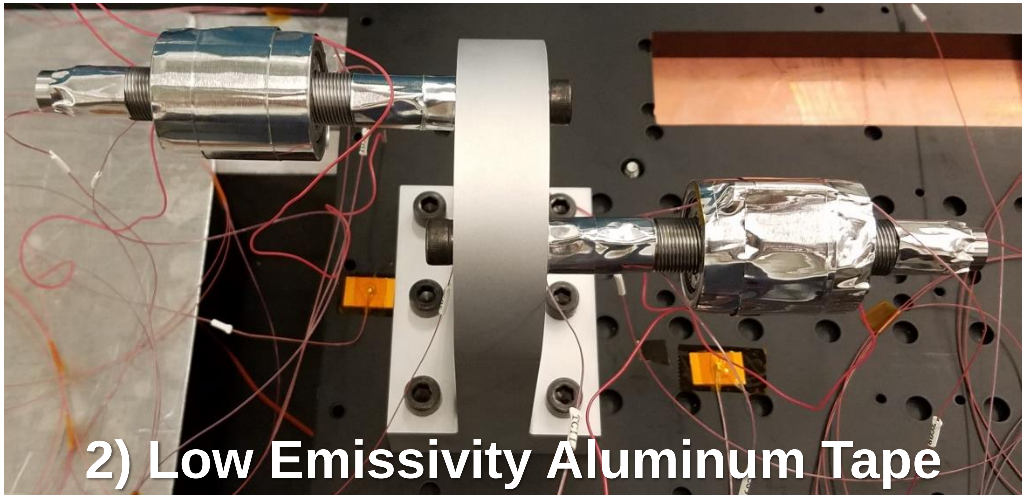


Note: Only one Test Article Shown for clarity

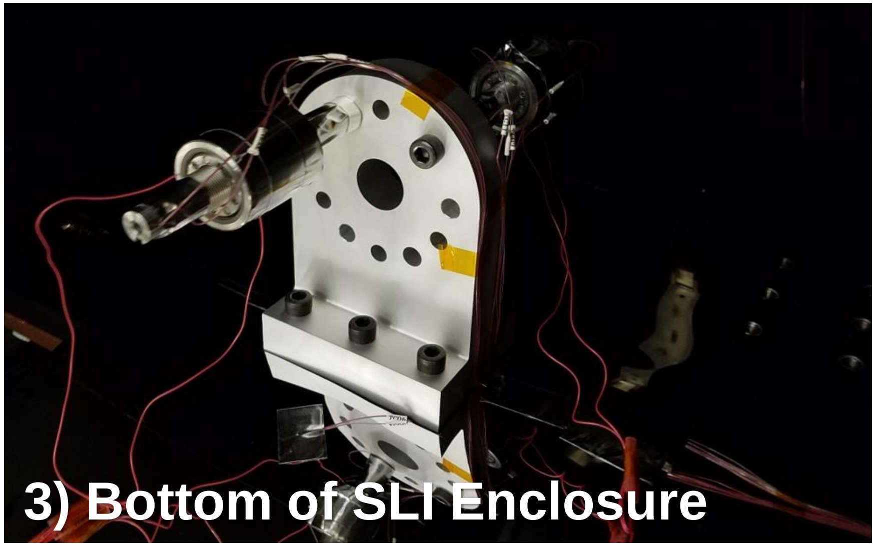
Test Assembly Sequence



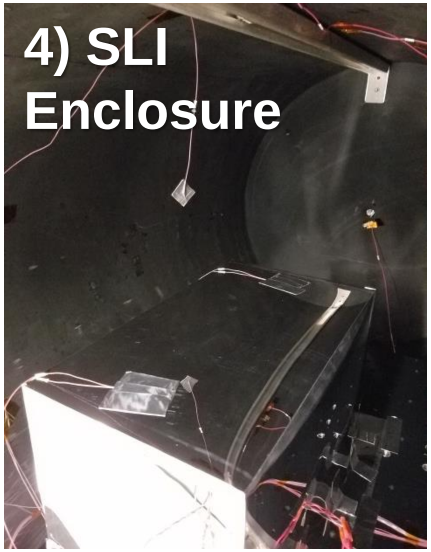
