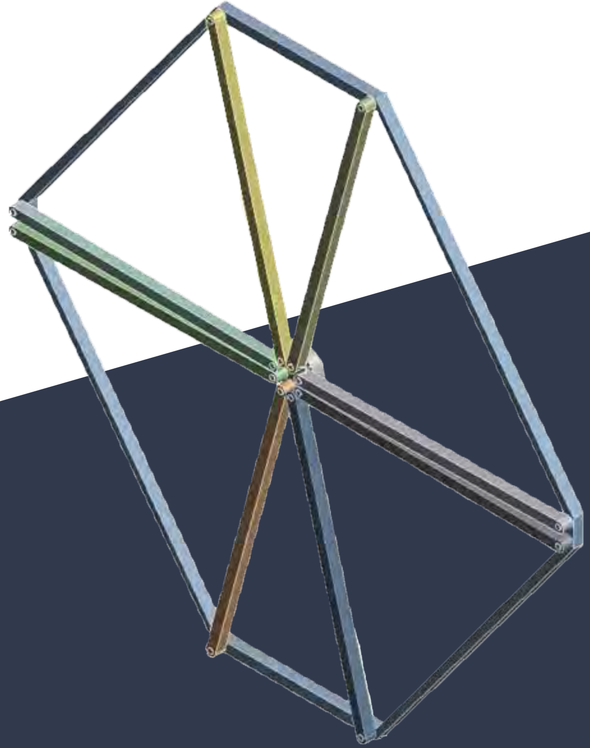
Design of a Passive Thermal Switch with Coupled Bi-material Triangles



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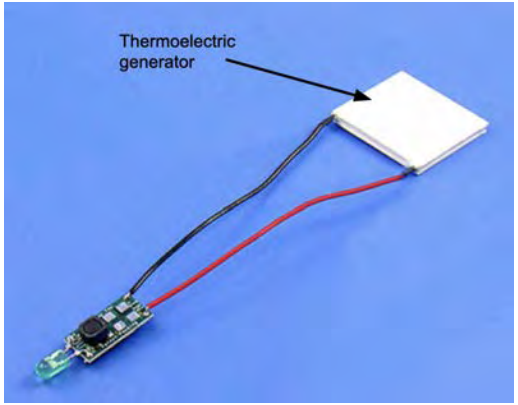
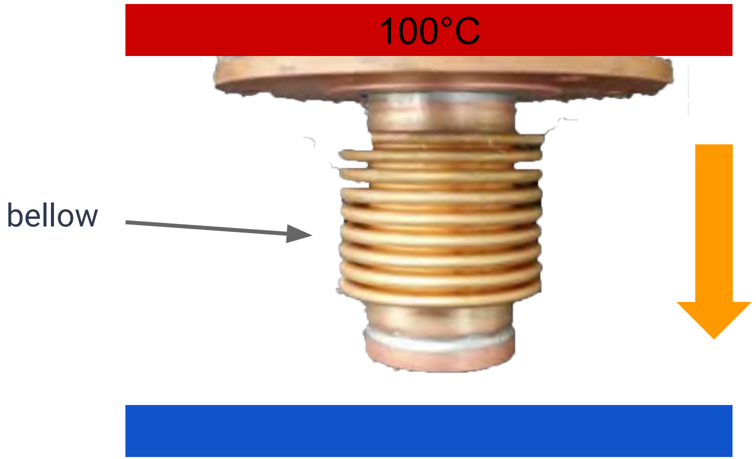
Historical Background

- **Planetary Exploration Mission** need to maintain rover's elements in their operational temperatures
- **Waste Heat Scavenging Technology** to redirect heat into thermoelectric generators and convert heat to electricity
- **Cold locations** uses thermosyphons to prevent permafrost from melting and stabilize buildings



Types of Thermal Switch

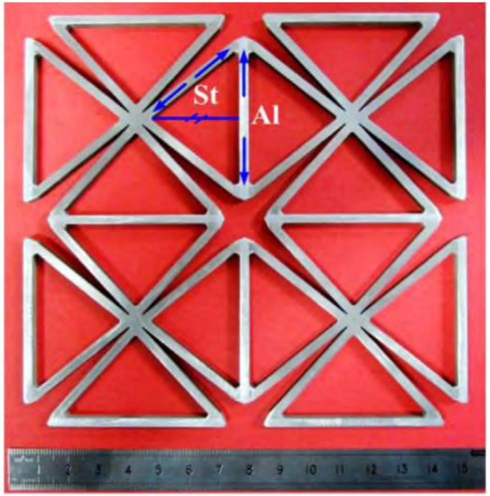
- There exist two type of thermal switch - **active** and **passive**
- A passive switch behaves **both** as a thermal insulator and conductor



1. Velson NV, Tarau C, Anderson WG. Two-phase thermal switch for spacecraft passive thermal management. *45th International Conference on Environmental Systems ICES*. 2015. http://hdl.handle.net/2346/64349.

