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# Multifunctional Fluid Power Components using Engineered Lattice Structures

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# Overview

- Introduction
- Multifunctional Unit Cells
- Determining Effective Thermal Conductivities
- Developing Thermal-Management Structure
- Experimental Results
- Next Steps
- Conclusions

# Multifunctional Structure

- Heat dissipation
- Load bearing
- Reduced dead weight
- Potential to reduce noise & vibration

# State-of-the-art

## Metal Foam

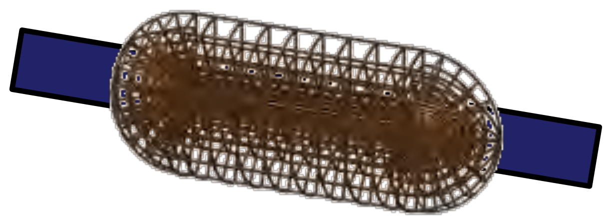
- Multifunctional capabilities
- Not optimized

## Finned Heat Structure

- Not multifunctional
- Not optimized

# *Ex.:* Powered Personal Devices

- Safety considerations of heat
  - Burn
  - Pain
  - "Toasting"
- Discomfort issues

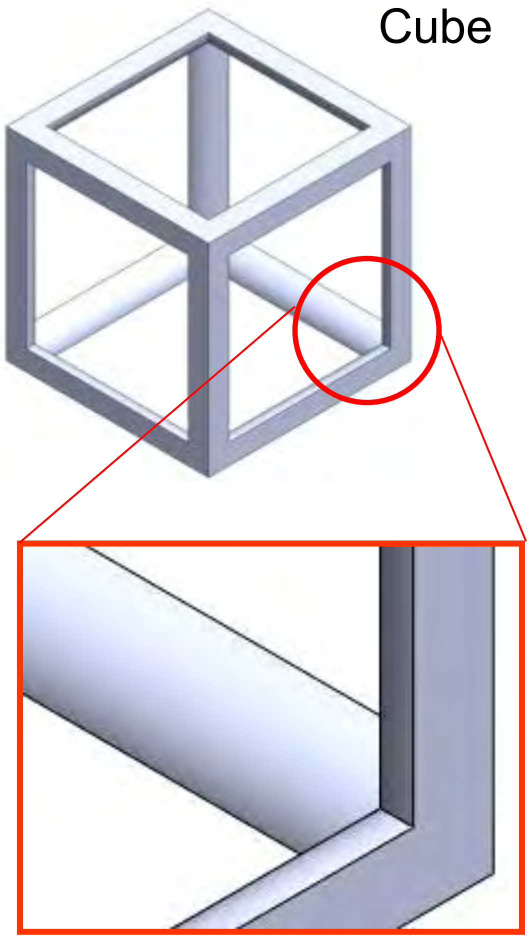


Multi-Institutional
Patent Pending

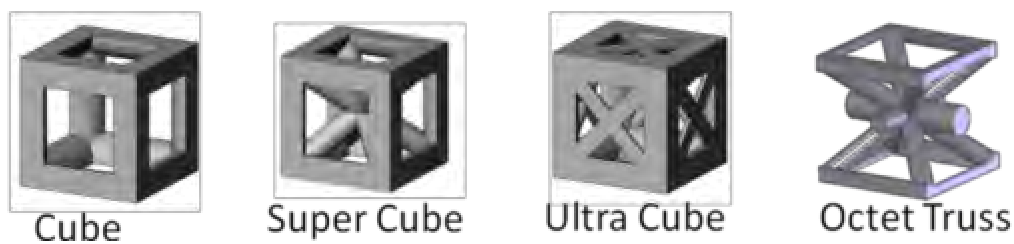
<u>CCEFP Project 2D & Test Bed 6 - Concept Models:</u>

Belt-worn or Orthosis-integrated Power Source

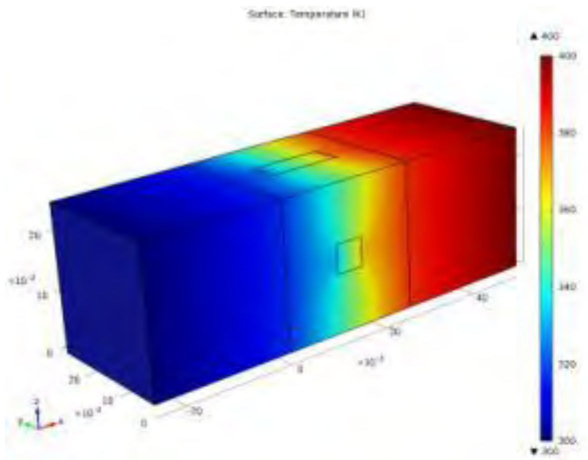
# Multifunctional Unit Cells




- Thermal conductivity as a function of strut diameter and cell size
- Varied strut diameters; 0.2L, 0.5L, and 0.8L
- Initial cell size 1 inch, later scaled to determine size effects
- Analyzed Cube, Ultra Cube, and Super Cube configurations



