THERMOSPRING

Thermal Exchange Reduction Mechanism Using Optimized SPRING

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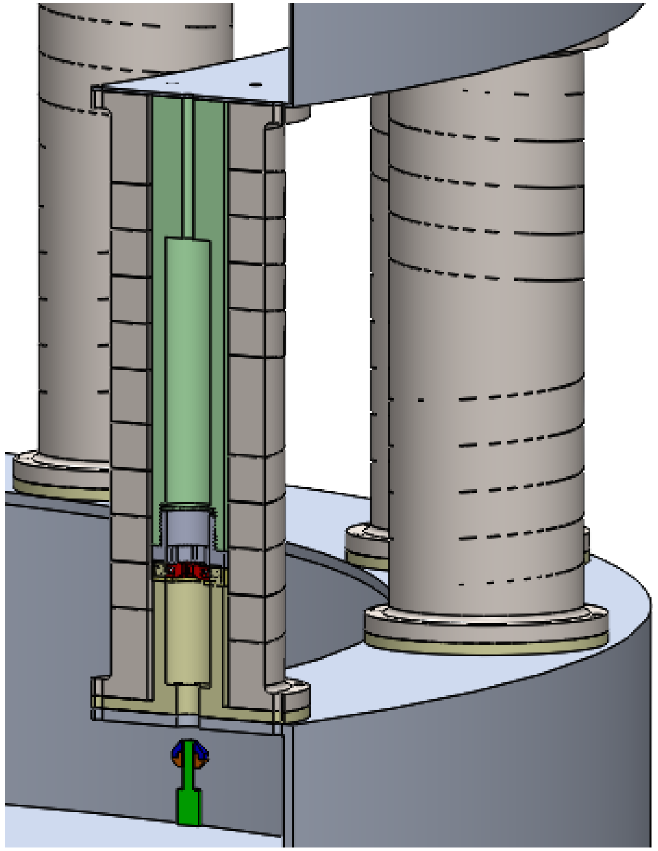
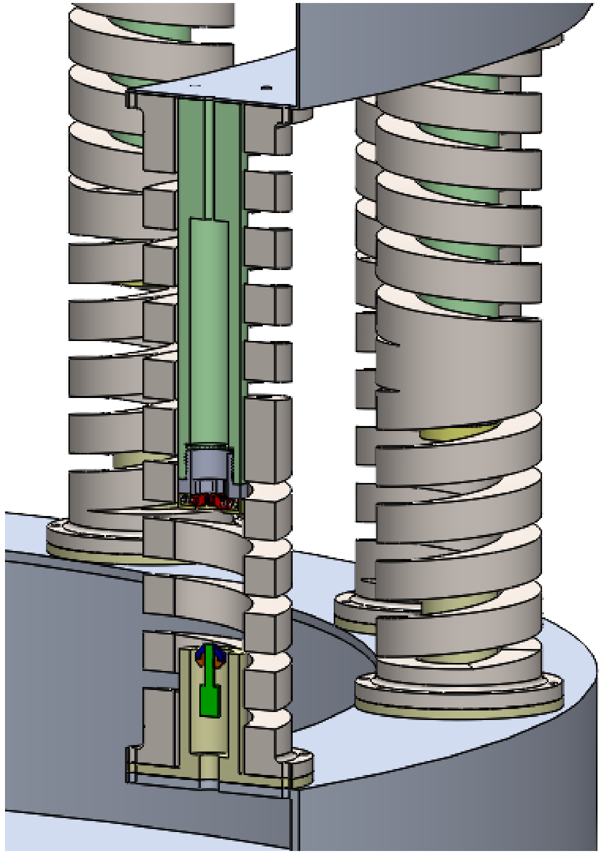