Design of a Passive Thermal Switch

- Thermal Properties: **thermal conductivity** of the constituent materials directly influences
- Thermomechanical Properties: **contact mechanism** is possible with smart adaptations



2. Wei K, Chen H, Pei Y, Fang D. Planar lattices with tailorable coefficient of thermal expansion and high stiffness based on dual-material triangle unit. *Journal of the mechanics and physics of solids*. 2016.

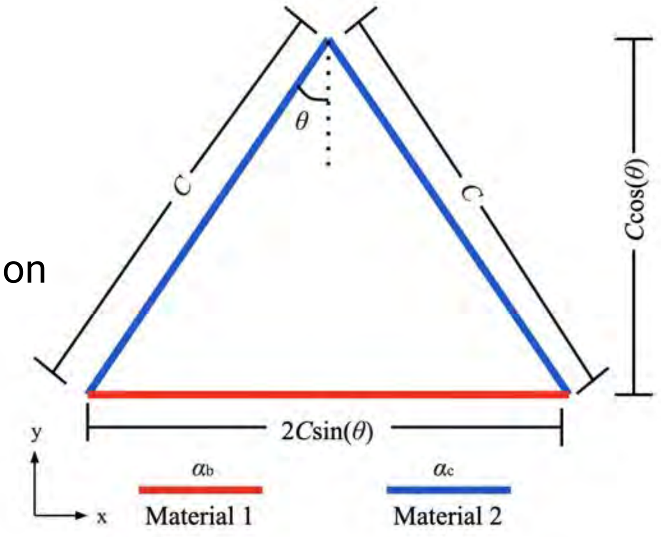
Thermal Expansion of Bi-Material Triangle

The **coefficient of thermal expansion** comes from the expansion of both crossed and base members

- The following equation gives the effective coefficient of thermal expansion:

$$\alpha_E = \alpha_c \cos(\theta)^2 [1 - (\alpha_b/\alpha_c) \sin(\theta)^2]$$

Where:
α_E = total bi-material triangle coefficient of thermal expansion
α_c = crossed member coefficient of thermal expansion
θ = half angle between the crossed members
α_b = base member coefficient of thermal expansion

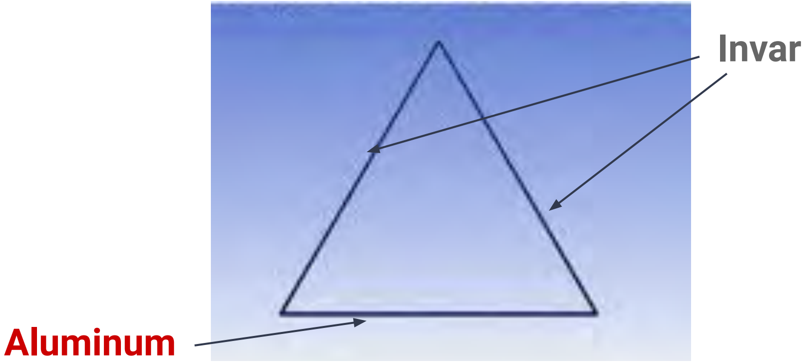


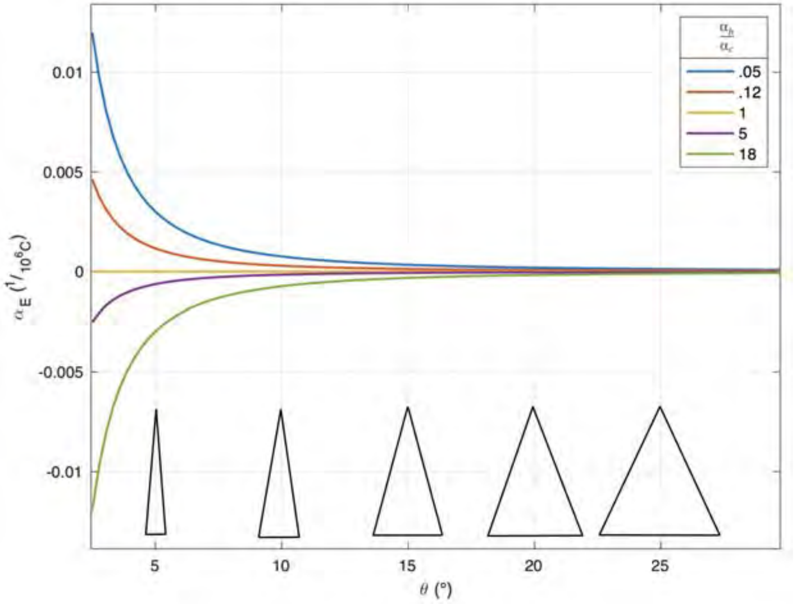
Bi-Material Triangle CTE

$\alpha_E = \alpha_c \cos(\theta)^2 [1 - (\alpha_b/\alpha_c) \sin(\theta)^2]$

From the graph below, we can observe how α_E relies from α_b/α_c and θ:

- The more difference in α_c and α_b, the more drastic in α_E
- The smaller the angle θ in between, the more in changes in height



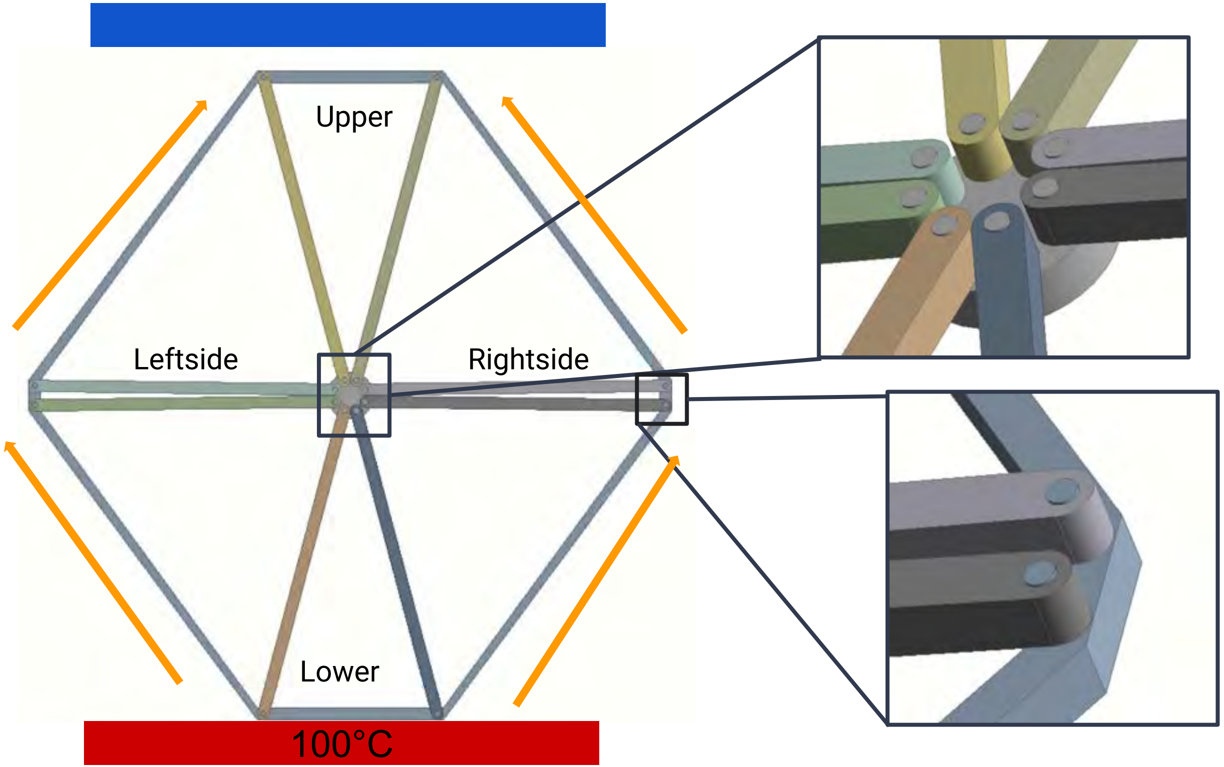


$$\frac{\text{Base}}{\text{Cross}} = \frac{\textbf{Aluminum}}{\textbf{Invar}} = \frac{24\ \mu m/m\cdot K}{1.2\ \mu m/m\cdot K} = 20$$