1) Heater and TC Installation



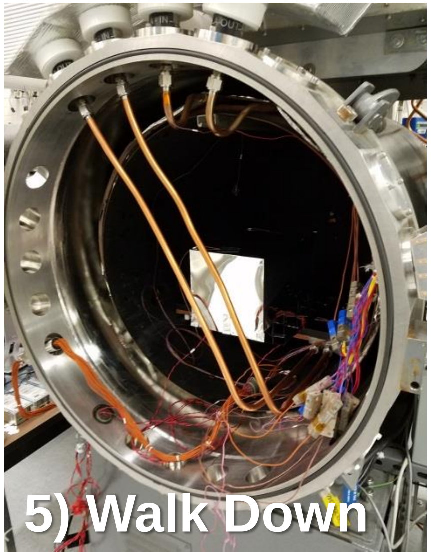
2) Low Emissivity Aluminum Tape



3) Bottom of SLI Enclosure

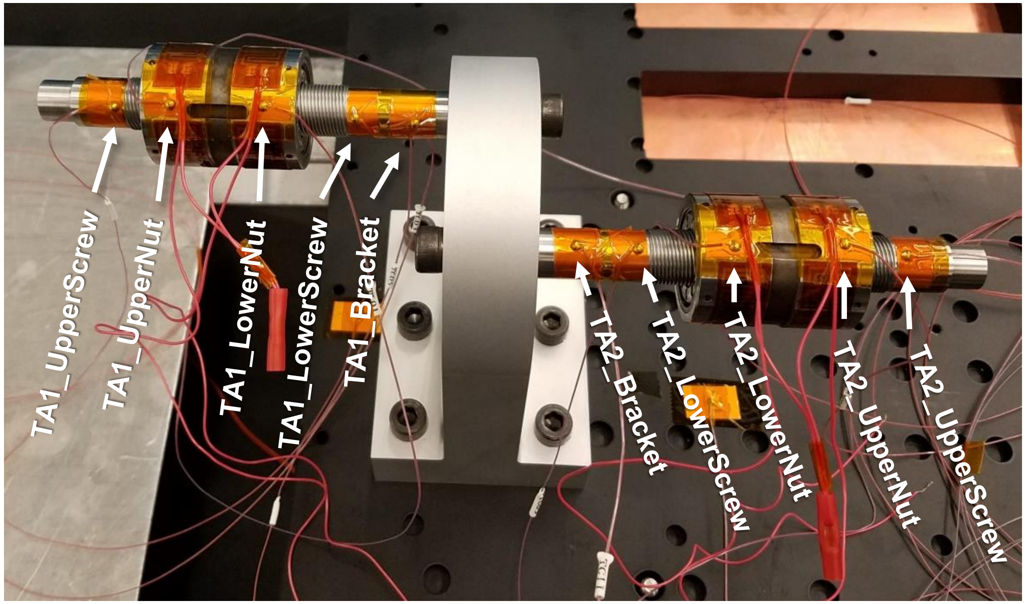


