

Additively Manufactured Lattice Structure Thermal Characterization

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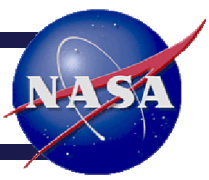
Presented By
Travis Belcher

TFAWS
LaRC 2019

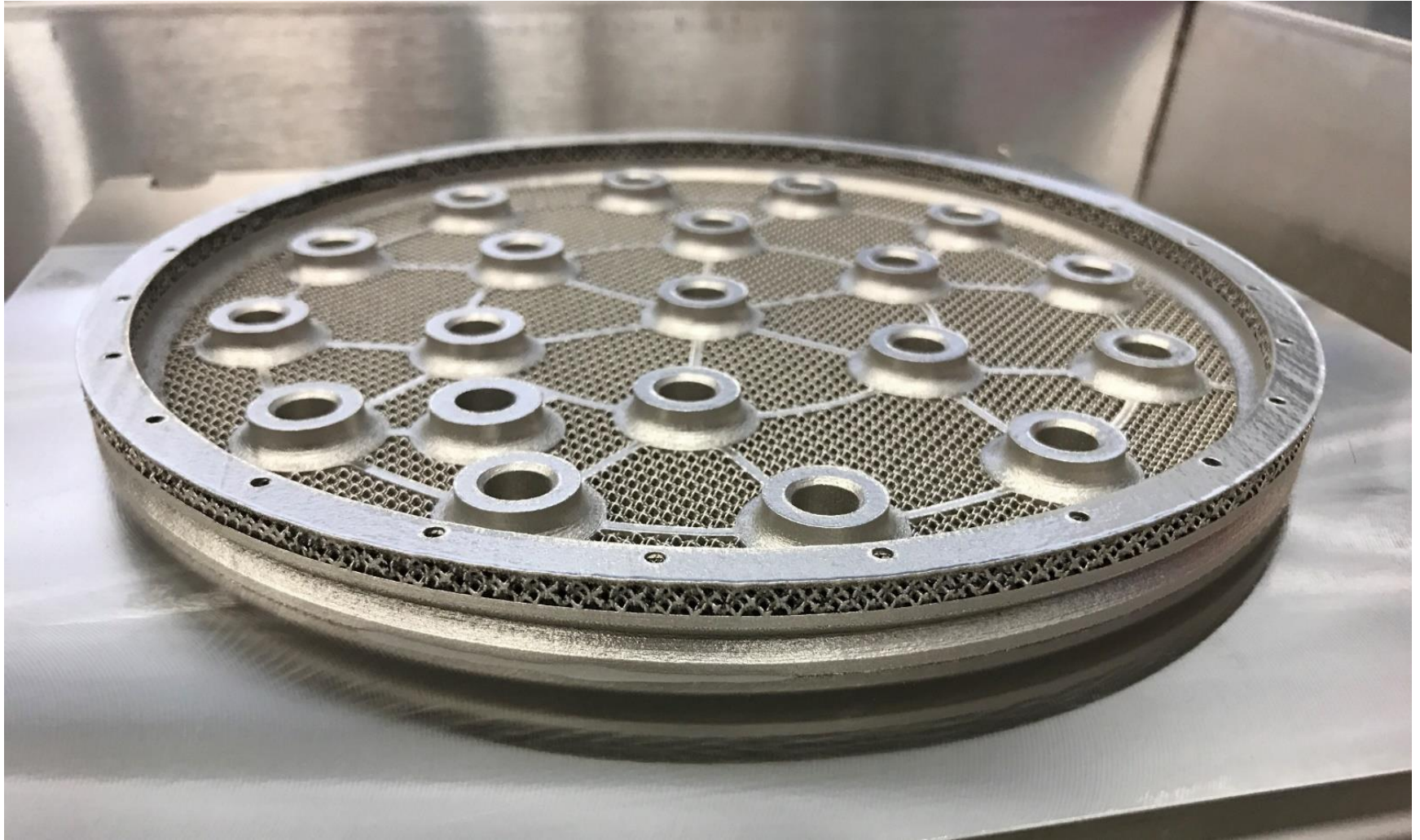
Thermal & Fluids Analysis Workshop
TFAWS 2019
August 26-30, 2019
NASA Langley Research Center
Hampton, VA



