Thermal Characterization of 3D Printed Lattice Structures

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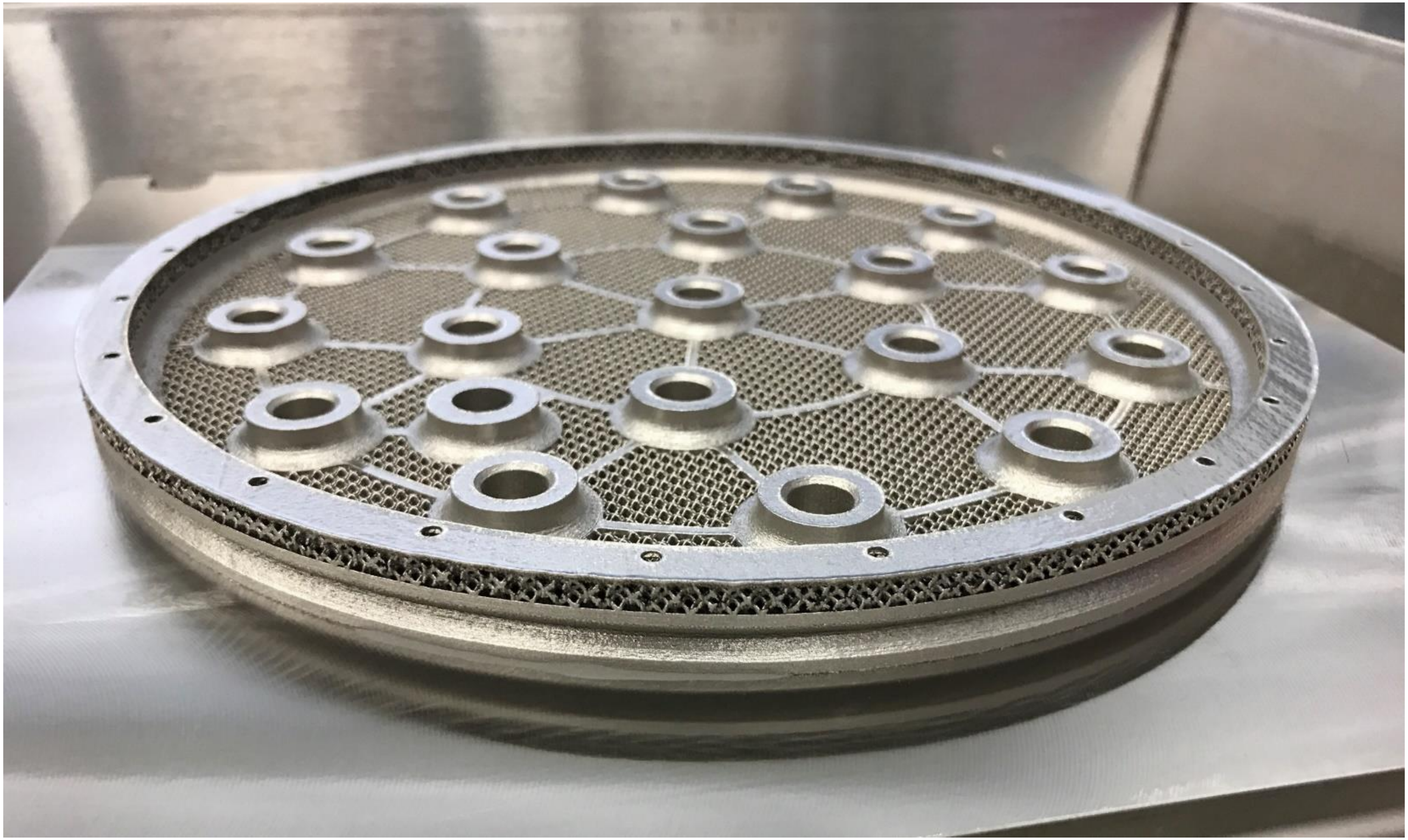
Agenda