AGENDA

THE THERMOSPRING – DESIGN SUMMARY

Specific cryogenic challenge: advanced structural supports

The system has

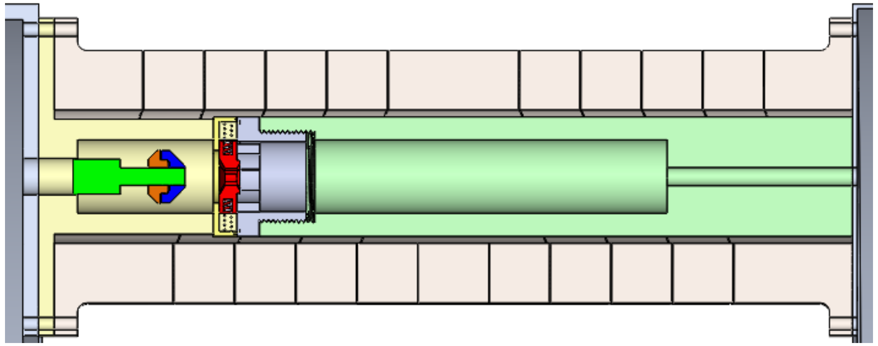
1. 14 springs
   - Each spring contains two inner concentric cylinders [28 total] that separate during expansion of the spring

2. A Push-Push lock mechanism that prevents premature spring expansion during high gravities during launch

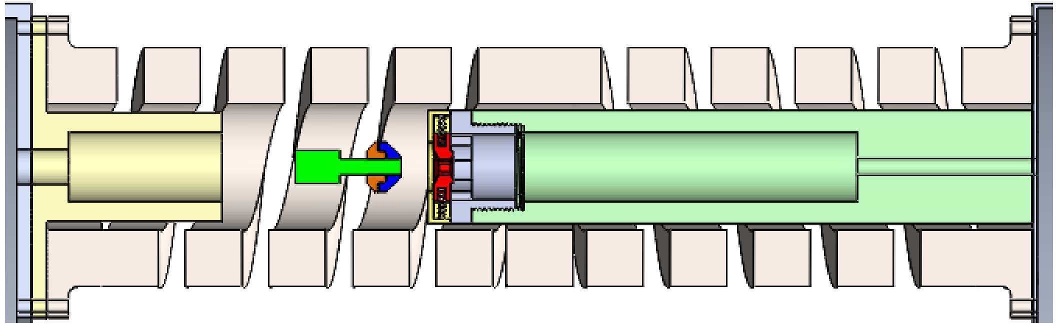
The system can

- Support the weight of the cryogenic tank on:
  - Earth at 6.1094E+06 N
  - Moon at 9.6234E+05 N
- Increase thermal efficiency by 99.76%

COMPRESSED VS EXPANDED SPRING



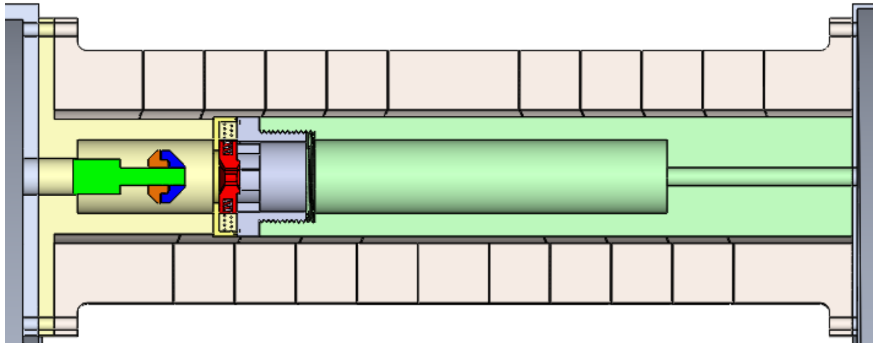
On the Earth (9.81 m/s^2) supporting 6.1094E+06 N

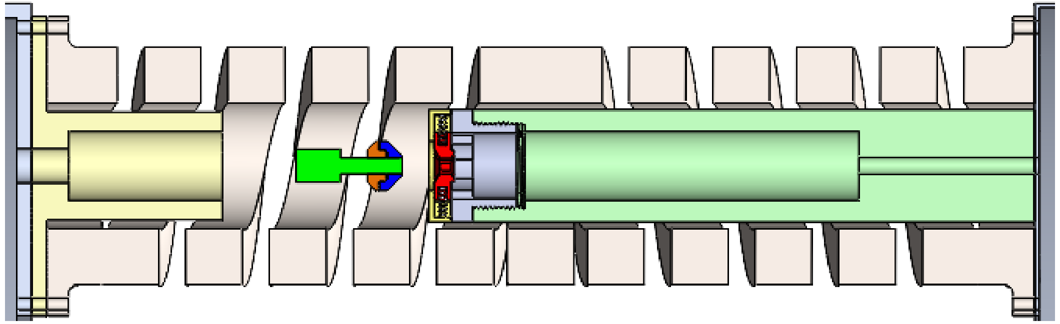


On the moon (1.625 m/s^2) supporting 9.6234E+05 N

- Due to the weight differences, the spring will expand automatically as it transitions from earth to the moon as there is now less weight compressing the spring
- Elimination of conductive heat transfer through inner cylinders in orbit and in low gravity environments [the moon] by using a gravity dependent expansion and compression system