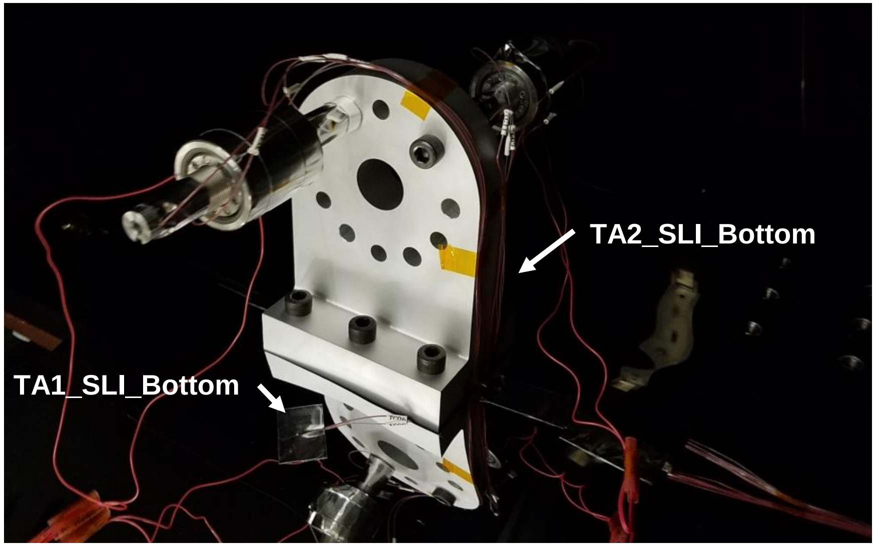
4) SLI Enclosure

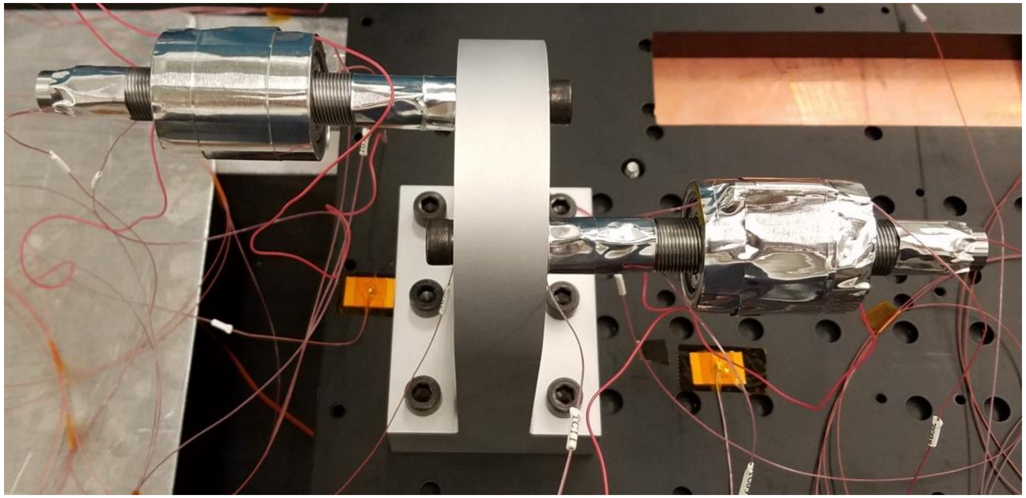


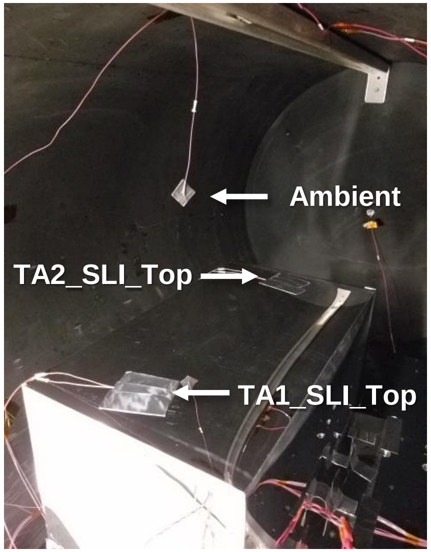
5) Walk Down