- Lattice Structures
- Experiment Design
- Modeling Correlations
- Future Work

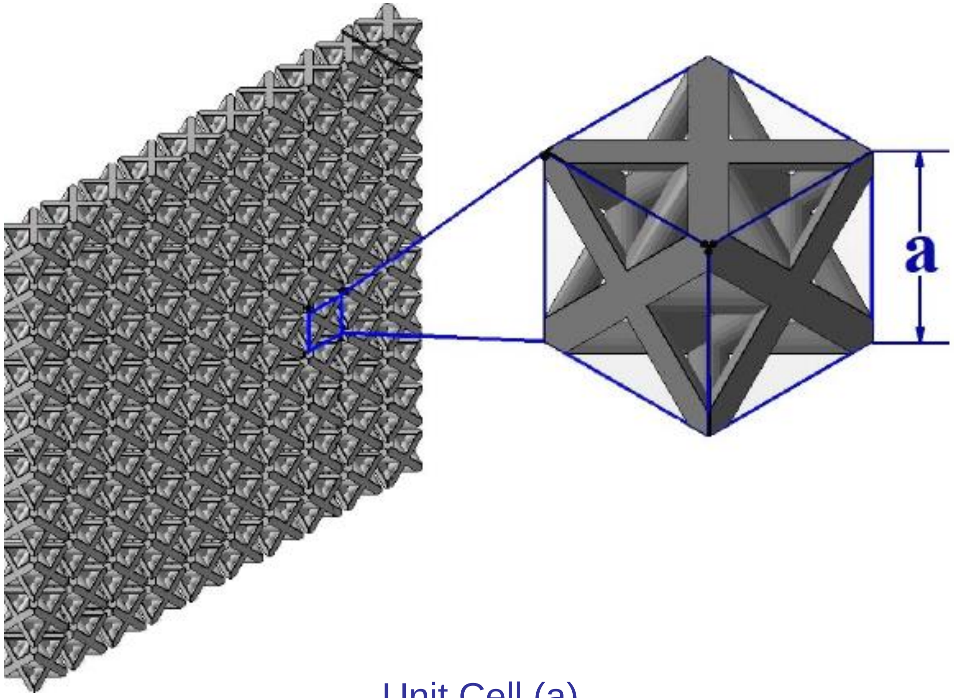
Lattice Structures



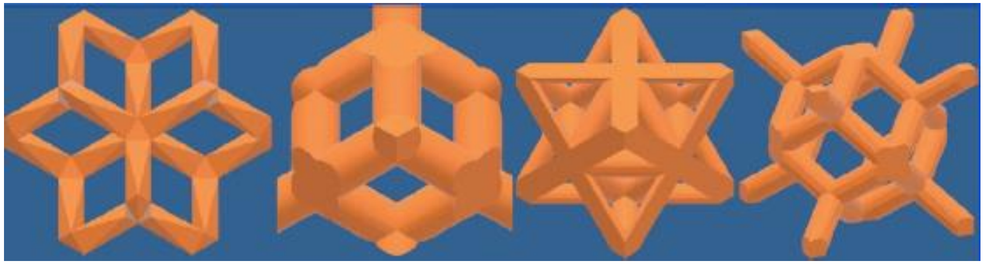
ECLSS 4-Bed Molecular Sieve (4BMS-X) Heater Plate

Lattice Structures

- Lattice Structures are repeating patterns which can be applied to Additively Manufactured (AM) parts
- Four lattice topologies were selected for assessment (1)
  - Dode Medium – 13% Relative Density (%RD)
  - Diamond – 20%RD
  - Octet Truss – 30%RD
  - Rhombic Dodecahedron – 20%RD
- Two unit cell sizes were down-selected
  - Coarse: 5mm
  - Fine: 2mm



Unit Cell (a)



Dode Medium (13%RD) | Diamond (20%RD) | Octet Truss (30%RD) | Rhombic Dodecahedron (20%RD)

Lattice Structures

Advantages

- Reduced mass, retain stiffness
- Variable relative density and surface area
- Tailorable thermal conductivity (*k*) to specific applications

Limitations

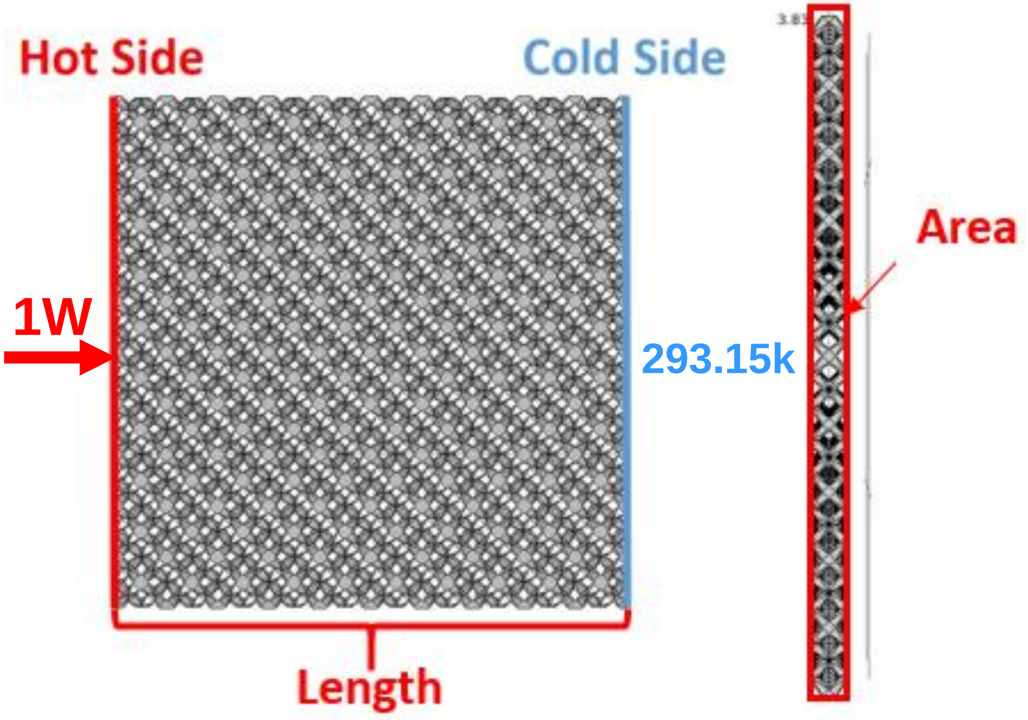
- Computationally expensive for analytical modeling
- Limited material property data (traditional properties are unreliable)