Geometrical Modeling of Bi-Material Triangle

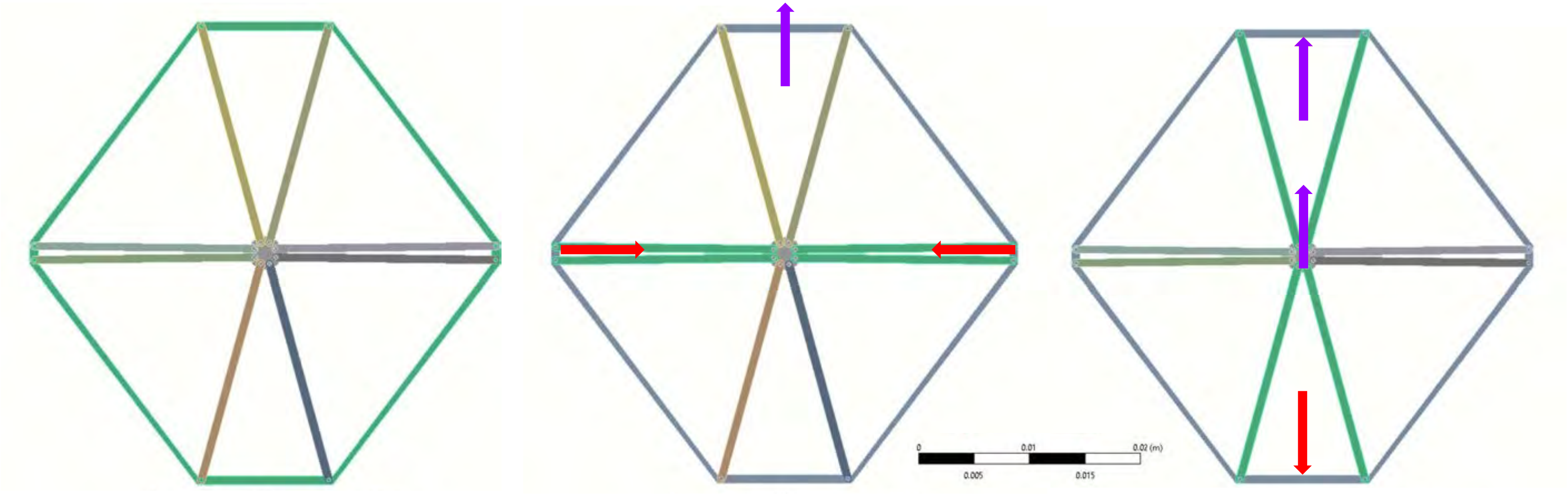
Modeling Statistics:

- 10 Bodies
  - 8 crossed members
  - 1 external member
  - 1 connector
- 117 Faces



Thermal Expansion with Increase in Temperature

Medium Coefficient of Thermal Expansion | **Low** Coefficient of Thermal Expansion | **High** Coefficient of Thermal Expansion