THERMOSPRING





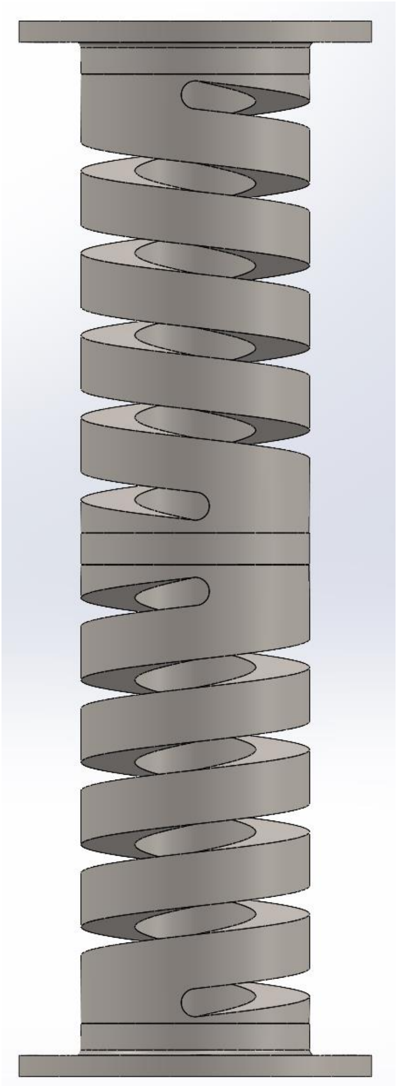
- Inner cylinders provide structural stability and prevent lateral movement
- Increased thermal resistance, therefore reduced heat leak, by increasing the length heat must travel through in the spring wire   R=L/KA
- Mostly mechanical system equating to rapid technological substitution

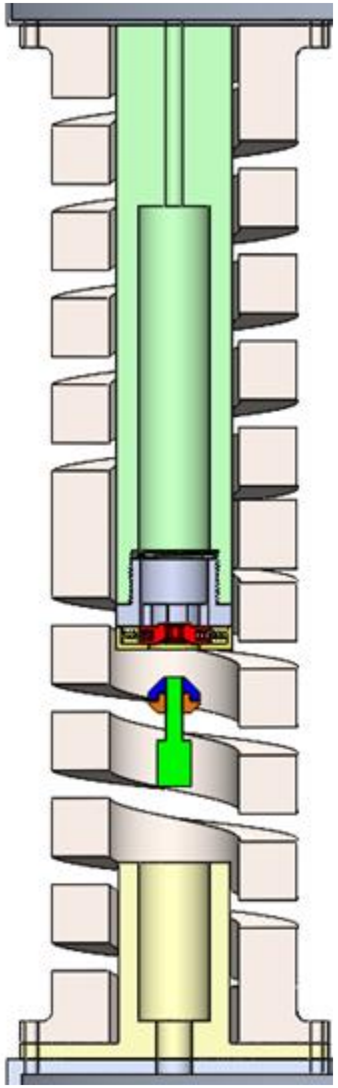
THERMOSPRING – SPRING DESIGN

- Square wire profile and opposing twists.
- Integrated flanges
- Machined spring design improves manufacturability and reduces part count