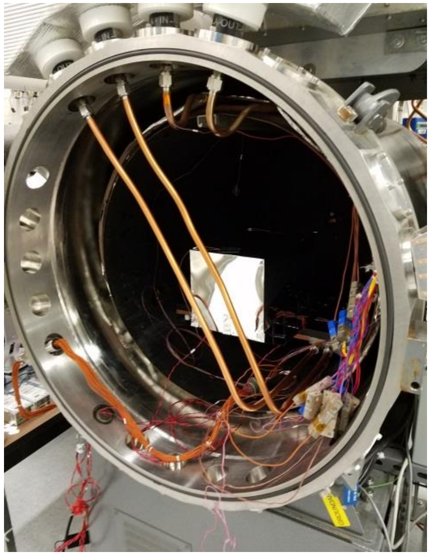
Actual TC Locations



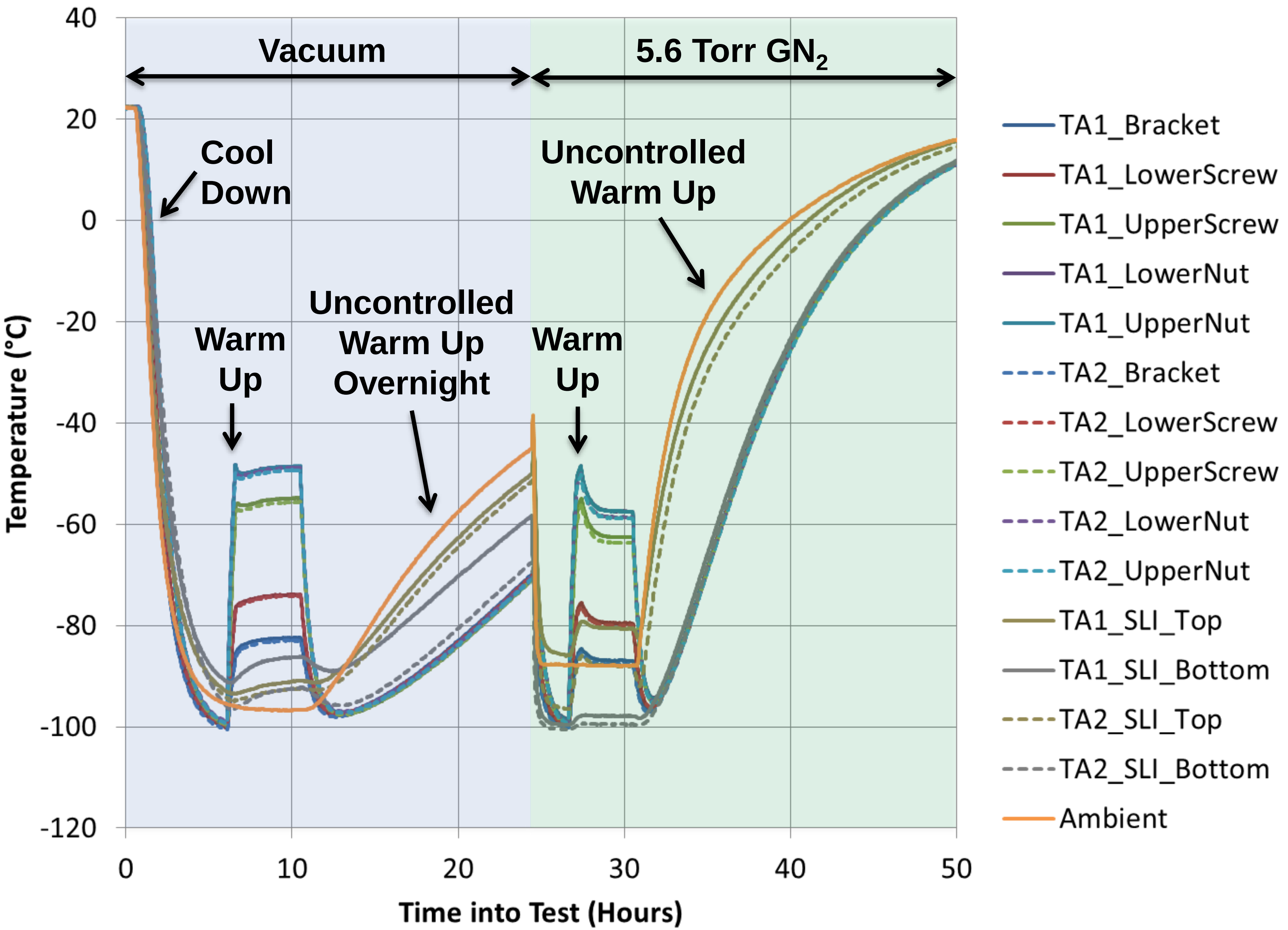




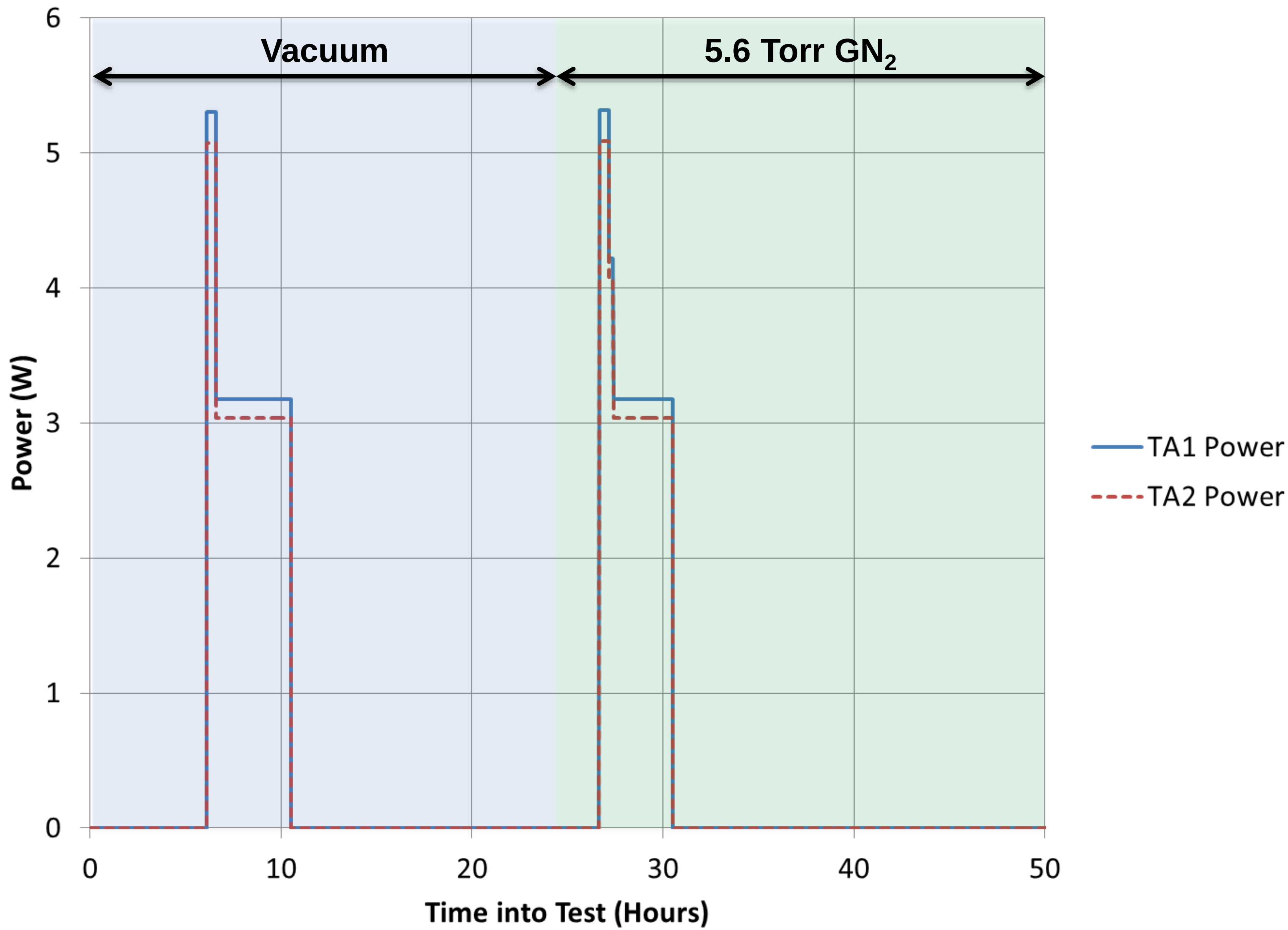




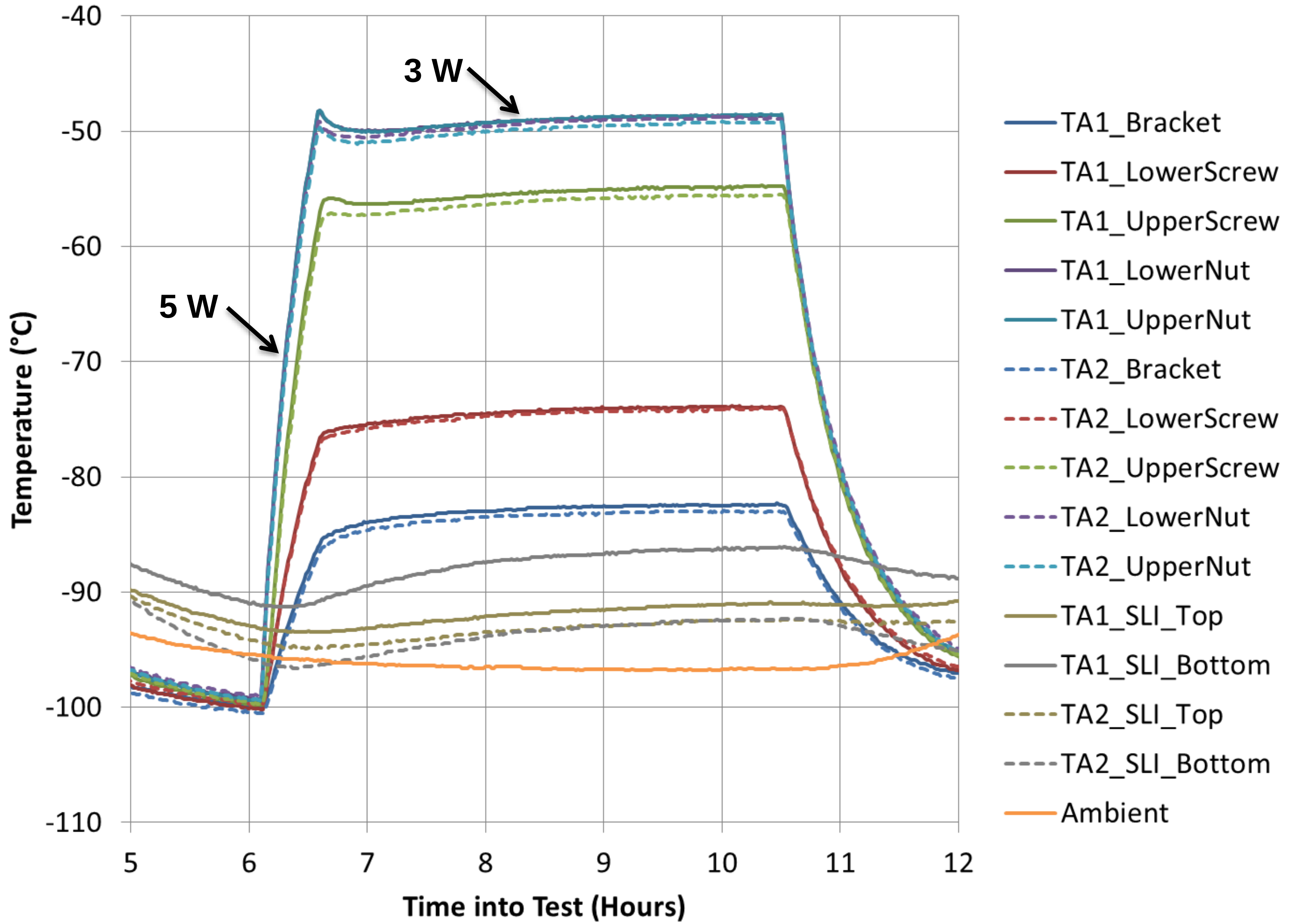