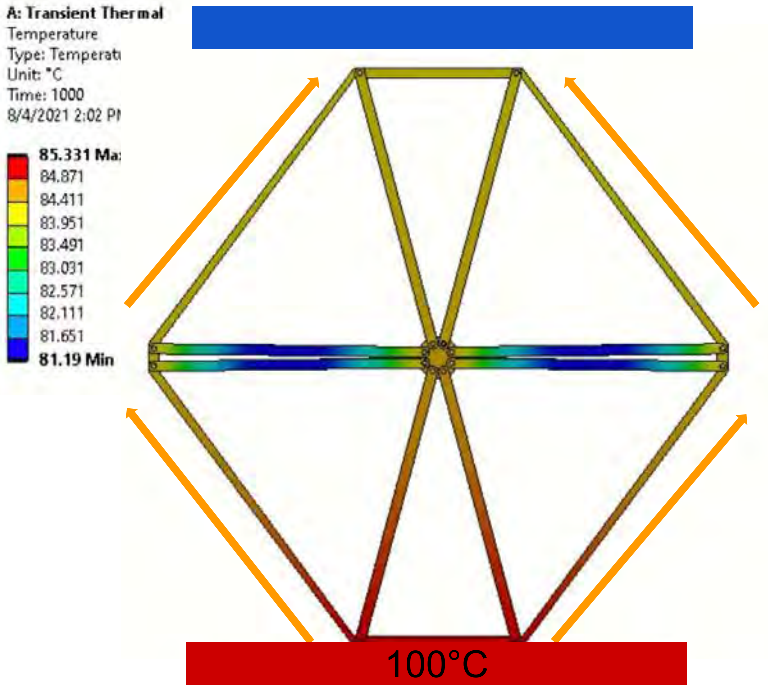


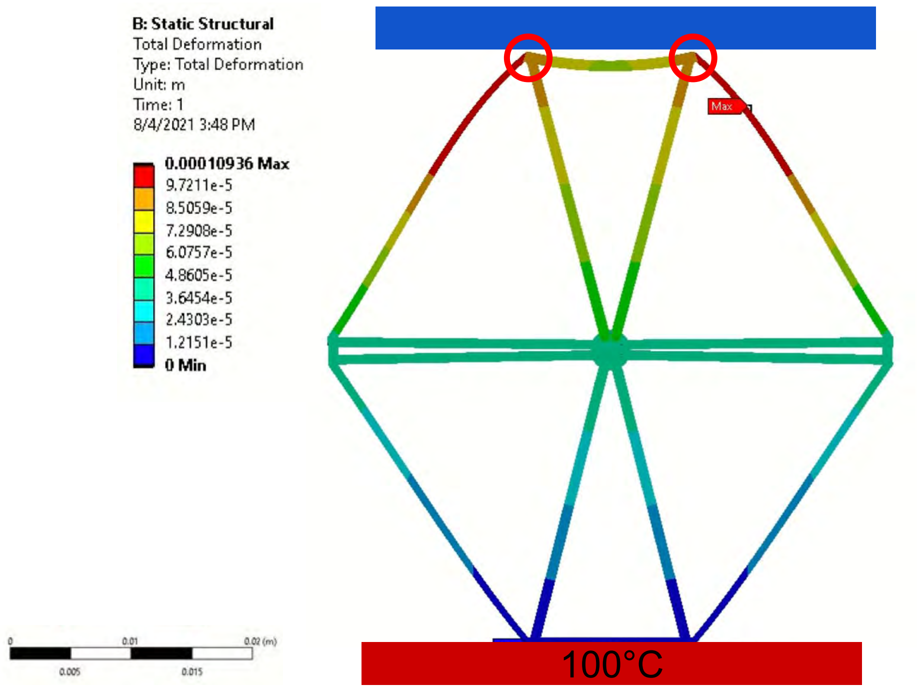
Copper Tungsten **7** µm/m·K
High Thermal Conductivity

Silica **.55** µm/m·K
Low Thermal Conductivity

Aluminium **24** µm/m·K
High Thermal Conductivity

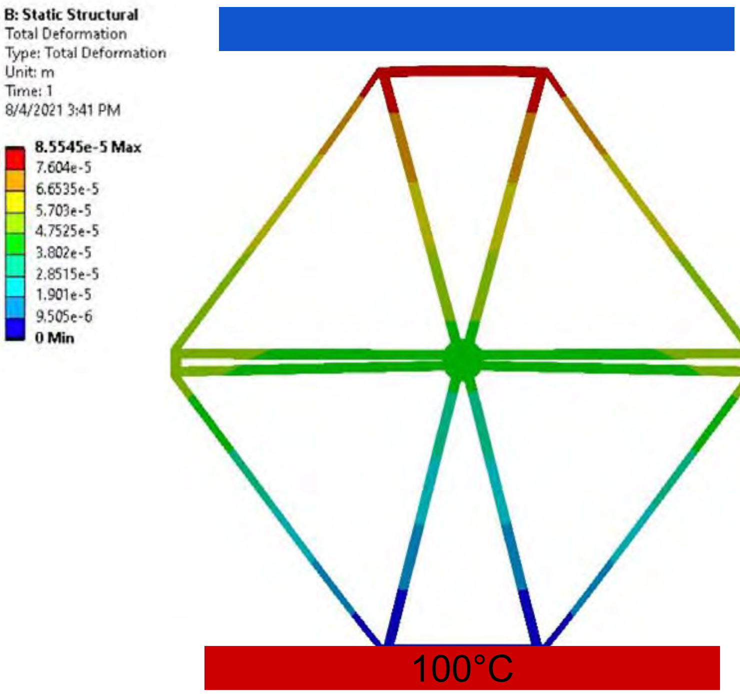
Thermal and Thermomechanical Performance

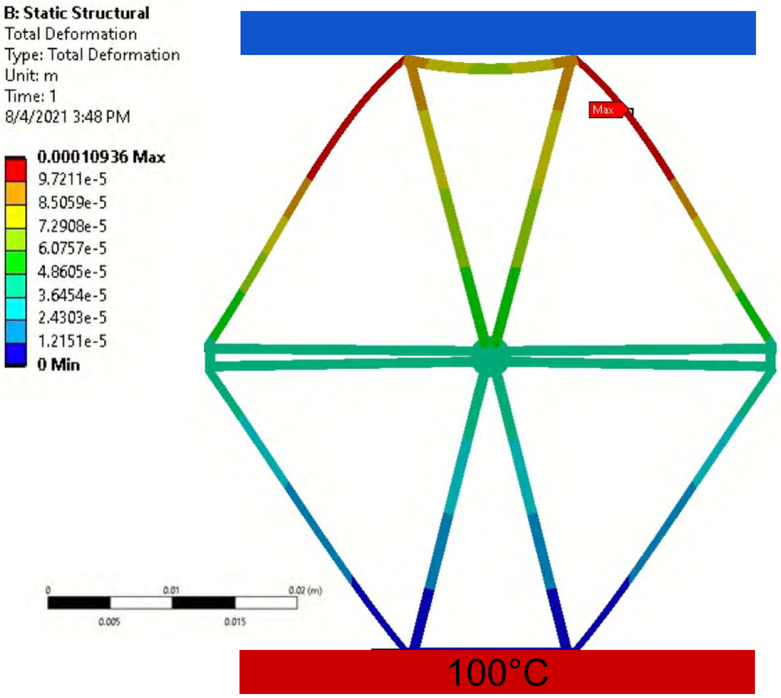




The maximum total deformation is **.00010936 meters** from a 80° temperature change.