$$k_{spring} = \frac{\Delta F * FOS}{\Delta x_{max}}$$

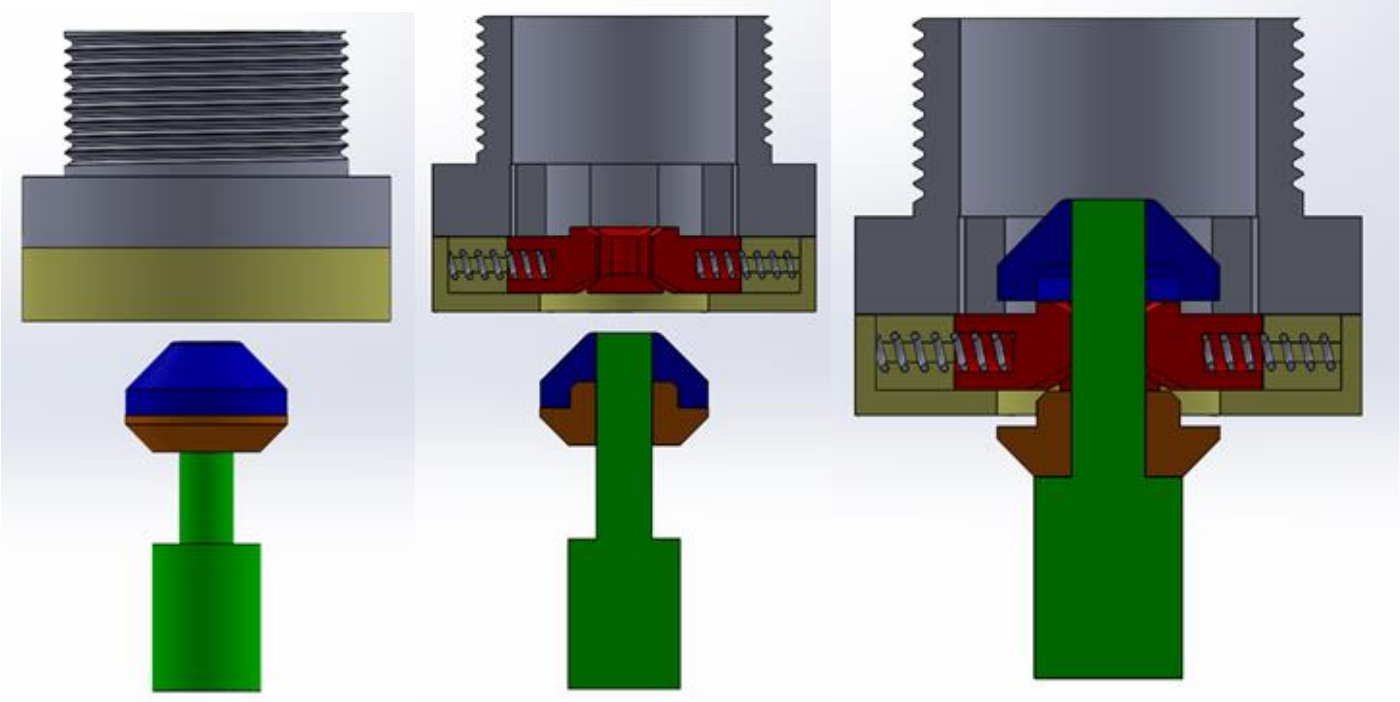
$$b_{wire} = \left(\frac{k_{spring} * \ 44.5 \ * \ \mathrm{r}_{\mathrm{spring}}^{3} \ * \ \mathrm{n}_{\mathrm{coils}}}{G_{titanium}} \right)^{1/4}$$