Complete Test Results



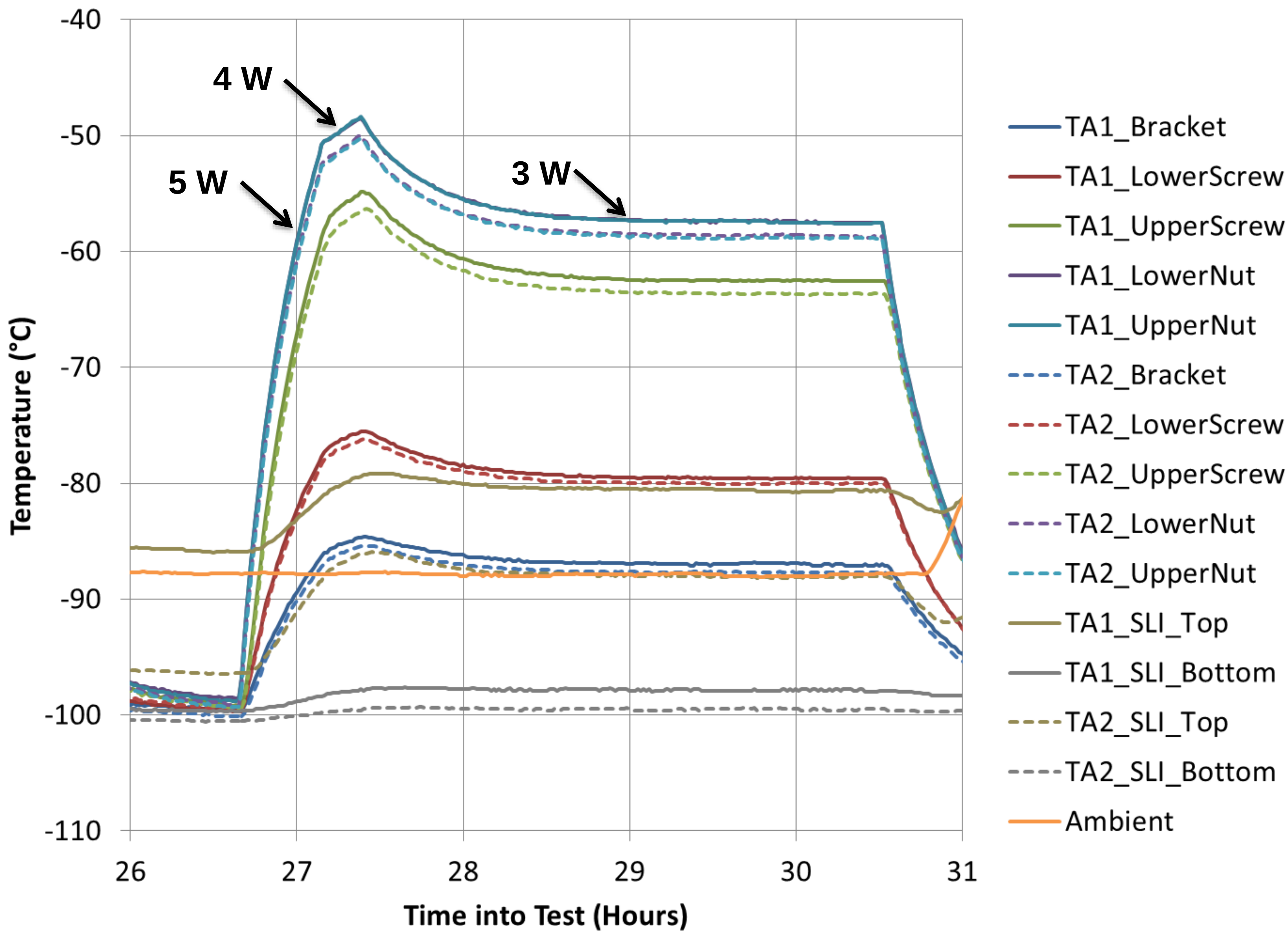
Heater Power



Vacuum Warm Up



5.6 Torr GN_2 Warm Up



Nut to Screw Conductance

- Rough Estimate:
  - $T_{Nut,Avg} = (T_{UpperNut} + T_{LowerNut})/2$
  - $T_{Screw,Avg} = (T_{UpperScrew} + T_{LowerScrew})/2$
  - $G_{Nut\text{-}Screw} = Power / (T_{Nut,Avg} - T_{Screw,Avg})$