Agenda



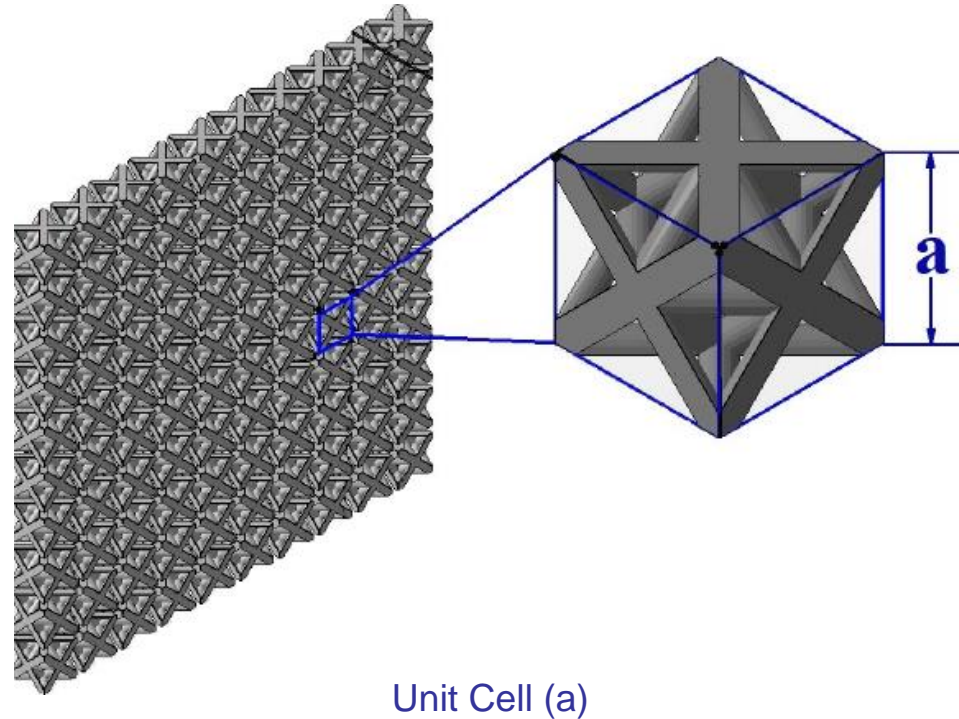
- Lattice Structure Introduction
- Thermal Analysis
- Current Experiments
- Proposed Experiments



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



Dode
Medium
(13%RD)

Diamond
(20%RD)

Octet
Truss
(30%RD)

Rhombic
Dodecahedron
(20%RD)

Advantages

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

Limitations

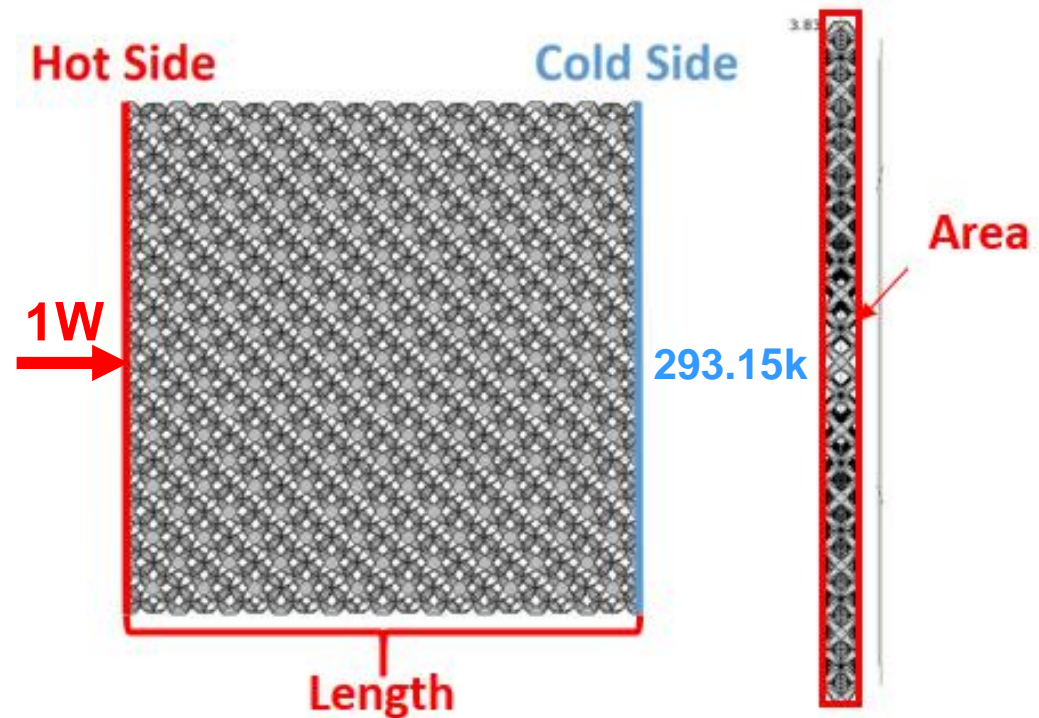
- Computationally expensive for analytical modeling
- Limited material property data (traditional properties are unreliable)



Lattice Regen Chamber
Demo

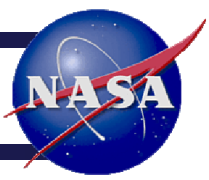
Early Modeling Attempts

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





Lattice Structures k Analysis



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)

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

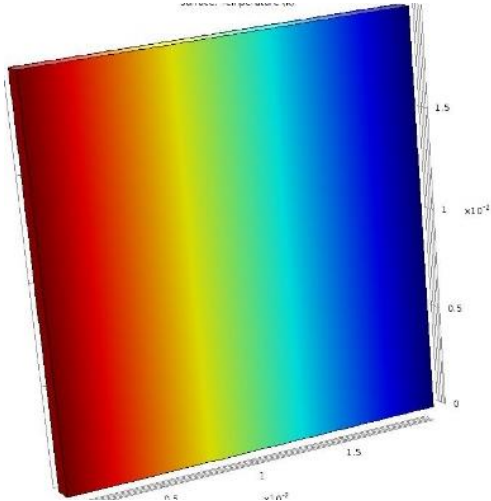
C_p - Specific Heat Capacity

Effective Density (ρ_{eff})