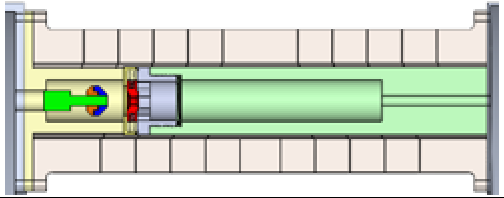
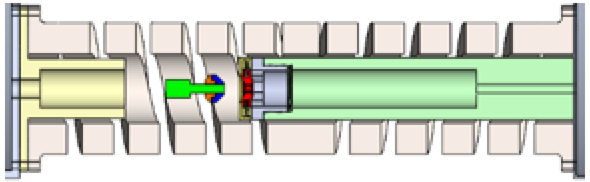
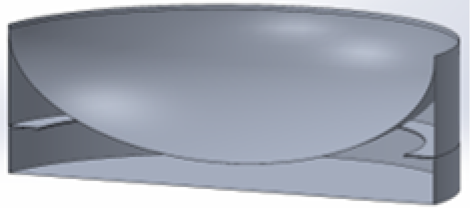
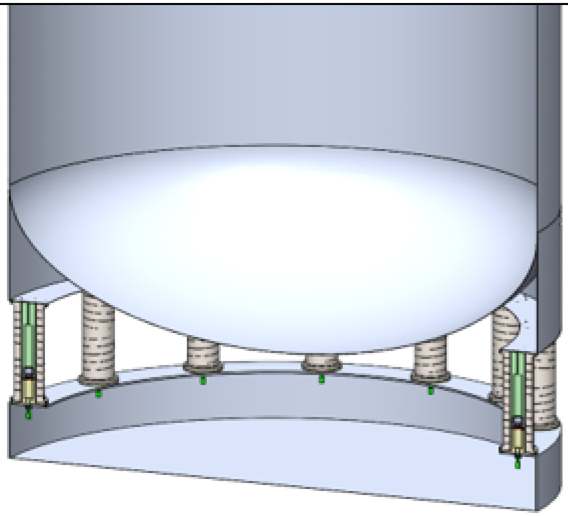
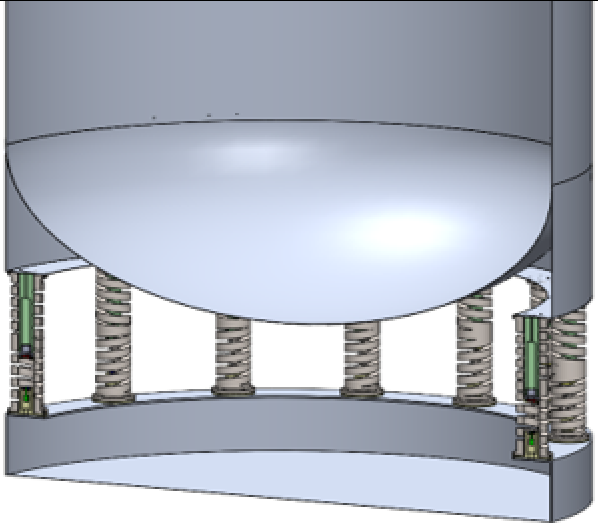


THE THERMOSPRING: PUSH-PUSH LOCK

- Provides positive control over system
- Self-aligning
- Able to integrate with jack screws and linear actuators



THERMAL RESISTANCE CALCULATIONS

CASE 1	**CASE 2**	**CASE 3**
Without THERMOSPRING	With compressed THERMOSPRING 	With expanded THERMOSPRING 
Flange to Flange	**Flange to Compressed Spring System to Flange**	**Flange to Expanded Spring System to Flange**
Applicable Environment This System Encounters: On Earth, in orbit, and on the moon	Applicable Environment This System Encounters: On Earth	Applicable Environment This System Encounters: In orbit, on the moon, or any low gravity situation.
		
$R_{flange} = 0.0396$ K/W $q_{flange} = 1930$ W	$R_{compressed} = 1.5443$ K/W $q_{compressed} = 49.5189$ W	$R_{expanded\_spring} = 16.75$ K/W $q_{expanded\_spring} = 4.57$ W

THERMAL RESISTANCE CALCULATIONS

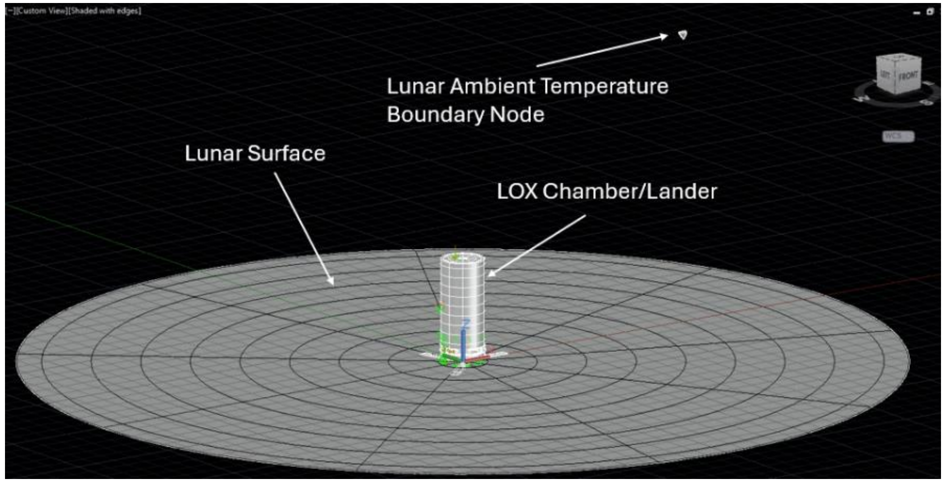
	Without THERMOSPRING		With THERMOSPRING	
	Rth (K/W)	Heat Rate $Q=\Delta T/Rth$ (W)	Rth (K/W)	Heat Rate $Q=\Delta T/Rth$ (W)
Pre-Launch (1-15 g, atmospheric)	R = 0.0396 K/W	Q=1930 W	R = 1.5443 K/W	Q = 49.5189 W
In Orbit (0 g, vacuum)	R = 0.0396 K/W	Q=1930 W	R = 16.75 K/W	Q= 4.57 W
On the Moon (0.17 g, vacuum)	R = 0.0396 K/W	Q=1930 W	R = 16.75 K/W	Q= 4.57 W