# Modeling the Cubes



$$q'' = \frac{\Delta T}{R_{equiv}}$$

$$K = \frac{x}{A\left(\frac{\Delta T}{q''} - 2R_{cop}\right)}$$

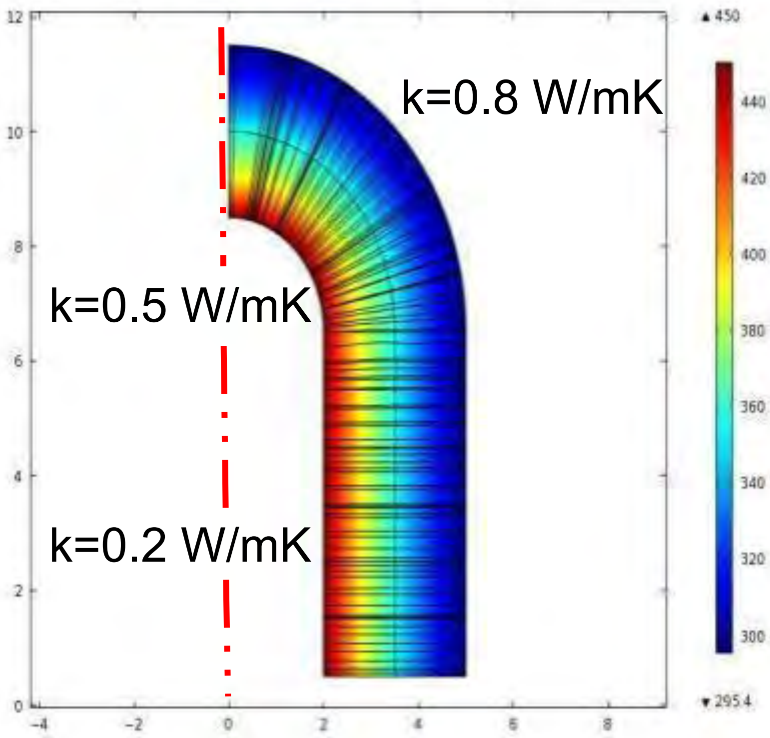
- Stagnant air (no convection)
- Base material aluminum (k=160 W/mK)
- Solved for three orthogonal directions
- Boundary conditions
  - T1=400K
  - T2=300K
  - Other four sides insulated

# Model Results

- Determined the bulk thermal conductivity of three lattice structures in the three orthogonal directions
- Heat flux scaled linearly to length of cell, resulting in a constant conductivity
- Analyzed structures with varying material, scaling equations based on thermal conductivity
- Investigated the effects of internal convection – negligible
- Working to determine the energy balance via mass transfer through the structure

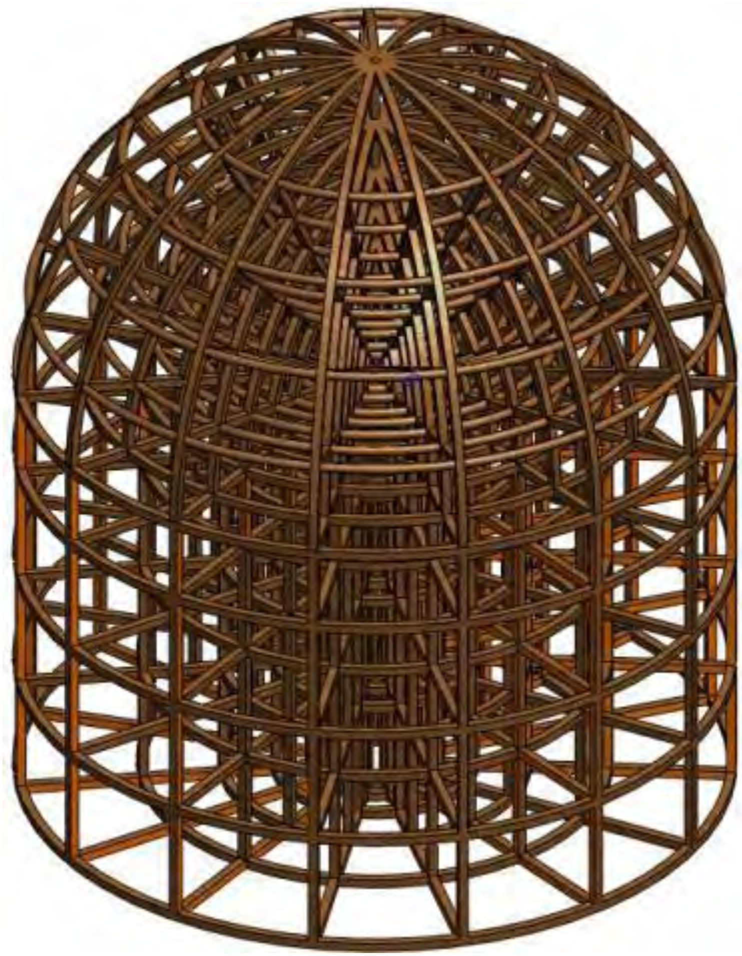
# Optimizing $K_{eff}$

- Specified inner temperature
- Free external convection on outer surface
- Target: 45℃ surface temp with “radial” heat flux