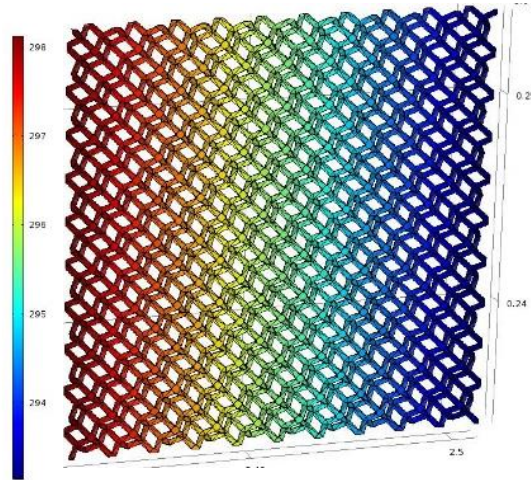
$$\rho_{eff} = \frac{M_{model}}{V_{max}}$$

M_{model} - Mass of the model

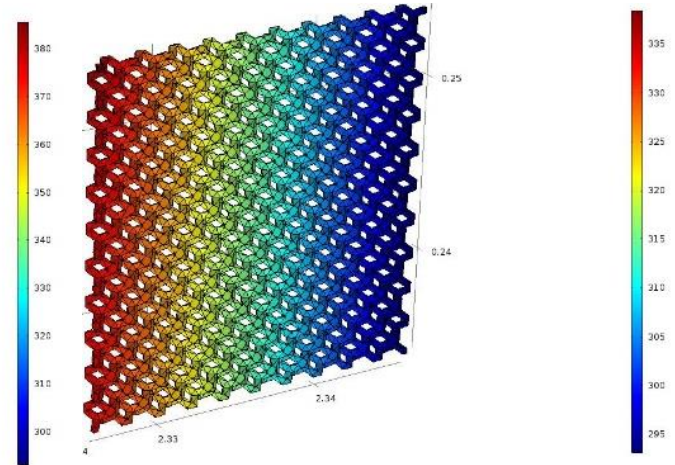
V_{max} - Volume of bounding envelope



Solid



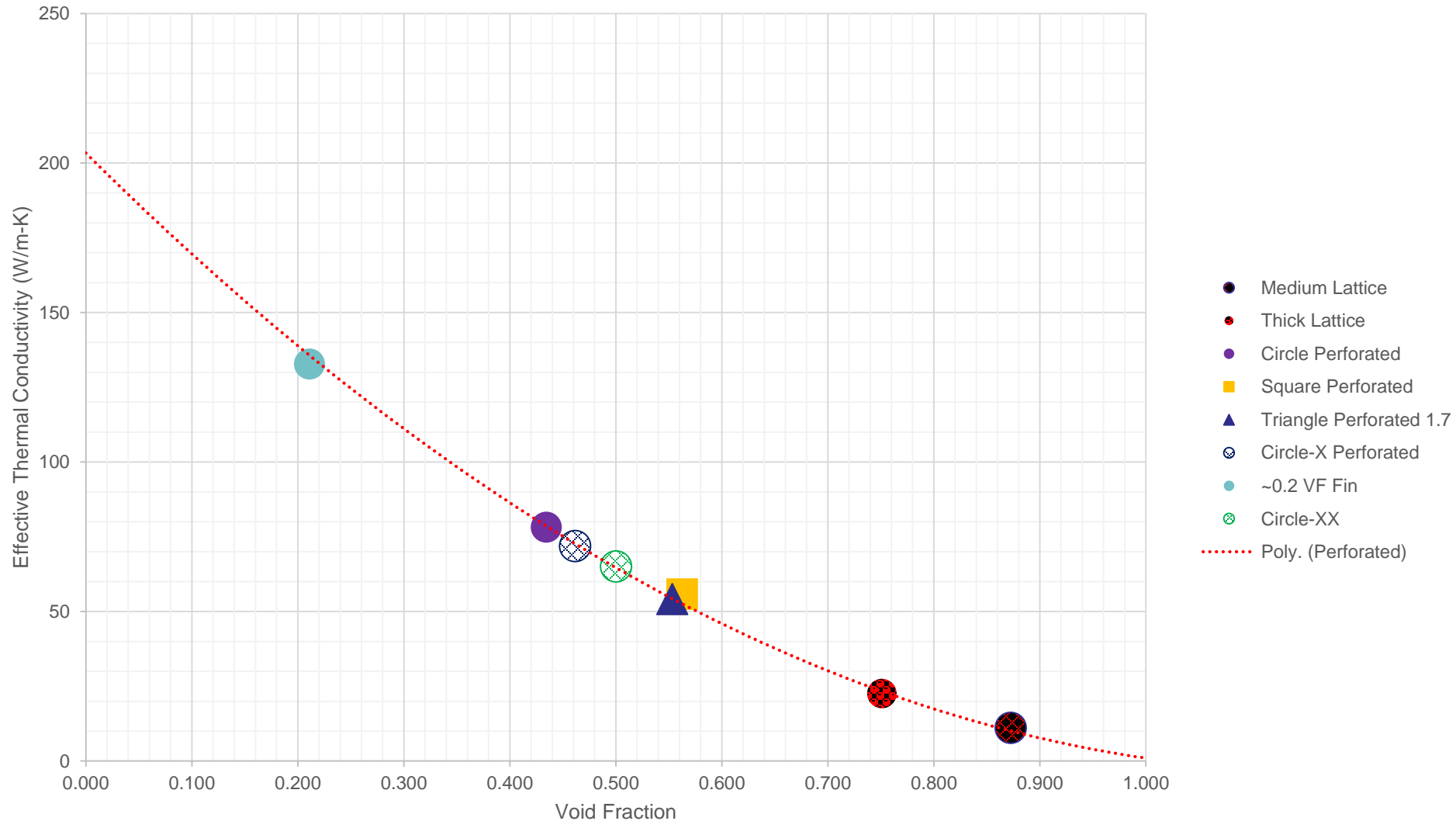
Dode Medium