Lattice Regen Chamber Demo

Lattice Structures

Early Modeling Attempts

- Steady State
- Dimensions
  - Width: 20mm
  - Length: 20mm
  - Thickness: 0.98mm
- Assumed Constant Aluminum Properties
  - k = 205 W/m-K
  - C_p = 0.9 J/g-K
  - ρ = 2700 kg/m^3



Lattice Structures

Effective Thermal Conductivity (k_{eff})

$$k_{eff} = \frac{QL}{A\Delta T}$$

Q - Heat Flux

A - Cross-Sectional Area

L- Length

ΔT - Differential Temperature

Thermal Diffusivity (α)

$$\alpha = \frac{k_{eff}}{\rho_{eff} C_p}$$

C_p - Specific Heat Capacity

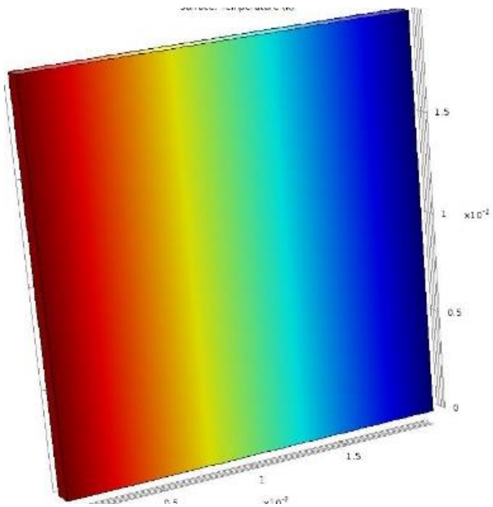
Effective Density (ρ_{eff})