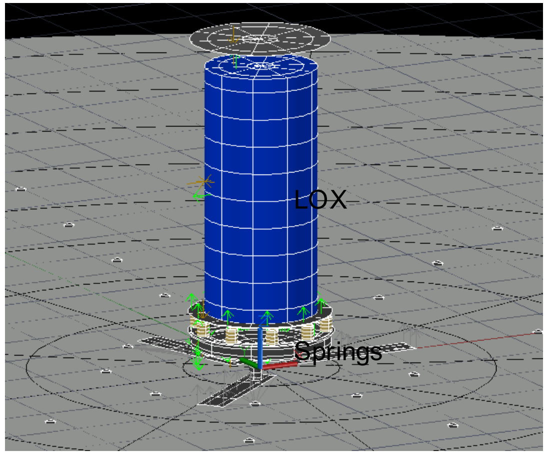
THERMAL SIMULATION

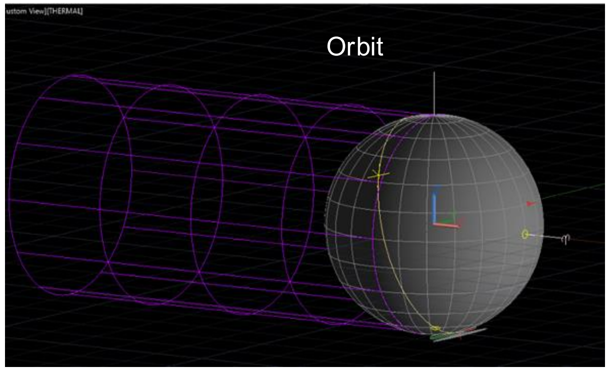
- Radiation and Conduction are only methods of heat transfer
- Surface emissivity used are from polished metals
- Solve estimated thermal resistances from resistance equations and Spacecraft Thermal Control Handbook Vol.1.

$$R_{cond} = \frac{L}{KA} \quad R_{rad} = \frac{1}{h_r A} \quad where\ h_r = \varepsilon\sigma(T_s + T_{env})(T_s^2 + T_{env}^2)$$

- Uses moon orbital simulation keeping the LOX lander around the same bottom portion to mimic the solar flux and angle of incident radiation