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

Effective Thermal Conductivity vs. Void Fraction



- 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)

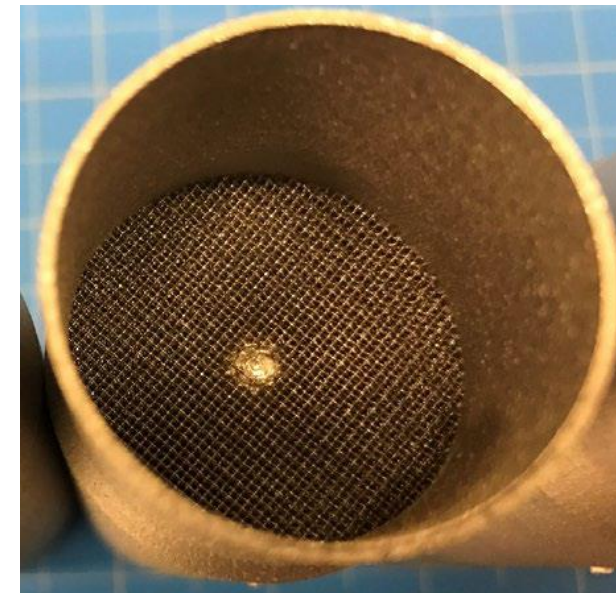
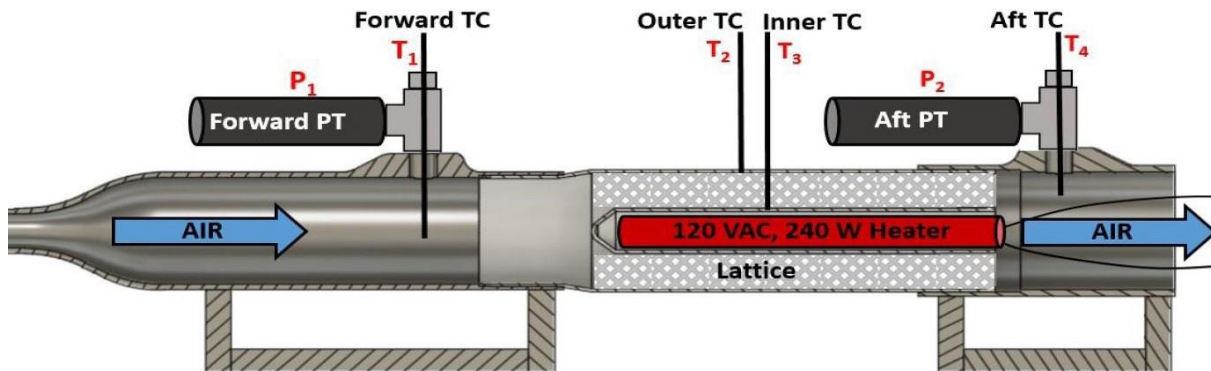
- Experiment Parameters

