Effective Emissivity of Nonisothermal Isogrid for Spacecraft Radiator Applications

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Introduction

The effective emissivity (ε_{eff}) of isogrid (an array of equilateral triangular cavities) is not well understood. In this research, the ε_{eff} of isogrid with a prescribed base temperature and nonisothermal walls is examined. The temperature profile of the cavity's walls and the overall ε_{eff} of the cavity are found using Thermal Desktop with Monte Carlo ray tracing.

The radiative emission of any object is described by

$$Q_{emission} = A\varepsilon\sigma T^4$$

where A is the area, ε is the emissivity, σ is the Stefan-Boltzmann constant, and T is the absolute temperature.

The effective emissivity of a cavity is defined as

$$\varepsilon_{eff} = \frac{Q_{cavity\ emission}}{Q_{blackbody}} \leq 1$$

where $Q_{cavity\ emission}$ is the radiative emission from the cavity and $Q_{blackbody}$ is the emission from a blackbody having the same surface area as the cavity's opening.

Methodology

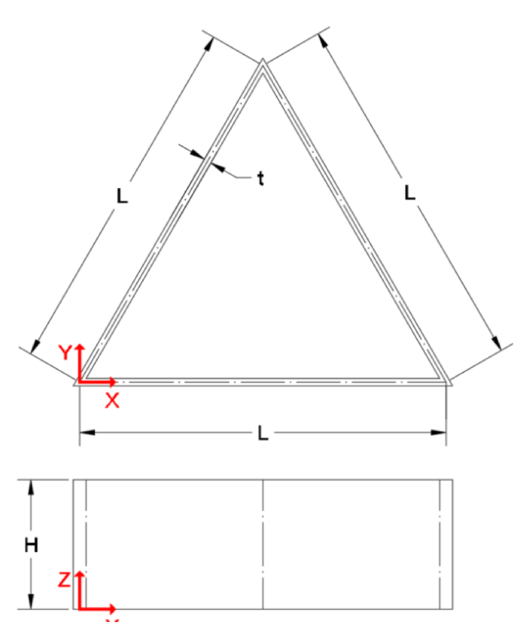
An isogrid array was modelled in Thermal Desktop with the following assumptions:

- A single cavity of interest lies within an arbitrarily large isogrid array
- The array is in space with no radiative backloading from other bodies
- The base of the array is isothermal at prescribed temperature $T_b = 300K$
- The cavity is diffuse with emissivity ε_{surf} independent of temperature
- Wall thickness $t \ll$ side length L

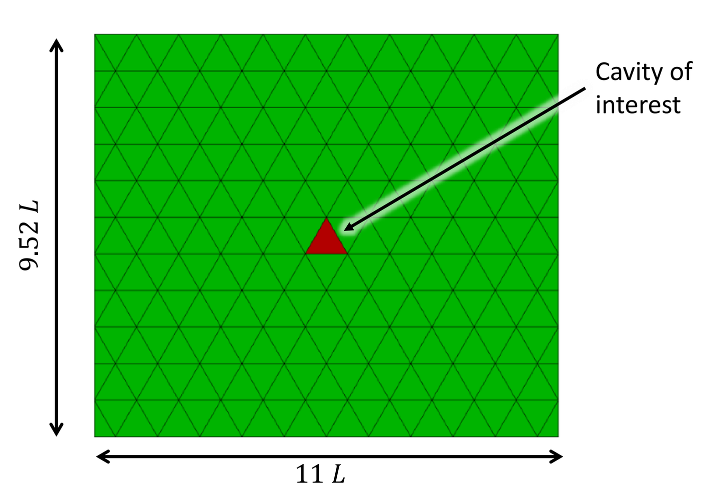
The following nondimensional parameters were established

$$\eta = \frac{A_{walls}}{A_{base}} = \frac{12H}{\sqrt{3}L} \qquad \lambda = t/L$$

Where η is the nondimensionalized wall height, λ is the nondimensionalized wall thickness, L is the side length, H is the cavity height, and t is the wall thickness.