$$\rho_{eff} = \frac{M_{model}}{V_{max}}$$

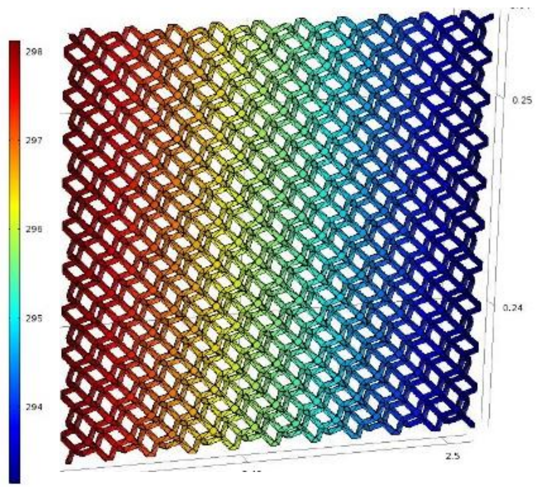
M_{model} - Mass of the model

V_{max} - Volume of bounding envelope

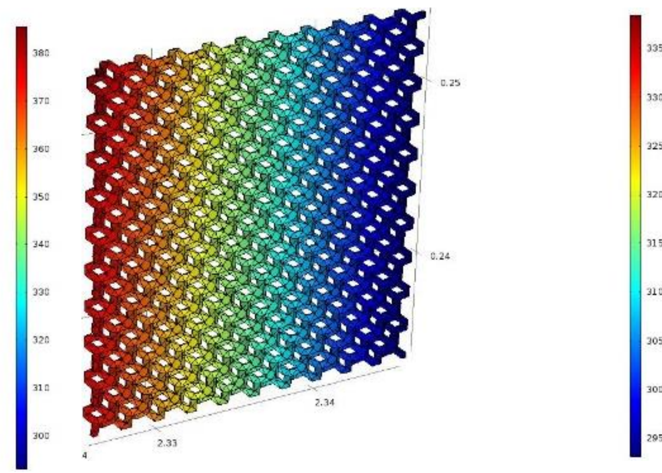
Lattice Structures



Solid



Dode Medium

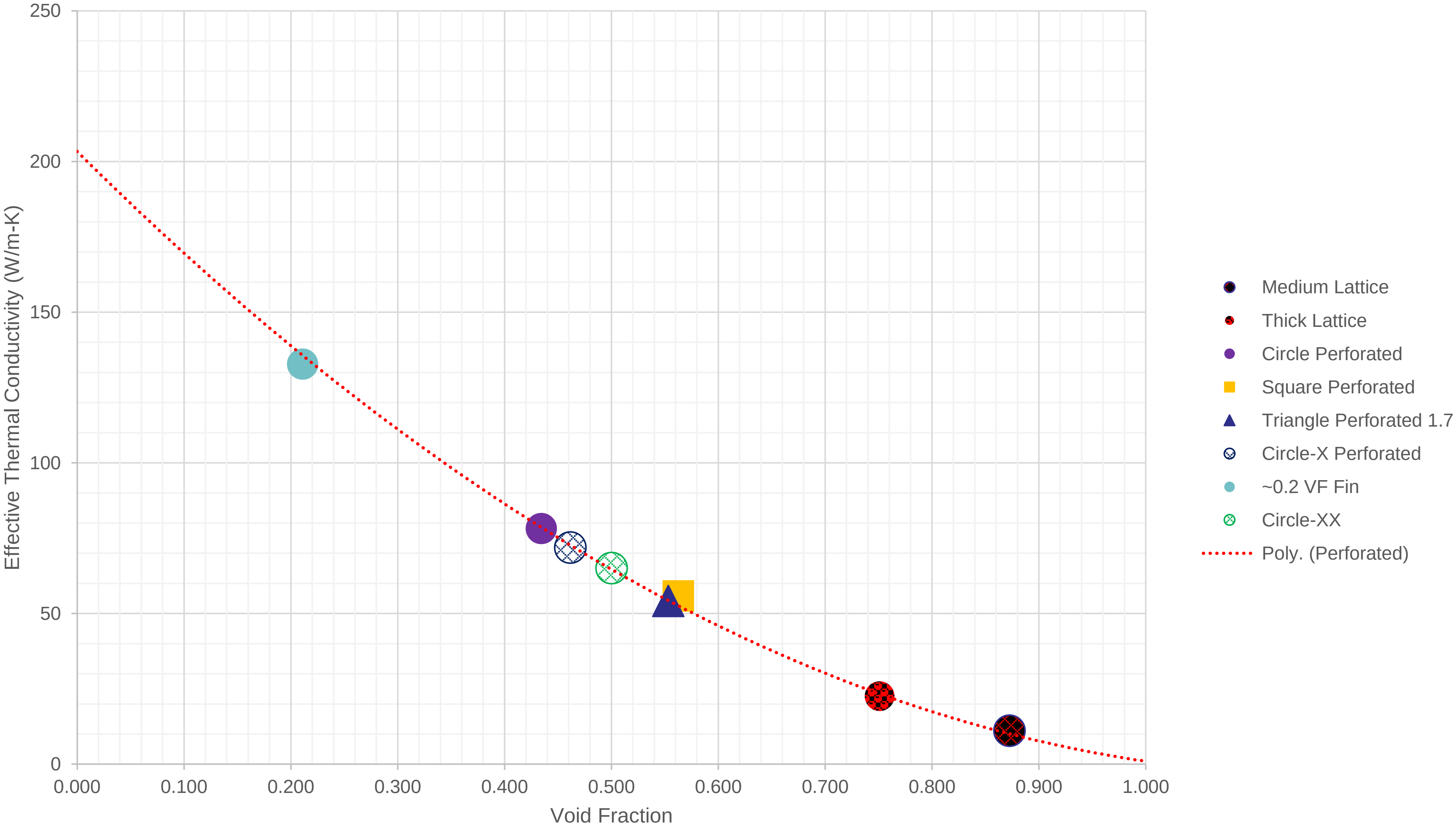


Dode Thick

Fin Type	Surface Area (mm^2)	Volume (mm^3)	Mass (g)	k_{eff} (W/m-K)	α (mm^2/s)	Void Fraction
Solid	878	392.00	1.058	204.90	84.32	0.000
Dode Medium	934	49.96	0.135	11.04	35.64	0.873
Dode Thick	1240	97.54	0.263	22.54	37.28	0.751