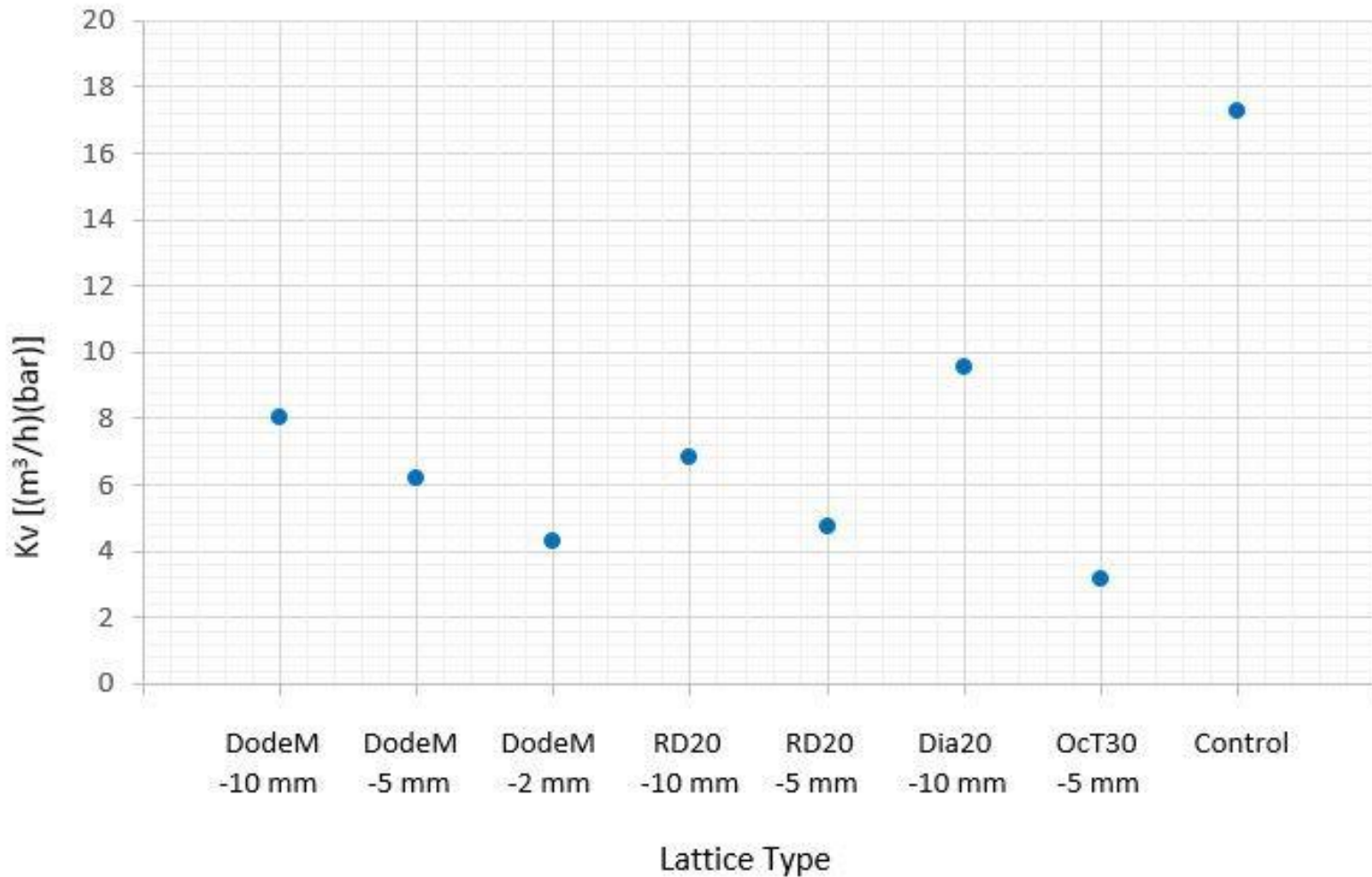
- Flow rate (m^3/hr) of water at 16°C with a pressure drop across a valve of 1 bar
- Convection uses packed bed model



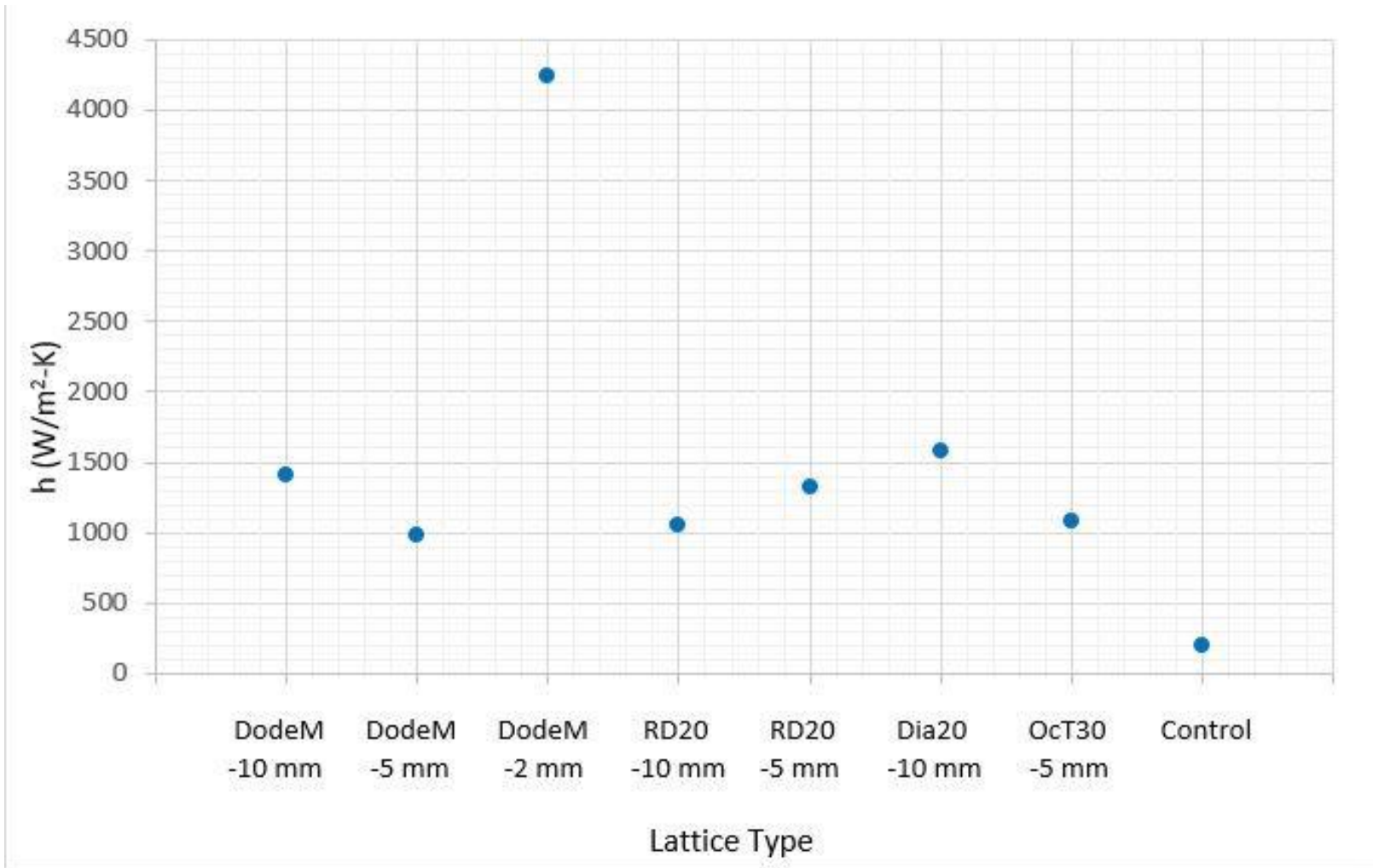
- Measured Quantities:

- Convective Heat Transfer Coefficient (h)
- Flow Coefficient (K_V) ($C_V = 1156 \cdot K_V$)

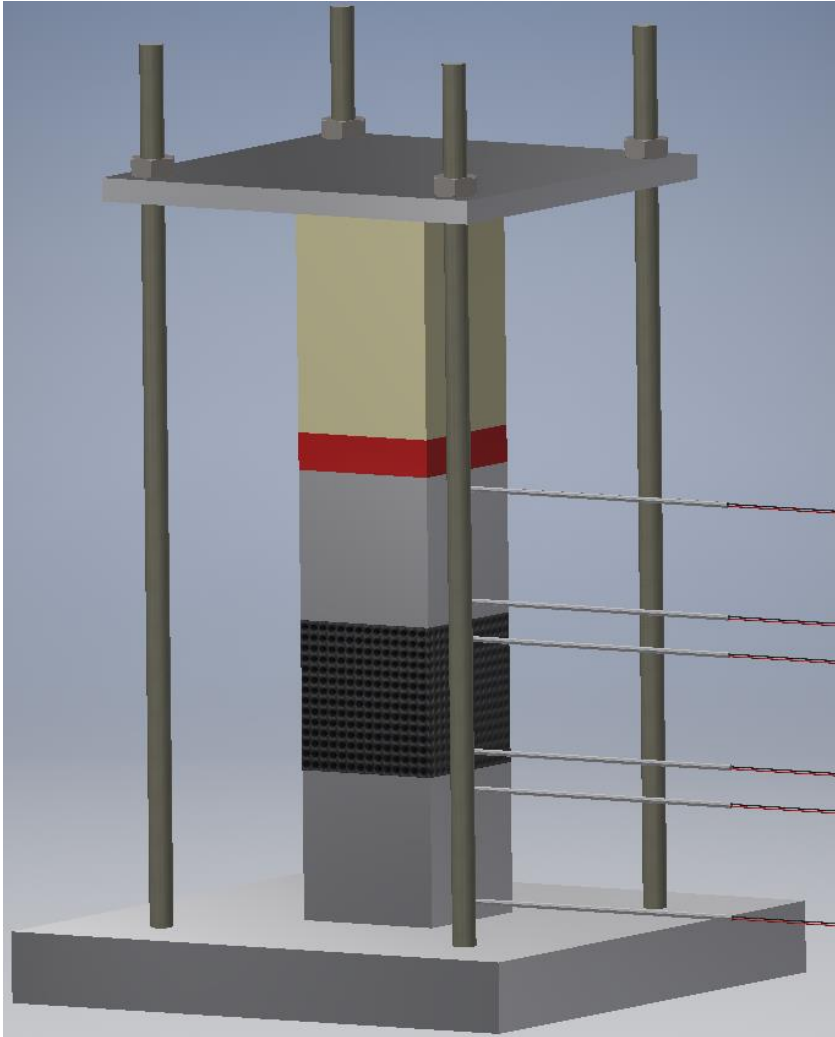




Flow coefficients of lattice types ($C_v = 1156 \cdot K_v$)