Unimaterial Triangle vs Bi-material triangle



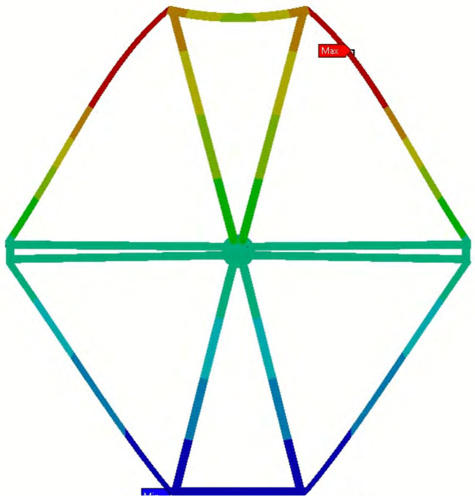


In contrast with uni-material triangle, bi-material triangle has a **27.84%** increase in thermal deformation

Design Improvements and Future Applications

- Improve **angle movement** and **adaptation** in the triangle members by using softer materials
  - Nanoengineered composite polymers achieve high flexibility and high thermal conductivity (2021).
- Implement round corners to allow **stress** to move more freely throughout the structures
- Introduce impurities in the outer shell part to become more **malleable** especially in the corners of triangles.

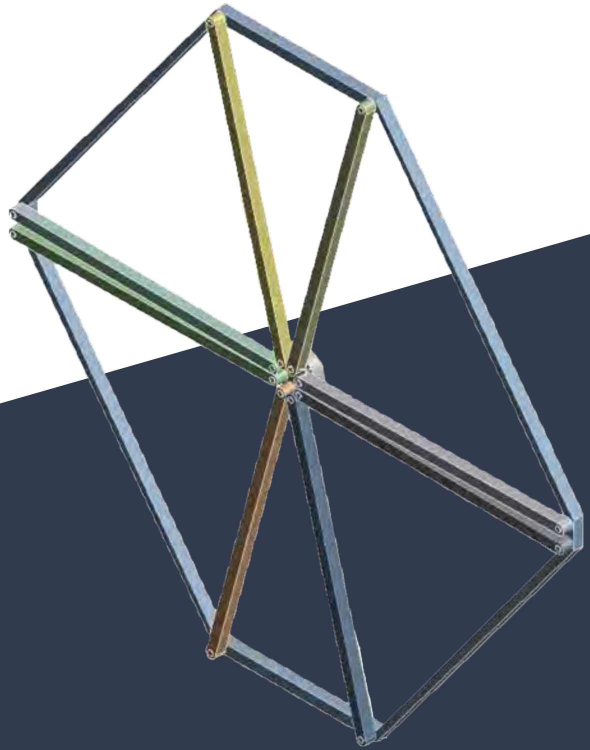
- Fine coating technology to achieve thermal control in flat surfaces
- Redirect heat using smart placement with their small size



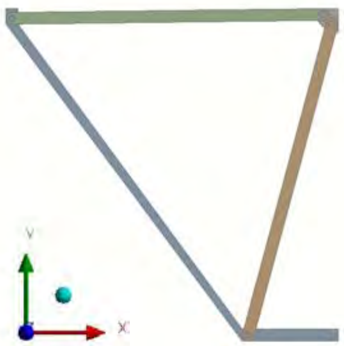
Acknowledgments

- Professor Jennifer Lukes for her guidance and feedback
- NSF [code number]