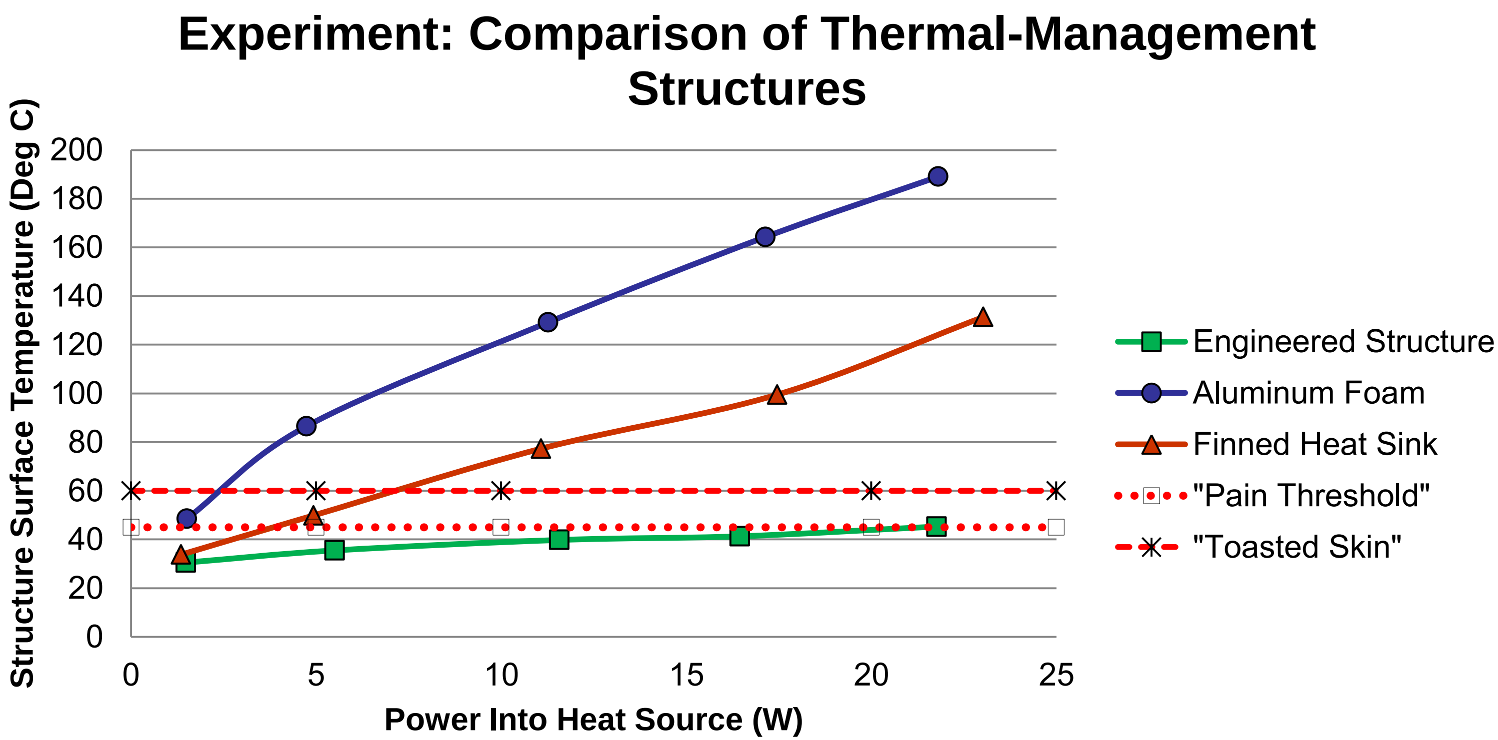


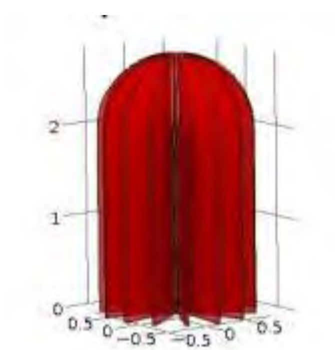
# Developing the Structure

- Geometric relationships derived to maintain "squareness"
- Matlab® script calculates divisions and strut lengths
- Iterate to meet minimum feature size (secondary structure optimization)