Lattice Structures

Effective Thermal Conductivity vs. Void Fraction

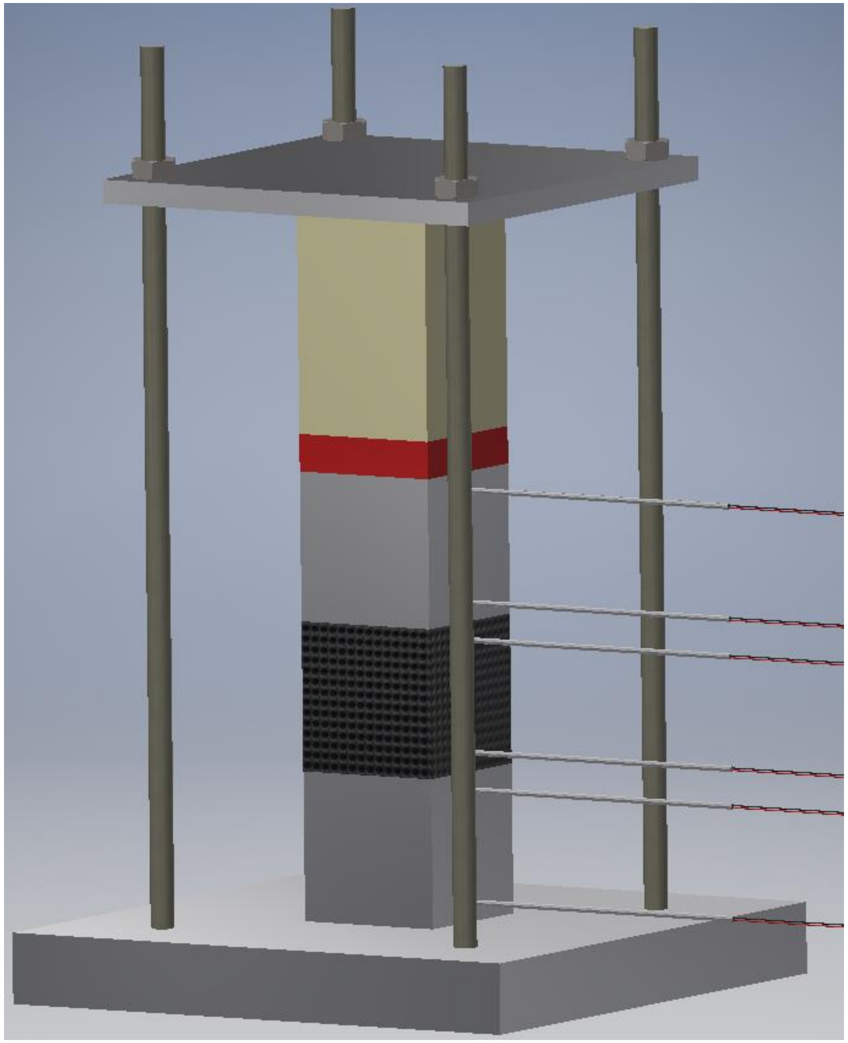


Modeling Shortcomings

- Models which contain lattice only come in .stl (Standard Tessellated Language) format
  - .stl (Right) is a specialized file type for 3D Printers
  - Converts a CAD solid into a hollow shape bounded by triangles with a normal direction
- Computationally expensive
  - Radiation effects are difficult to usefully incorporate
  - Convection/CFD has not been attempted, could be problematic
- Limited material property data (traditional properties are unreliable)

.stl File Example (2)