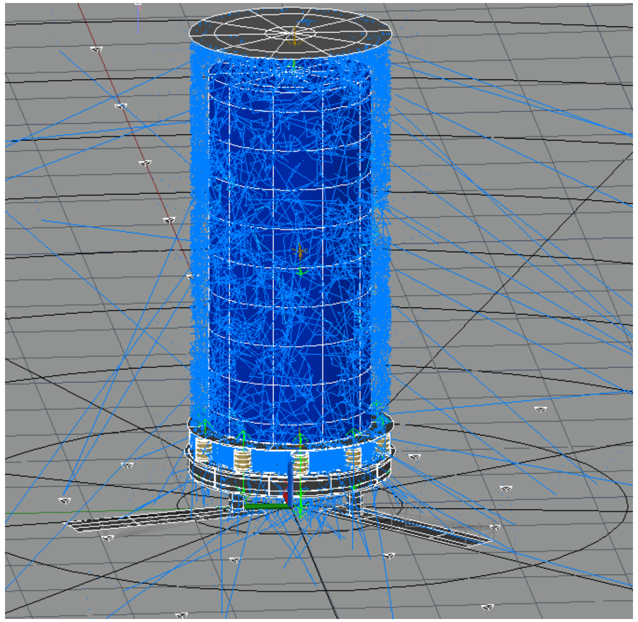


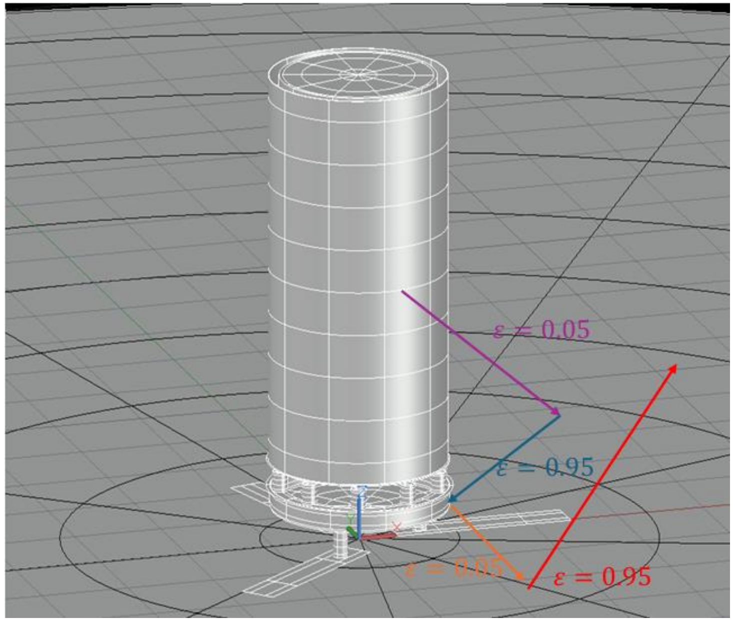




RADIATION CONDUCTORS- MONTE CARLO METHOD

- Radiation conductors solved in the simulation by the monte carlo method.
- Radks ray tracing are shown by the blue lines and are plotted for 1 ray per node in the model, while the simulation runs at 25,000 rays per node, until the ray thermal energy falls below a threshold value.
- Far right is an example calculation for deposited thermal energy dependent on the surface emissivity which will give the gray body factor.





$$Radk = (G_{rad})_{ij} = \varepsilon_i A_i B_{ij}$$

ε_i – emittance of node i

A_i – surface area of emittance node (i)