# Experimental Results

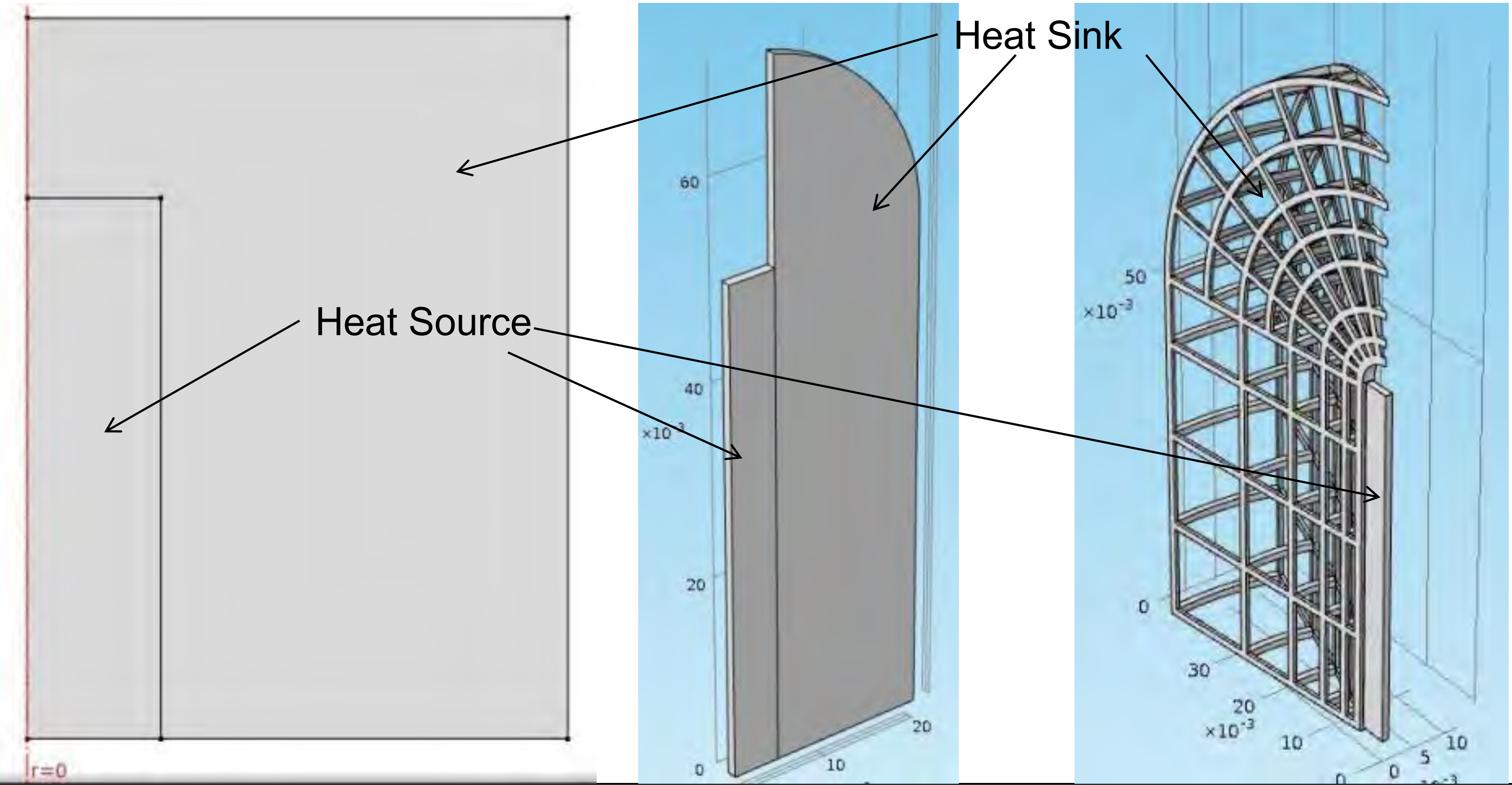


- Same mass
- Same material
- Structure area = 2(fin area)