Q & A

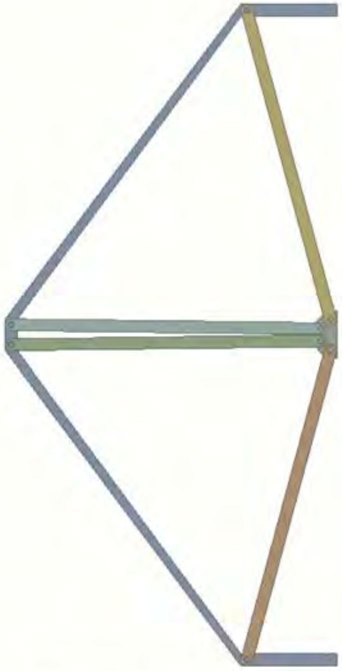


Geometric Modeling Design



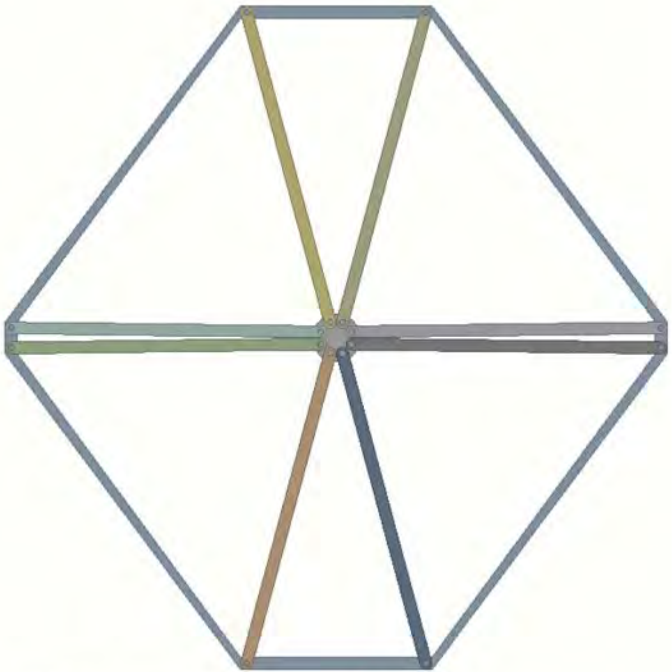
Mirror

xy-axis

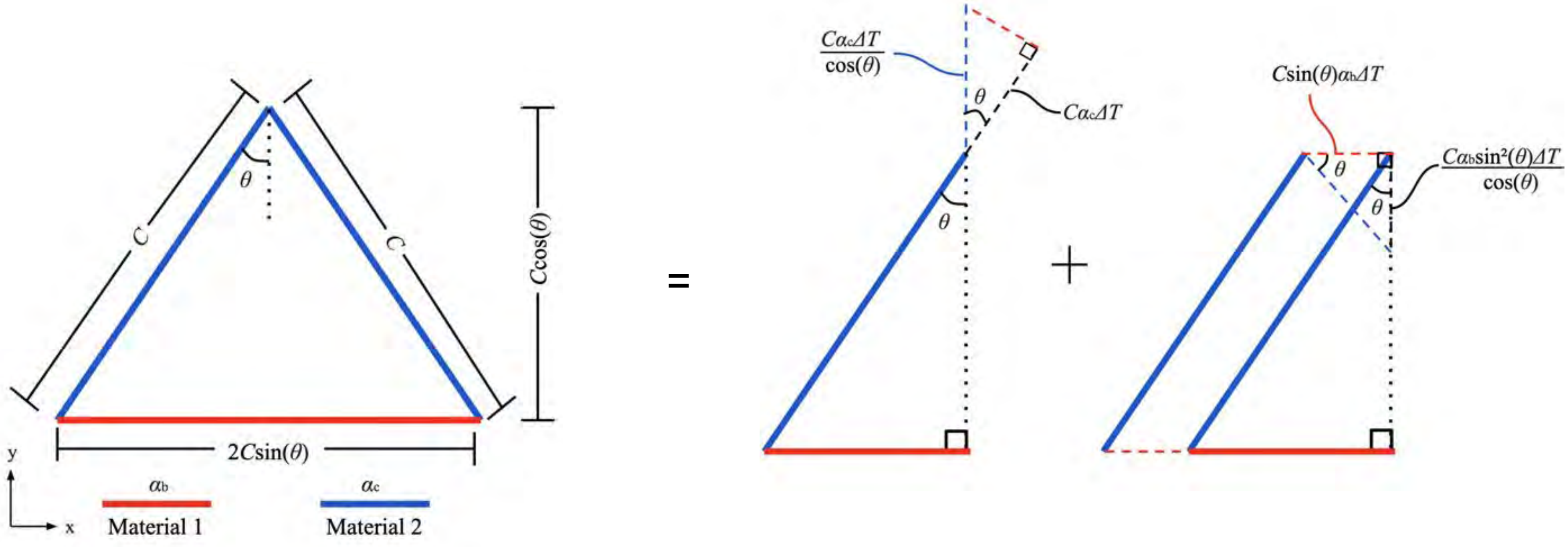


Rotation

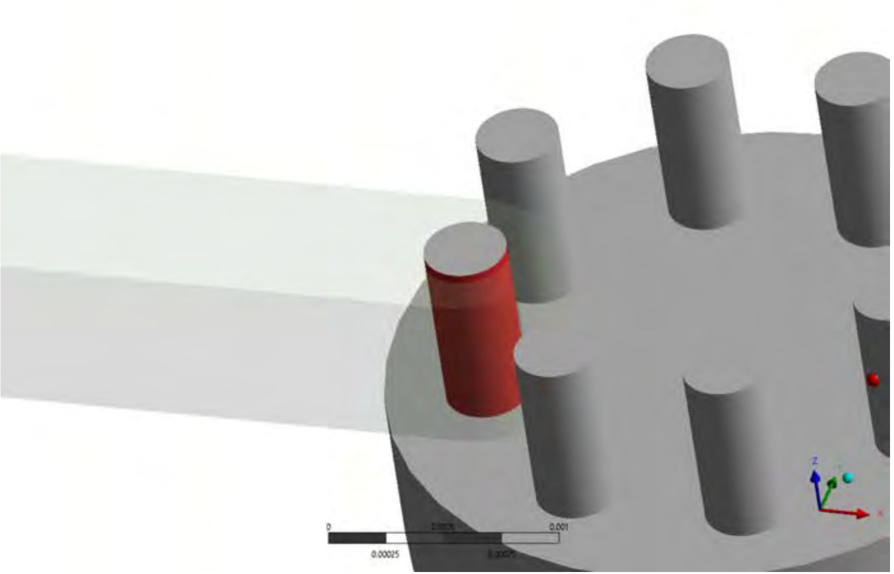
180° in z-axis