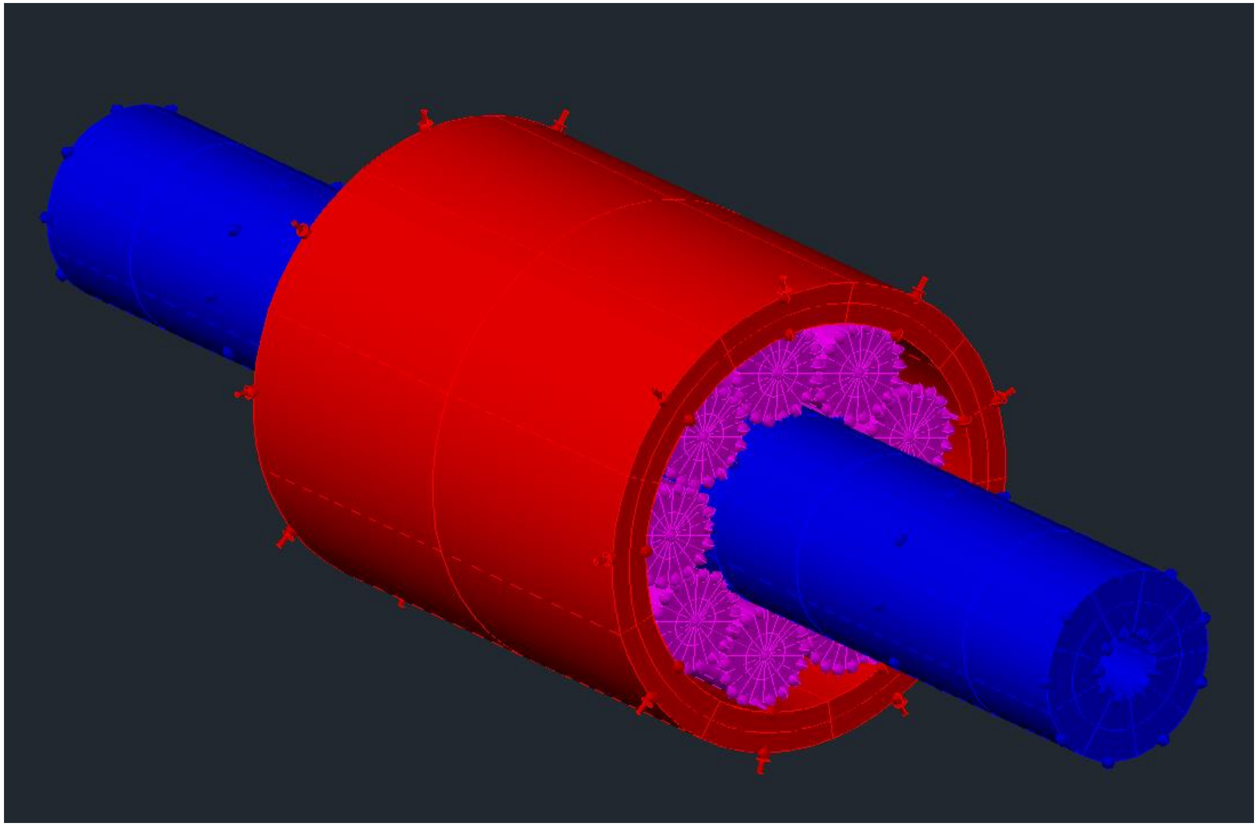
- Model correlation accounts for sources of error in the conductance measurement:
  - Thermocouple placement was not directly under the nut due to presence of screw threads, and axial screw gradients are significant.
  - Some heater power (< 7% estimated) is lost to the environment.

	Pressure	Test Article 1 Conductance (W/C)	Test Article 2 Conductance (W/C)
Rough Estimate	Vacuum	0.20	0.19
	5.6 Torr GN_2	0.23	0.23
Model Correlated	Vacuum	**0.25**	**0.25**
	5.6 Torr GN_2	**0.30**	**0.30**

Both conductance estimates exceed the goal value of 0.15 W/C

Thermal Model

- Detailed Thermal Model allows for correlation of Nut-Screw conductance.
- Key model assumptions are that:
  - Nut-Roller contact conductance = Roller-Screw contact conductance