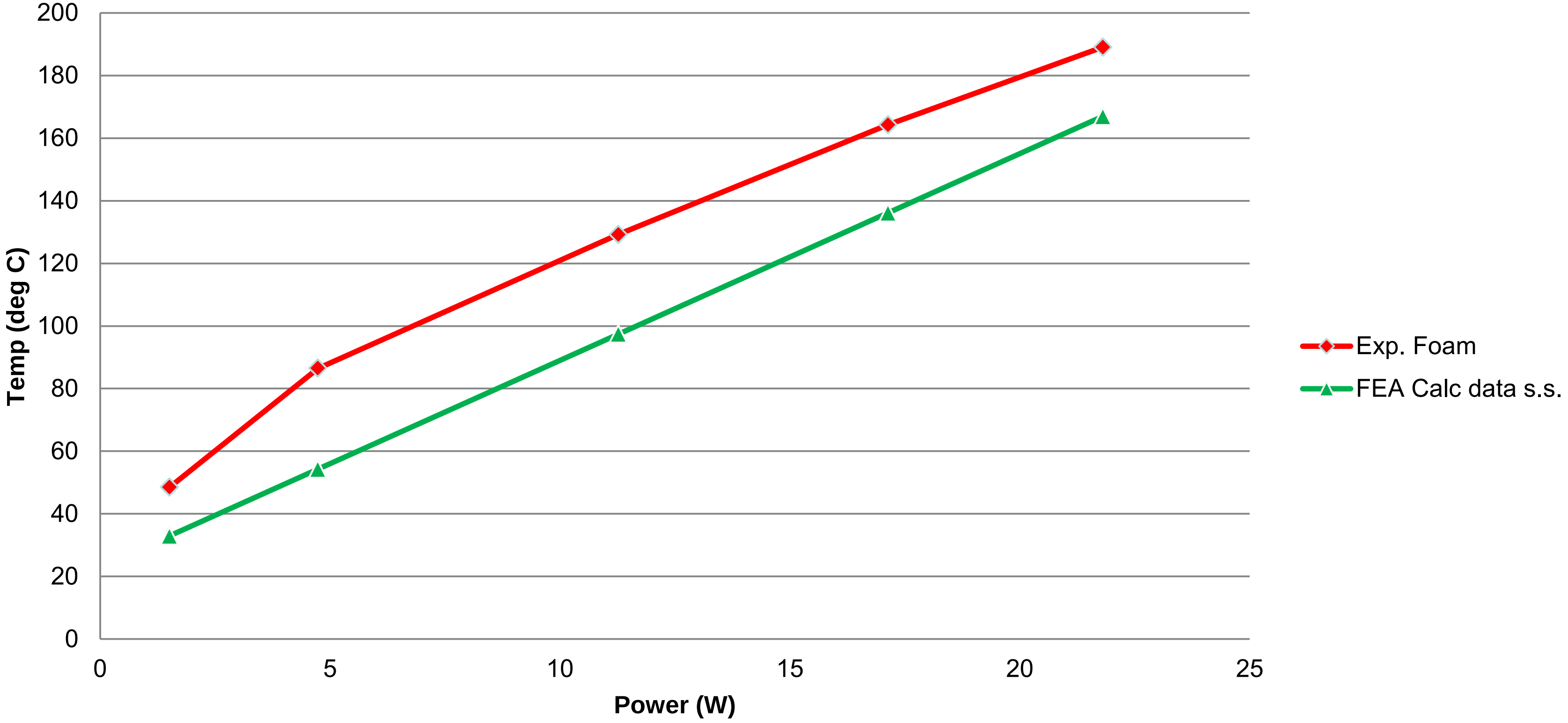
- Both cast
  - Cu/Al alloy
  - 43W/mK

# Model Setup

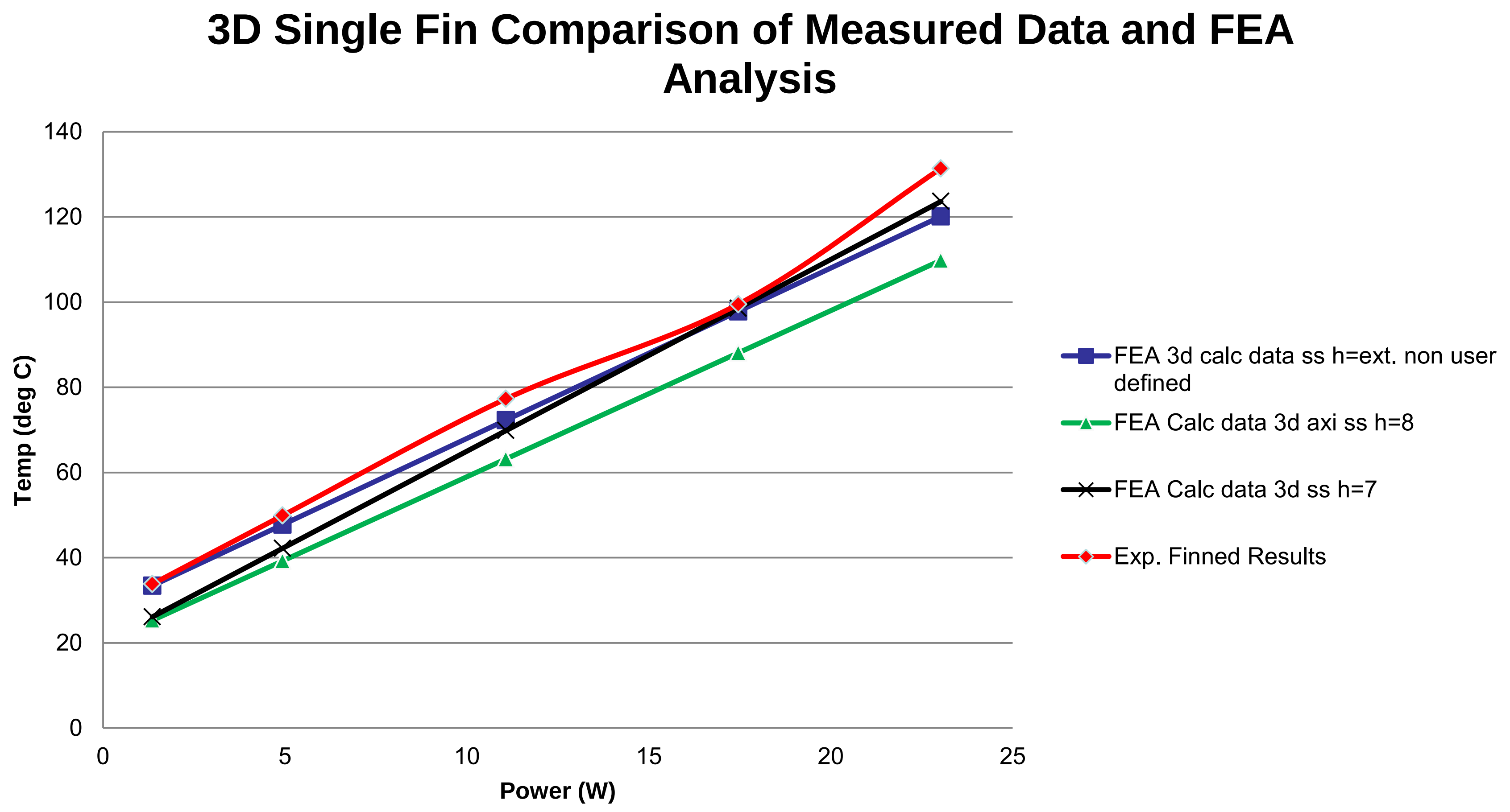