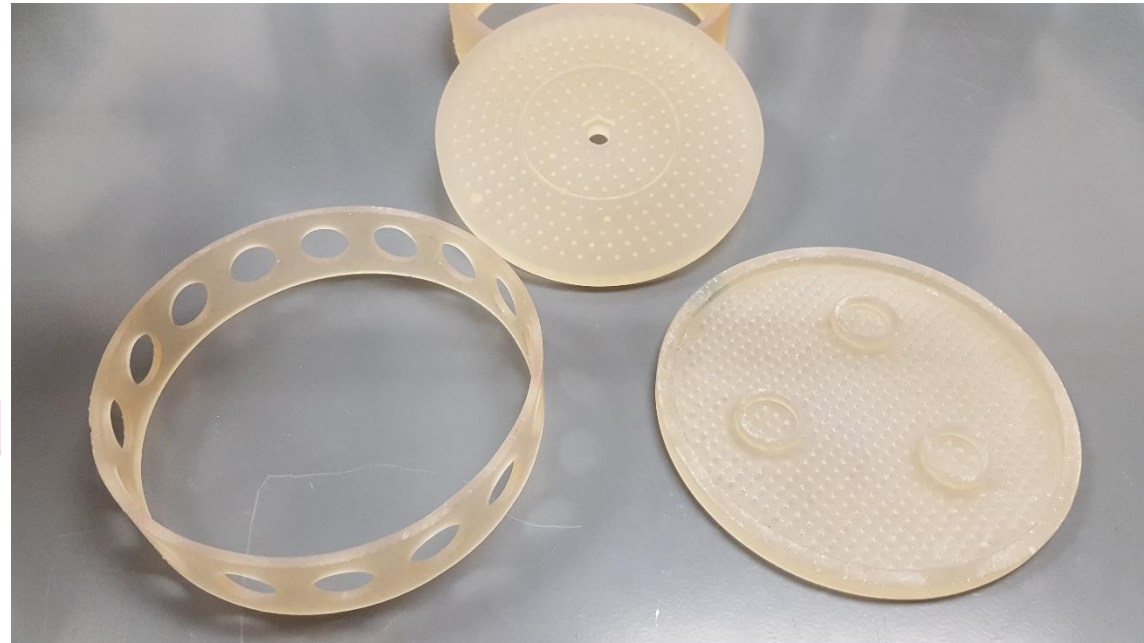
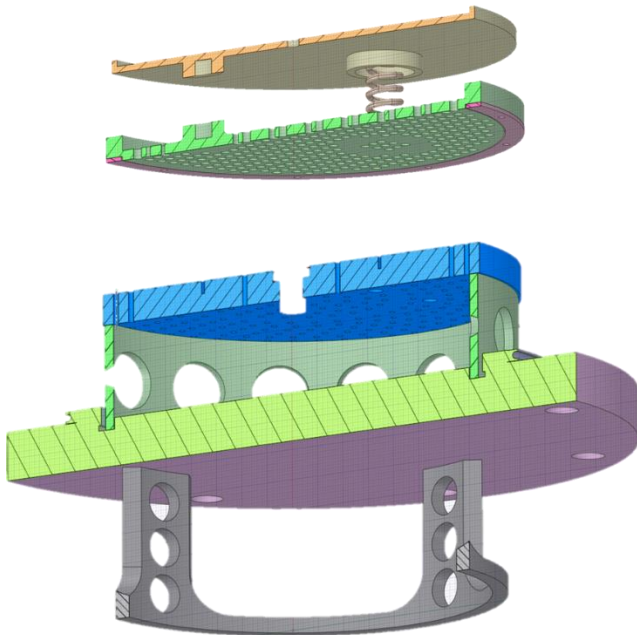


Convective heat transfer coefficients of lattice types



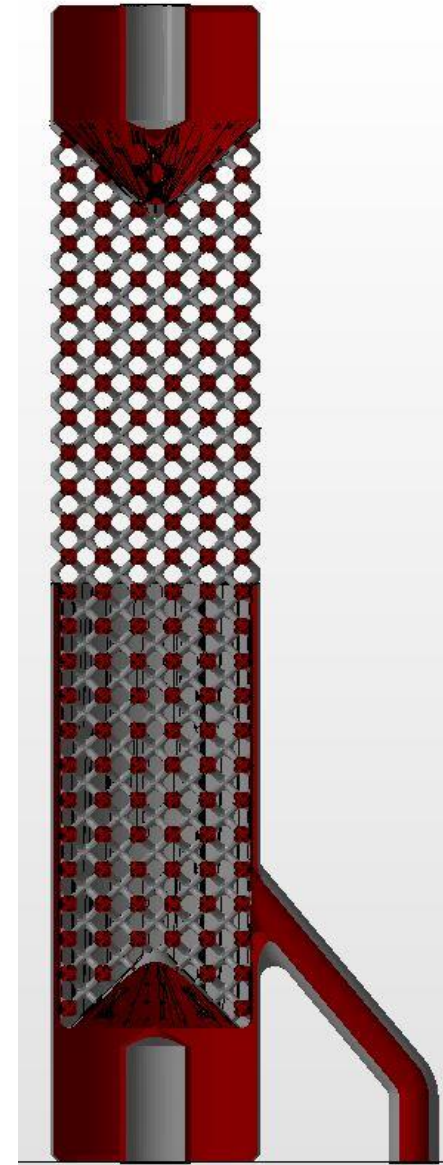
- Internal funding was obtained at Marshall Spaceflight Center (MSFC) to experimentally measure the k through lattice structures and non-fully dense solids
- The experiment will create a capability unique to MSFC
- This experiment is currently in the design/procurement phase