Experiment Design

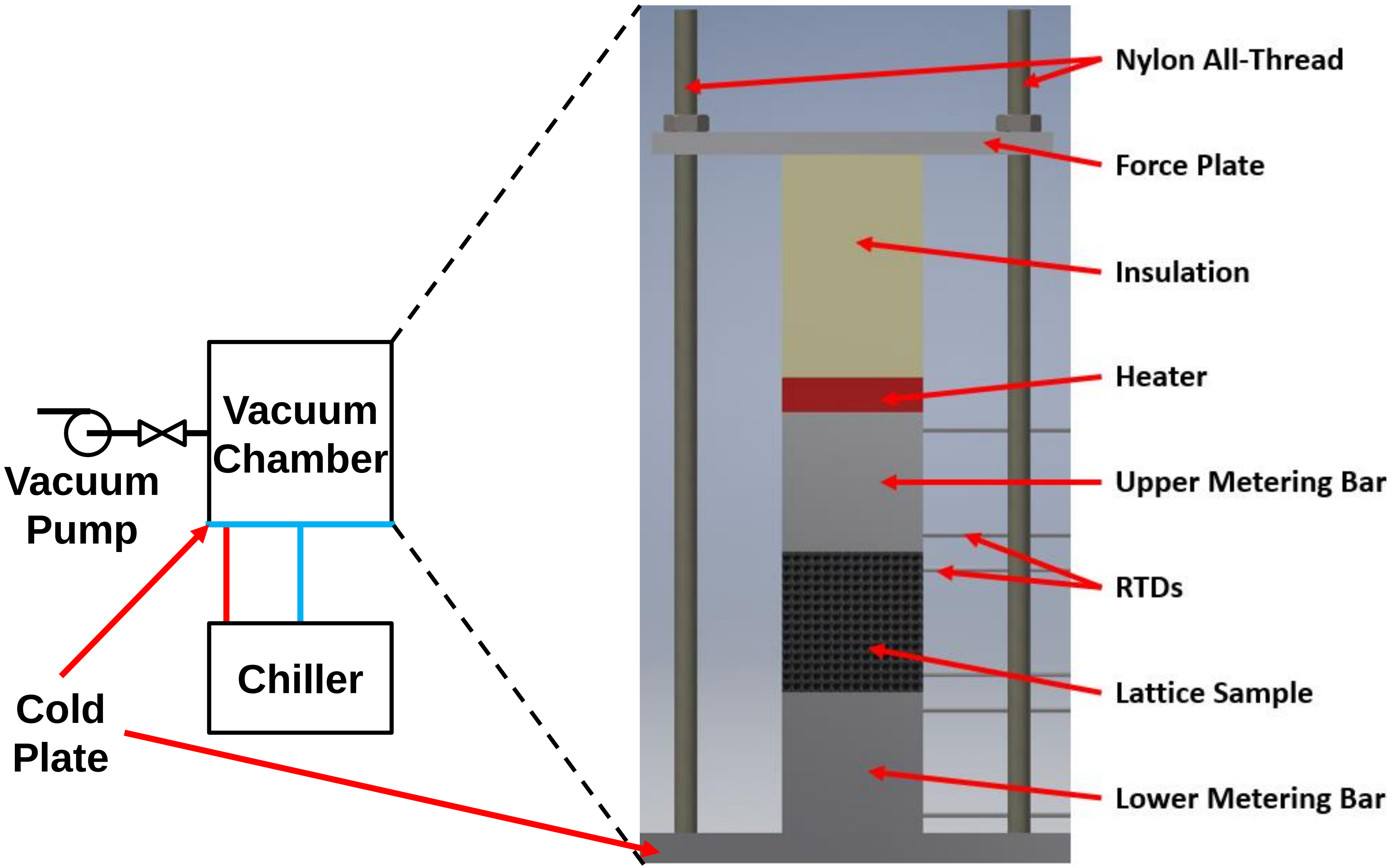


- Internal funding was obtained at Marshall Spaceflight Center (MSFC) to experimentally measure the thermal conductivity through lattice structures and non-fully dense solids
- The experiment will create a capability unique to MSFC
- This experiment is currently in the design/procurement phase