# Metal Foam Comparison

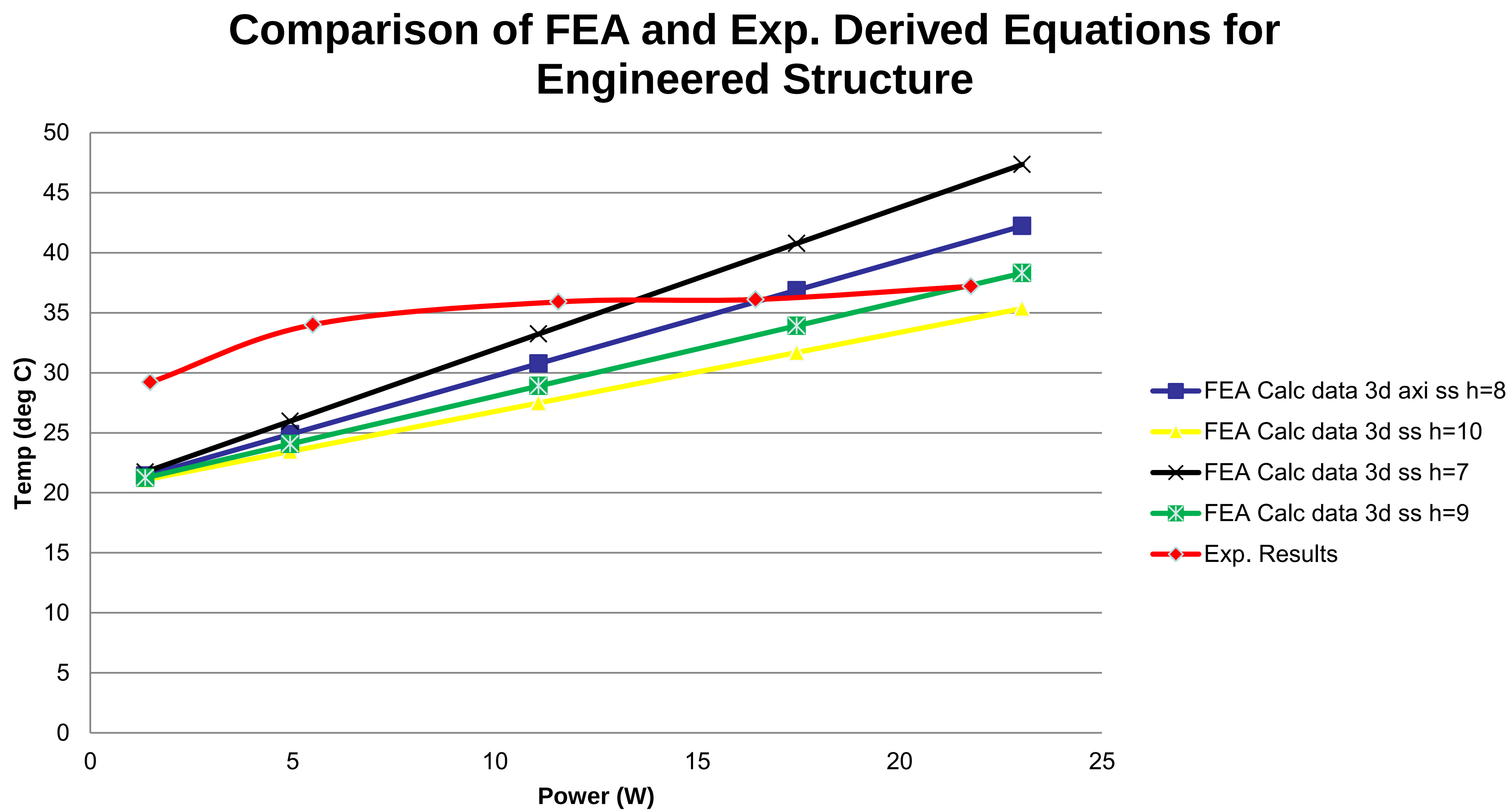
**Comparison of Linearly Derived Equations of Foam FEA to Exp.**