Model Correlation

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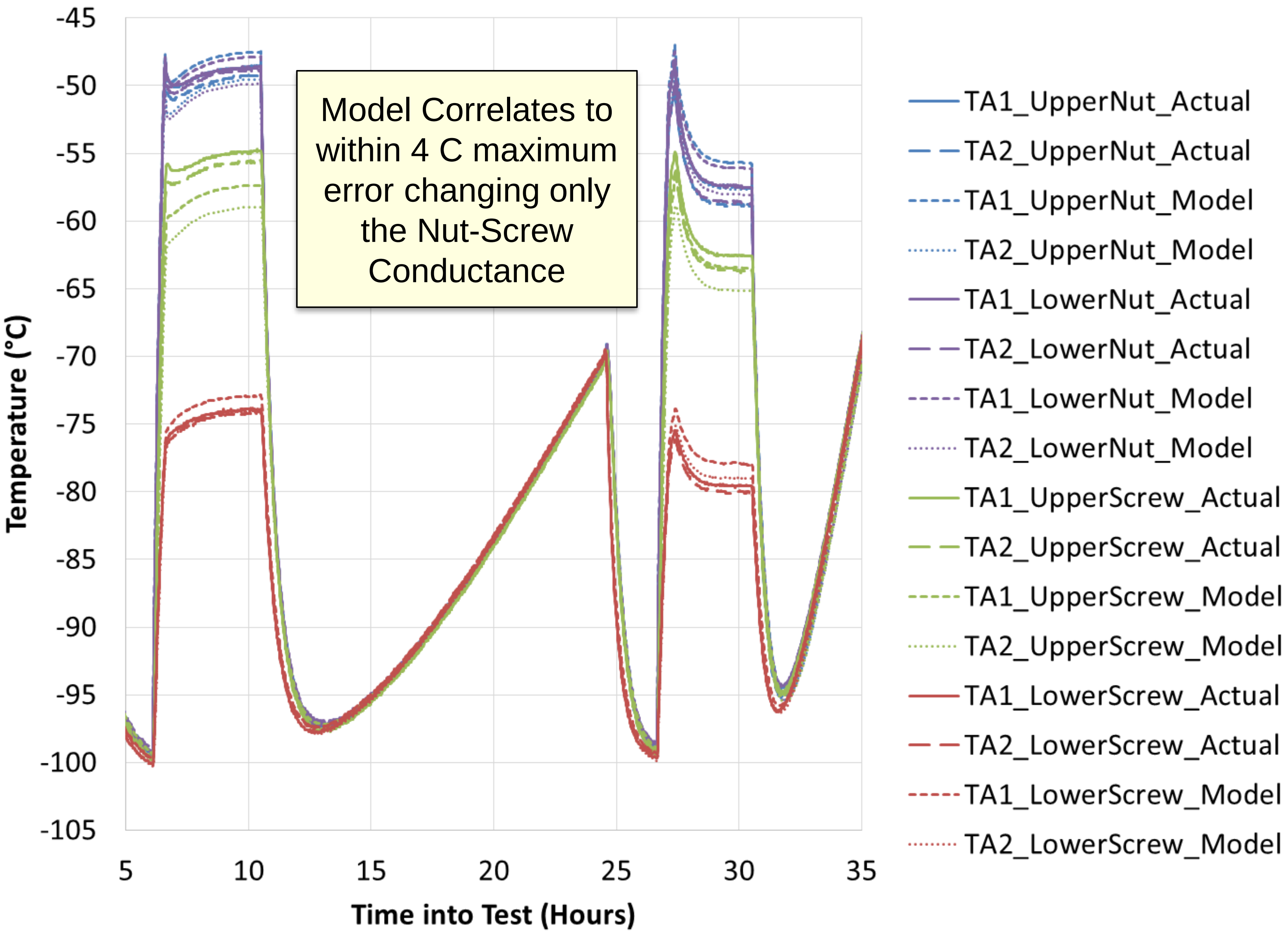

Sources of Error and Uncertainty

- Power Dissipation Uncertainty
  - Leads and feed throughs account for < 1% of 160 Ω Heater Resistance
  - **Error Contribution is < 1 %**

- Thermocouple Temperature Uncertainty
  - All TCs read +/- 0.25 C prior to testing
  - Nut-Screw Temperature Differences range from 5 to 25 C
  - **Error Contribution is < 5%**

- Uncertainty due to Heat Losses
  - Maximum estimated heat loss from nut = 7%
    - 2.82 W of 3.03 W transferred through assembly
  - **Error Contribution is < 7 %** (*accounted for in model correlation*)

Conclusions

- The conductance of the tested planetary roller screw is sufficiently large (> 0.15 W/K) so that it will not excessively slow down mechanism warm up.

- The Nut-Screw conductance of a 43 mm length, 35 mm diameter has been estimated as G = 0.25 to 0.30 W/K.
  - Extrapolation is possible for lubricated (grease plated) planetary roller screws of different dimensions, and conductance should scale linearly with length and diameter.
  - For comparison, a grease plated static ball bearing with OD of 35 mm would have an expected thermal conductance of 0.11 W/K +/- 50% [2].

- Nut-Screw Conductance is dominated by solid and grease conduction.
  - Nut-Screw conductance is significantly higher than would be expected from gas conduction alone.
  - Nut-Screw conductance is only a weak function of chamber pressure.

- Nut-Screw Conductance is only a very weak function of tolerances.
  - Any tolerance tighter than the loosest tested EDU unit is acceptable.

[2] Redmond, M., Novak, K., and Mireles, V., "Static Ball Bearing Thermal Conductance in Air and Vacuum: Review and Correlation," *AIAA Journal of Thermophysics and Heat Transfer* (accepted).

Acknowledgements

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References

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1. Farley, K., “Mars 2020 Project Update,” Committee on Astrobiology and Planetary Science, September 17, 2015. Accessed on 12/9/2016 from http://sites.nationalacademies.org/cs/groups/ssbsite/documents/webpage/ssb_169425.pdf

2. Redmond, M., Novak, K., and Mireles, V., “Static Ball Bearing Thermal Conductance in Air and Vacuum: Review and Correlation,” *AIAA Journal of Thermophysics and Heat Transfer* (accepted).