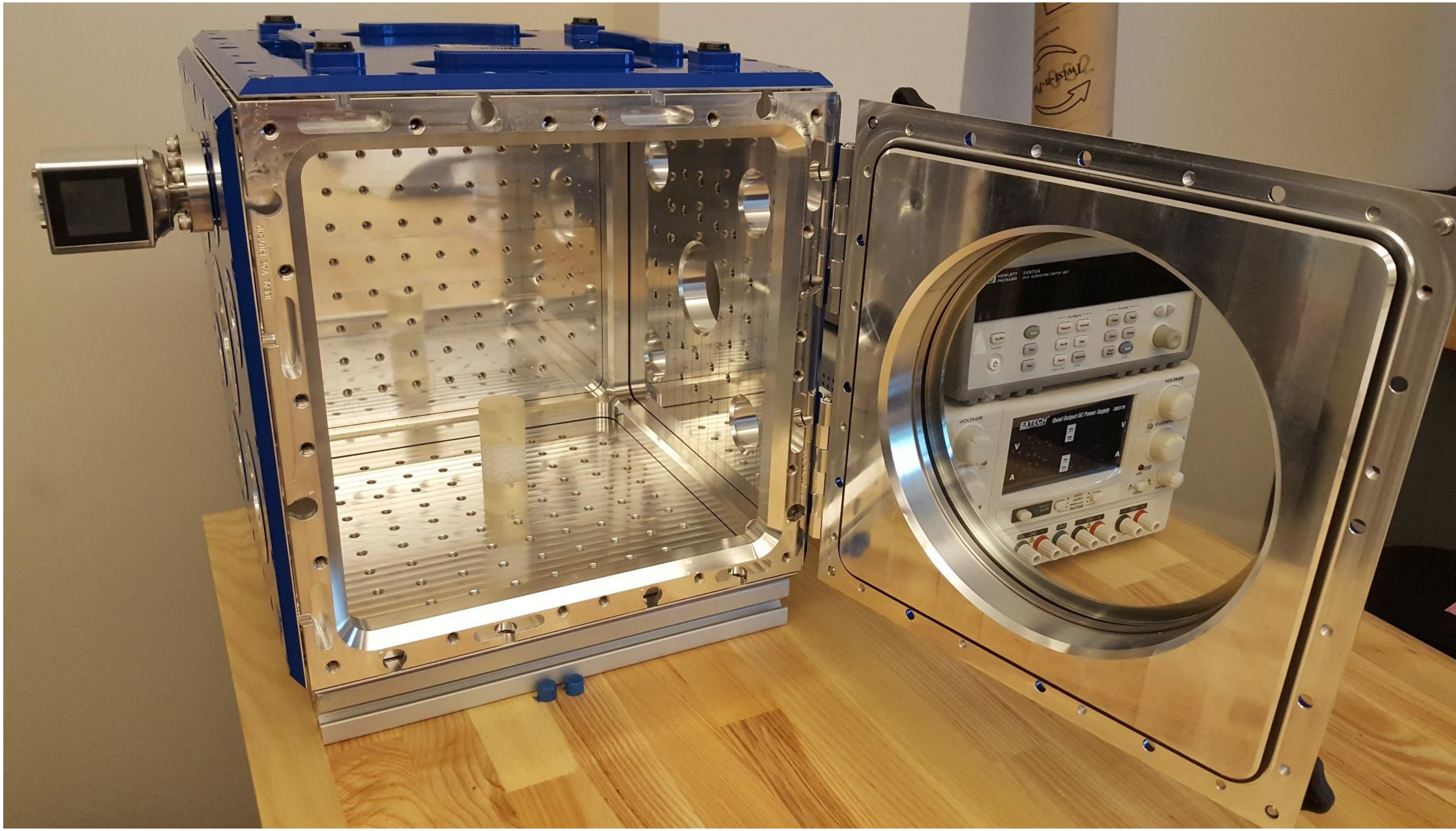
Experiment Design

- Well established standards are available to determine the *k* of homogeneous materials
  - ASTM E1225-13 Thermal Conductivity of Solids Using the Guarded-Comparative-Longitudinal Heat Flow Technique
  - ASTM D5470-17 Thermal Transmission Properties of Thermal Conductive Insulation Materials
- Measuring *k* through complex geometries/non-homogenous materials has not been standardized
- Notable changes:
  - Much smaller samples (max ~30x30x30mm cube)
  - Samples will not be homogenous
  - No guard will be used (excessive with upper and lower meter bars)
  - Test will occur in vacuum (10^{-2} to 10^{-3} torr) to mitigate convection
  - Meter bar conductivity will be selected based on estimated sample conductivity (not necessarily >50 W/m-K)

Experiment Design



Experiment Design

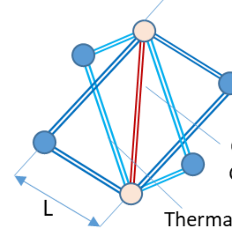


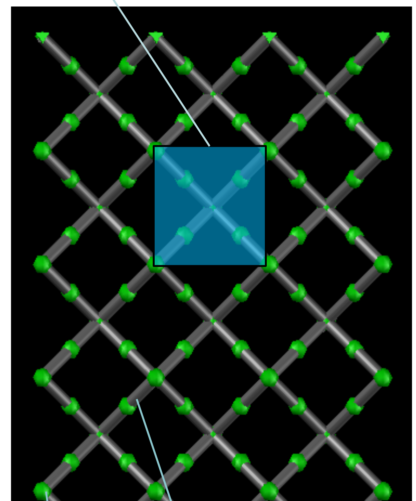
Experiment Design

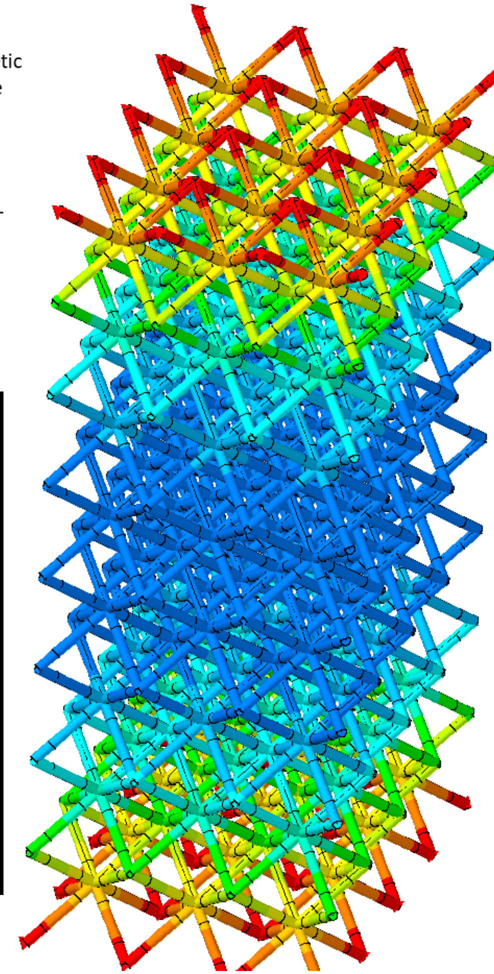
- Heater
  - Several heaters are being considered
  - 20 watts(W) or less of power will be applied to the experiment
- Instrumentation
  - Meter bars and samples will be instrumented with at least three 4-wire RTDs
  - Chiller has built in temperature measurement and control to maintain 20ºC±0.1 up to 250W
- Samples
  - At least three different sample thicknesses will be measured at least three times for repeatability and reliability

Modeling Correlations

- Correlated thermal math models of lattice structures are needed to inform the design and optimization of specific applications utilizing additive manufacturing.
- Depending upon the application, the thermal model may need to consider all modes of heat transfer: conduction, radiation and convection to a stationary or moving fluid.
- Radiation and convection may be computationally prohibitive for large or complex geometries.
- A simplified network method to model conduction through a lattice structure is illustrated.
- An individual lattice cell may be parsed into nodes and conductors. The nodes represent “junction” points where the beams that define the lattice structure meet.
- Temperature is computed via an energy balance at each node based on conductive heat transfer through the beams.