# Finned Heat Sink Comparison



# Engineered Structure Comparison



# Next Steps

- Design & fabrication of multi-functional orthosis structure
- Continue multi-functional characterizations
- Determine if second-order relations are best
- Continue development of the structure-sizing relations
- Continue development of automated free-form algorithms

# Conclusions

- Passive thermal management can be achieved through the design of components using engineered lattices
- Target performance can be attained by varying material and geometry
- Benefits
  - Integrated, minimal-mass, multifunctional design, e.g. load bearing and thermal management

# Acknowledgements

- CCEFP
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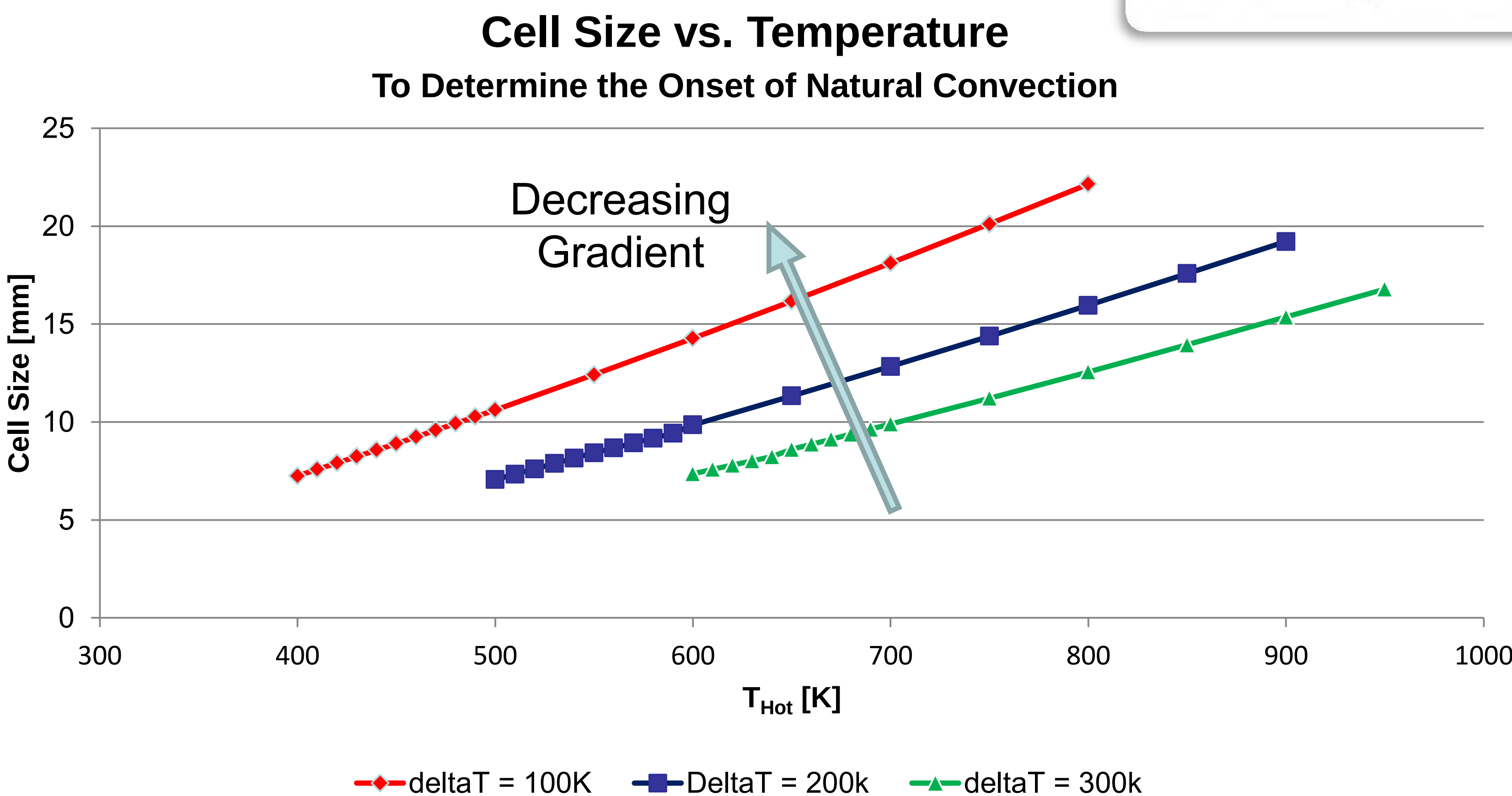
# Thank you!