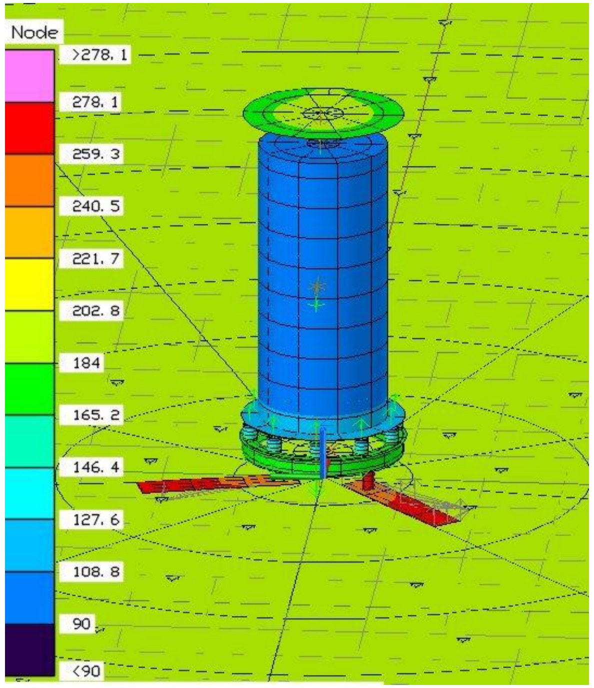
B_{ij} – gray body factor from i to j

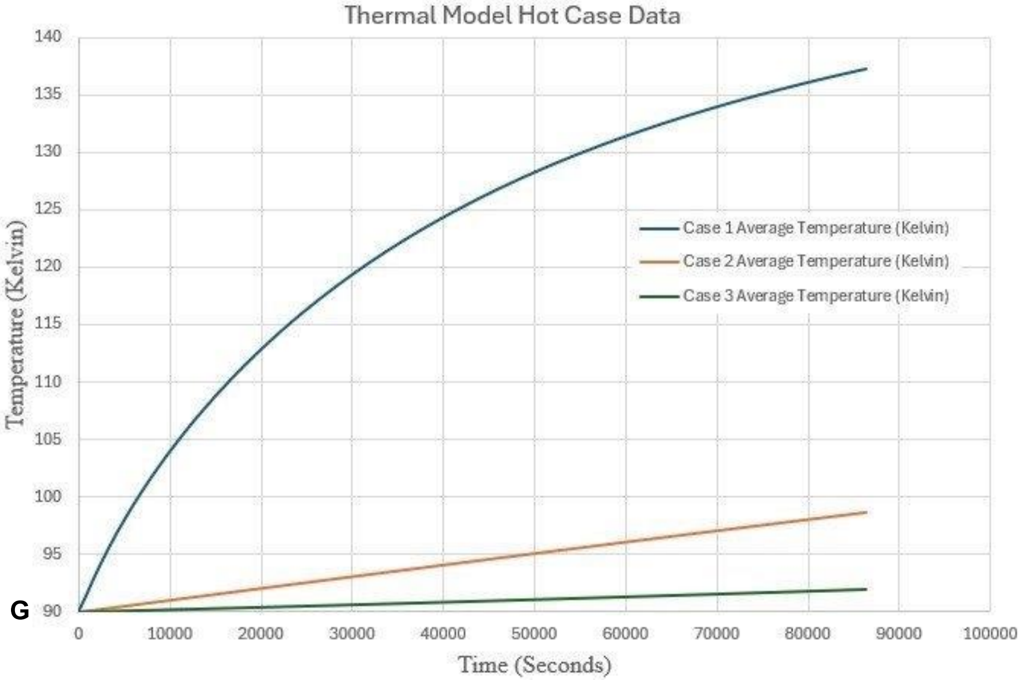
$$q_{rad} = \varepsilon_i A_i B_{ij}(T_i^4 - T_j^4)$$

Path	Fraction of Deposited Energy	Fraction of Reflected Energy
1-2	0.95	0.05
2-3	0.0025	0.0475
3-4	0.045125	0.002275

THERMAL SIMULATION RESULTS

- 3 Cases for each thermal resistance no spring, compressed spring, and expanded spring.
- A 24-hour transient thermal simulation was performed for three cases with different thermal resistances.
- Case 1 (0.0396 K/W) showed rapid heating, reaching over 95% of its ~137 K equilibrium in about 3.5 hours.
- Case 2 (1.5443 K/W) warmed more slowly, reaching only ~98 K after 24 hours.
- Case 3 (16.75 K/W) had minimal temperature rise, reaching just ~92 K, showing how higher resistance slows and limits heating.





PATH TO FLIGHT: PROJECT TIMELINE

- At this given state THERMOSPRING shows a NASA TRL of 2-3, as we have formulated a concept and the application, as well as done some preliminary analysis (proof-of-concept)

YEAR 1 QUARTER 1-2	YEAR 1 QUARTER 3-4	YEAR 2 QUARTER 1-2	YEAR 2 QUARTER 3-4	YEAR 3 QUARTER 1-3	YEAR 3 QUARTER 4
Defining mission objectives, constraints, and performance. Along with preliminary CAD Modeling	**Analysis on design making iterations and begin making manufacturing plan with preliminary testing**	**Material Durability testing such as vibration and damage tolerance to ensure long term stability**	**Exposing prototype to thermal cycling to check for thermal expansion and iterate design based on results**	**Begin fabricating flight hardware as well as begin system assembly and integration testing**	**Final testing and submission for mission integration**

PATH TO FLIGHT: PROJECT BUDGET

- $150,000 Proposed Budget, which includes manufacturing, labor, and any overhead costs
- 3-year Timeline to Final Prototype and integration
- Estimations made from Analogs and NASA costing tools
- Estimated budget ensures long-term reliability and re-usability

Component	Quantity	Unit Cost ($)	Labor (Hrs)	Total ($)
Spring	14	3,471.16	4,000	80,596.24
Outer Cylinder	1	376.32	8	1016.32
Inner Cylinder	1	35.32	8	675.51
Skirt	1	1530.84	4,000	33,530.84
Screws	28	100	0	2,800
Washers	28	5	0	140
Push-Push Lock	14		8	14,538.02
Total				133,297
Budget				150,000

CONCLUSION AND FUTURE WORK

- System improves resistance to heat transfer by conduction over traditional structures
- Low part count and complexity improves reliability and manufacturability.
- Future work
  - Integrate linear actuator
  - Revise thermal analysis