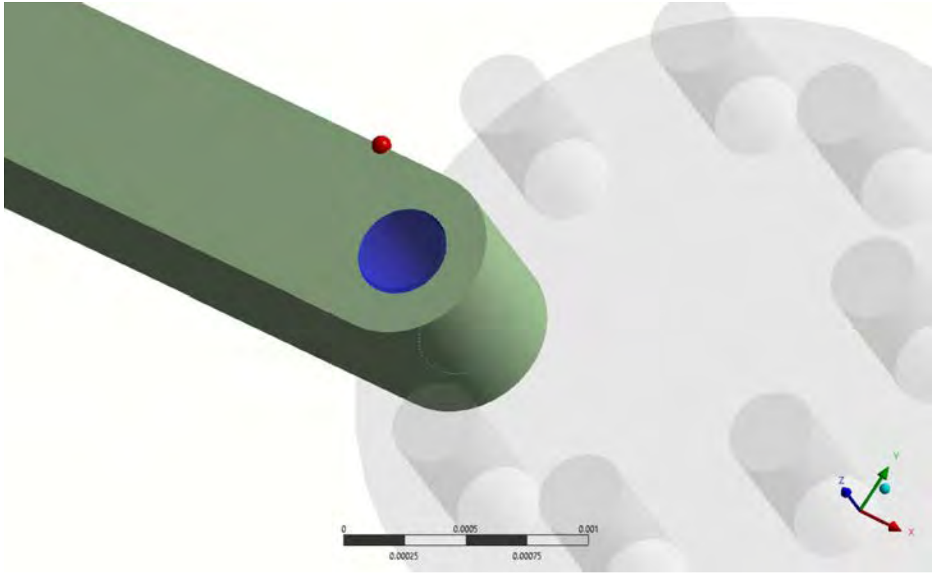


Derivation of Effective CTE of Bi-Material Triangle



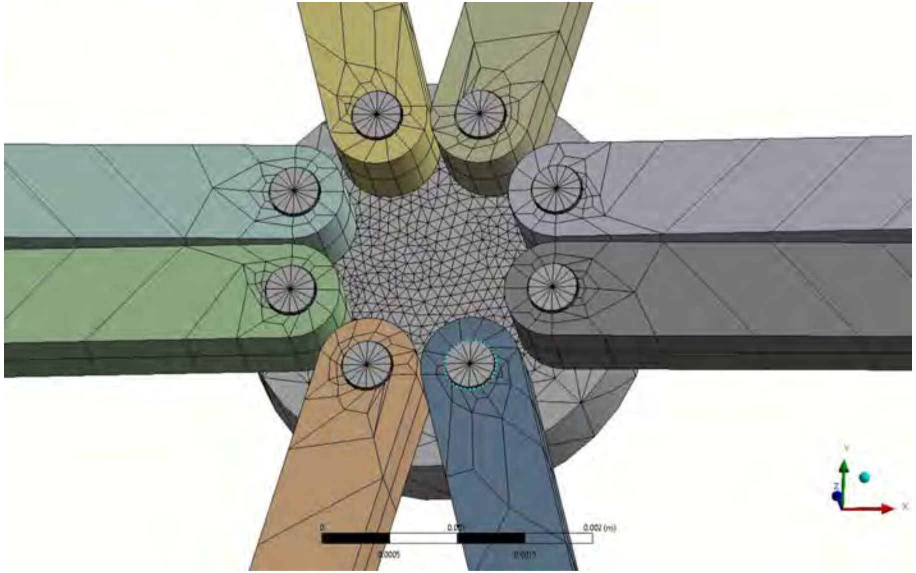
Rotational Pins and Corners





Meshing during Thermal and Structural Simulation

Middle View



Right View