# Questions?

# Onset of Convection

$$Ra \equiv \frac{g\beta(T_1 - T_2)L^3}{\alpha\nu} > 1708$$



# Geom.-Dependent $K_{eff}$

## Simple Cube

$$Kxx(x,y,z) = 7.098\emptyset x^2 + 24.463\emptyset y^2 + 24.484\emptyset z^2 + 33.195\emptyset x\emptyset y + 33.204\emptyset x\emptyset z + 7.391\emptyset y\emptyset z + 54.746\emptyset x - 25.441\emptyset y - 25.465\emptyset z$$

$$Kyy(x,y,z) = 24.491\emptyset x^2 + 7.094\emptyset y^2 + 24.473\emptyset z^2 + 33.190\emptyset x\emptyset y + 7.380\emptyset x\emptyset z + 33.181\emptyset y\emptyset z - 25.463\emptyset x + 54.755\emptyset y - 25.443\emptyset z$$

$$Kzz(x,y,z) = 36.417\emptyset x^2 + 36.373\emptyset y^2 + 77.304\emptyset z^2 - 24.288\emptyset x\emptyset y + 28.356\emptyset x\emptyset z + 28.318\emptyset y\emptyset z - 20.033\emptyset x - 19.977\emptyset y + 28.343\emptyset z$$

## Ultra Cube

$$Kxx(x,y,z) = 232.076\emptyset x^2 + 176.753\emptyset y^2 + 176.7531\emptyset z^2 - 205.439\emptyset x\emptyset y - 205.437\emptyset x\emptyset z - 120.536\emptyset y\emptyset z + 26.394\emptyset x + 37.753\emptyset y + 37.747\emptyset z$$

$$Kyy(x,y,z) = 176.760\emptyset x^2 + 232.100\emptyset y^2 + 176.751\emptyset z^2 - 205.453\emptyset x\emptyset y - 120.55\emptyset x\emptyset z - 205.456\emptyset y\emptyset z + 37.750\emptyset x + 26.383y + 37.761\emptyset z$$

$$Kzz(x,y,z) = 176.755\emptyset x^2 + 176.755\emptyset y^2 + 232.100\emptyset z^2 - 120.556\emptyset x\emptyset y - 205.462\emptyset x\emptyset z - 205.457\emptyset y\emptyset z + 37.750\emptyset x + 37.757\emptyset y + 26.386\emptyset z$$

## Super Cube

$$Kxx(x,y,z) = 198.514\emptyset x^2 + 232.055\emptyset y^2 + 228.267\emptyset z^2 - 183.149\emptyset x\emptyset y - 186.909\emptyset x\emptyset z - 206.603\emptyset y\emptyset z + 50.686\emptyset x + 19.065\emptyset y + 25.510\emptyset z$$

$$Kyy(x,y,z) = 231.324\emptyset x^2 + 197.766\emptyset y^2 + 231.324\emptyset z^2 - 185.432\emptyset x\emptyset y - 205.144\emptyset x\emptyset z - 185.432\emptyset y\emptyset z + 20.690\emptyset x + 52.332\emptyset y + 20.690\emptyset z$$

$$Kzz(x,y,z) = 229.014\emptyset x^2 + 229.031\emptyset y^2 + 199.260\emptyset z^2 - 208.119\emptyset x\emptyset y - 184.677\emptyset x\emptyset z - 184.664\emptyset y\emptyset z + 23.892\emptyset x + 23.871\emptyset y + 49.069\emptyset z$$