Predicted Thermal Distribution thru Lattice

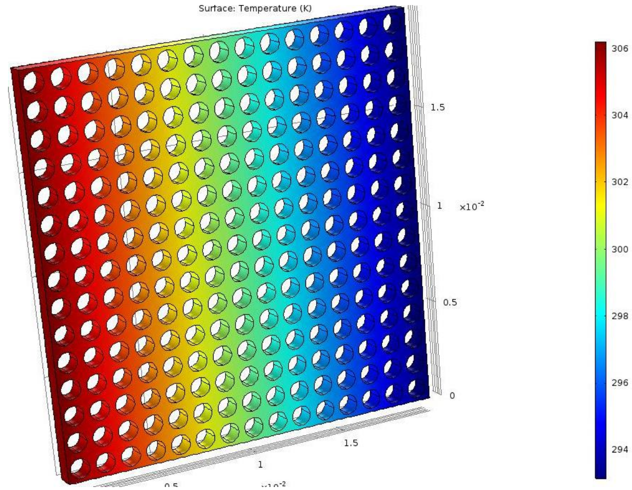
Future Work

- Finish procurement
- Build test system/apparatus
- Verify system with sample of known conductivity
- Test initial samples
- Correlate model results with experimental data
- Numerous potential applications including Cryogenic Fluid Management and Nuclear Thermal Propulsion

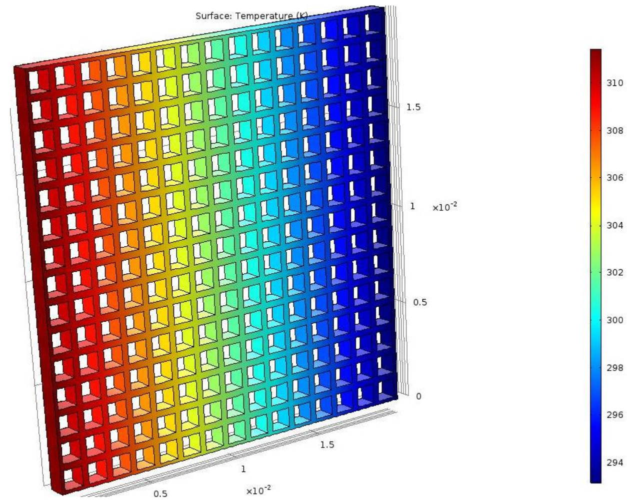
References

1) Mireles, O. R. (2018). *Thermal, Fluid, Mechanical, and Microstructural Property Characterization of Additively Manufactured Lattice Structures*. Retrieved from: https://ntrs.nasa.gov/archive/nasa/casi.ntrs.nasa.gov/20180006367.pdf
2) *Working with File Types*. (2019). Retrieved from: https://www.simplify3d.com/support/articles/working-with-file-types/

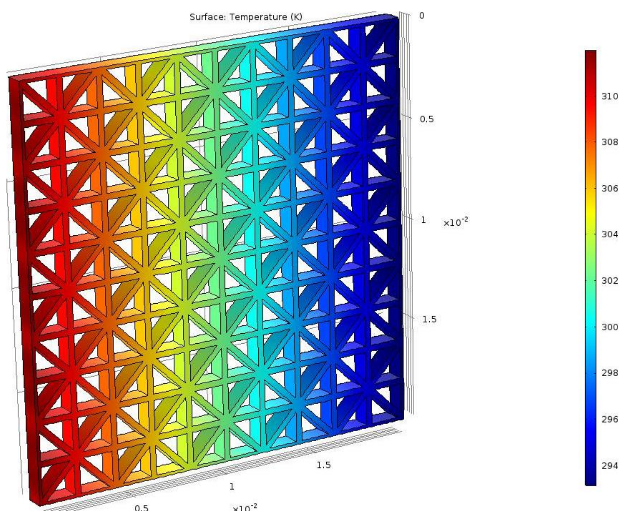
Backup Slides



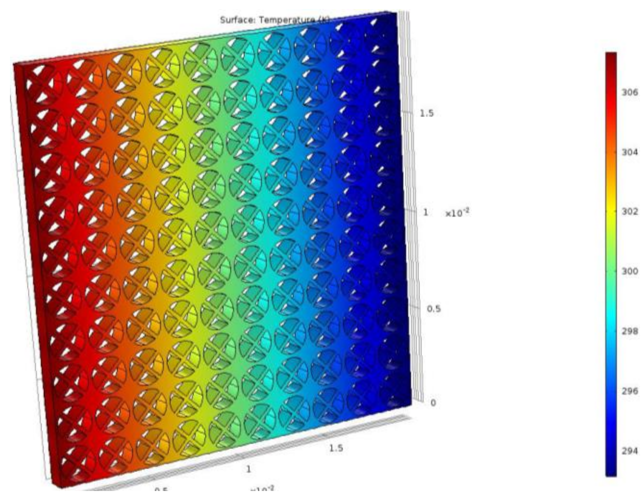
Circle Perforated



Square Perforated



Triangle Perforated



Circle-X Perforated

Backup Slides