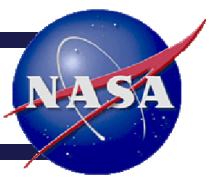
- Lattice Structures
 - Mechanical testing
 - Fracture toughness research
 - Lattice infiltration
 - Study with topologies provided by Autodesk Netfabb
- Functional Parts



Proposed Thermal Work

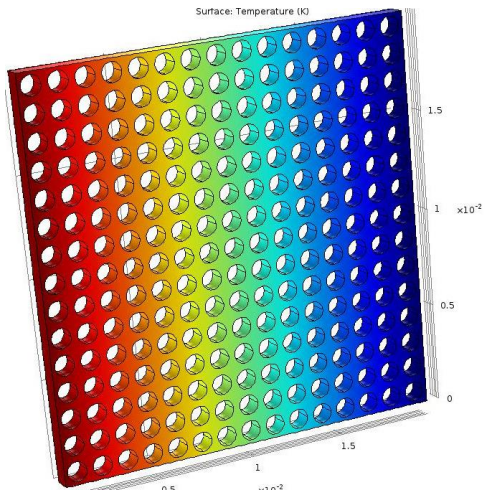
- 3D Printed Cryogenic Strut
- AM Thermal Property Database
- Further Convection Testing
- Enhancement of Thermal Modeling Techniques



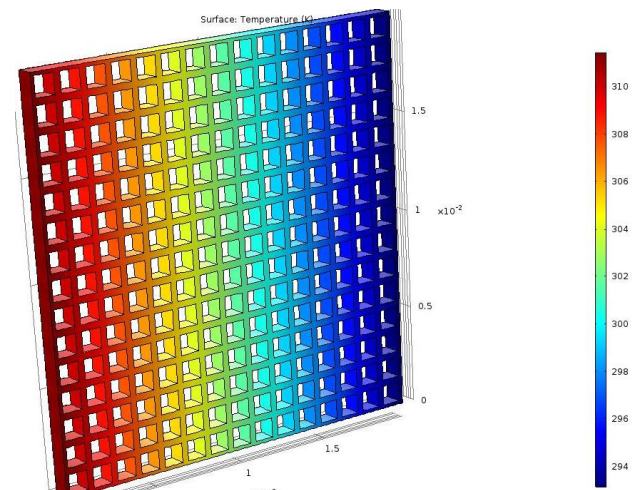


References

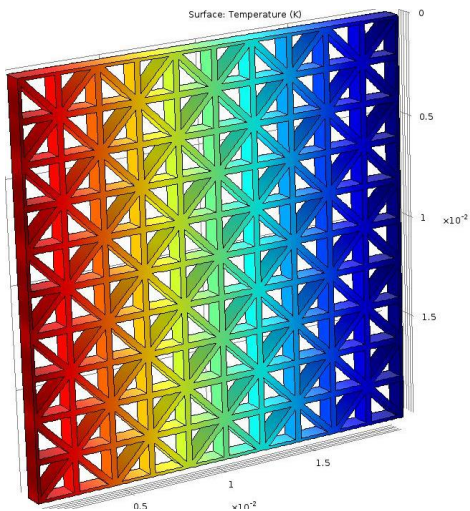
- 1) Mireles, O. R. (2018). *Thermal, Fluid, Mechanical, and Microstructural Property Characterization of Additively Manufactured Lattice Structures*. Retrieved from: <https://ntrs.nasa.gov/archive/nasa/casi.ntrs.nasa.gov/20180006367.pdf>
- 2) *Working with File Types*. (2019). Retrieved from: <https://www.simplify3d.com/support/articles/working-with-file-types/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



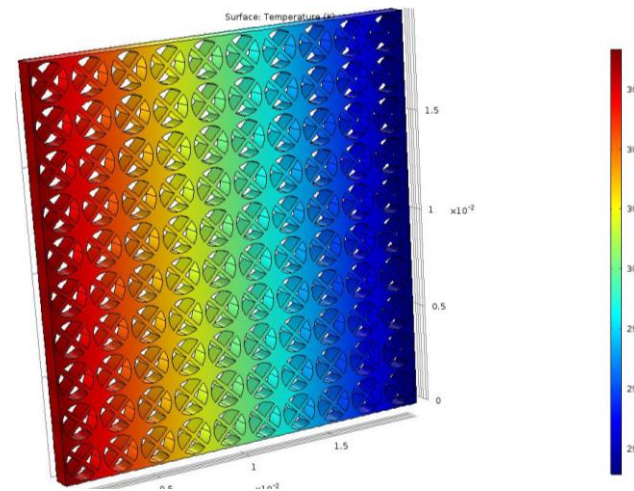
Circle Perforated



Square Perforated



Triangle Perforated



Circle-X Perforated