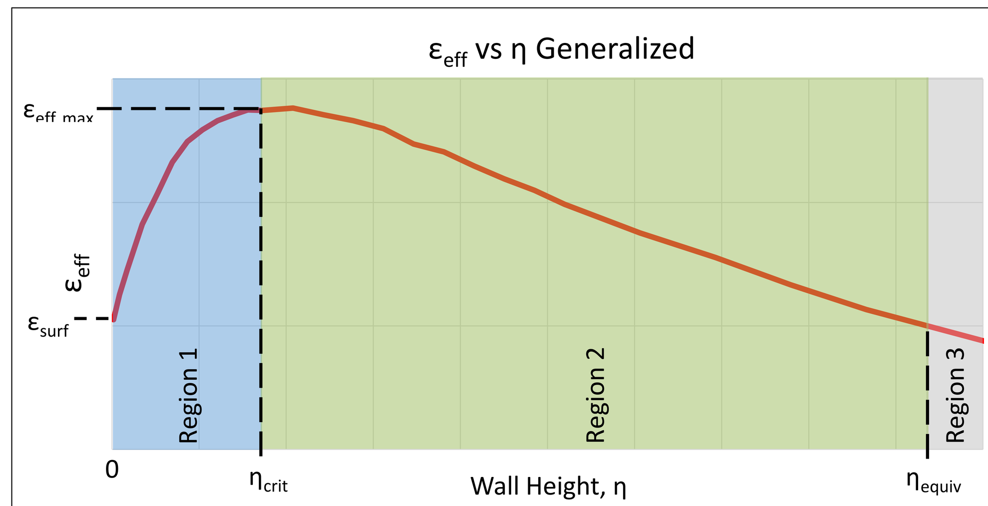


Isogrid Cavity Geometric Parameters

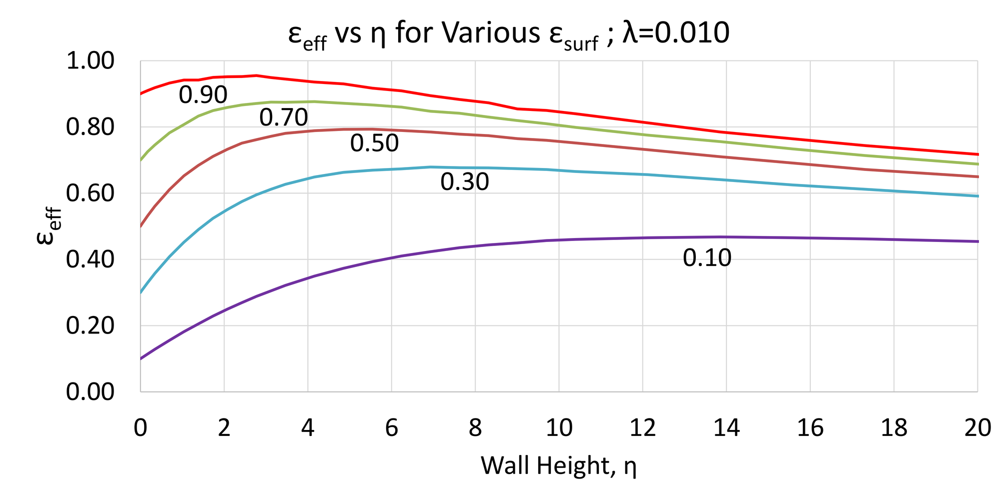


Isogrid Array in Thermal Desktop

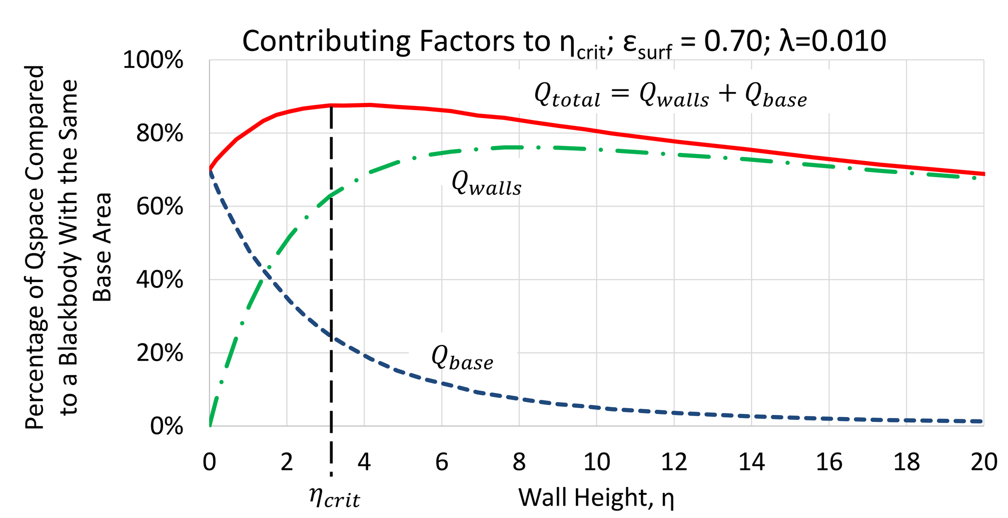
Results



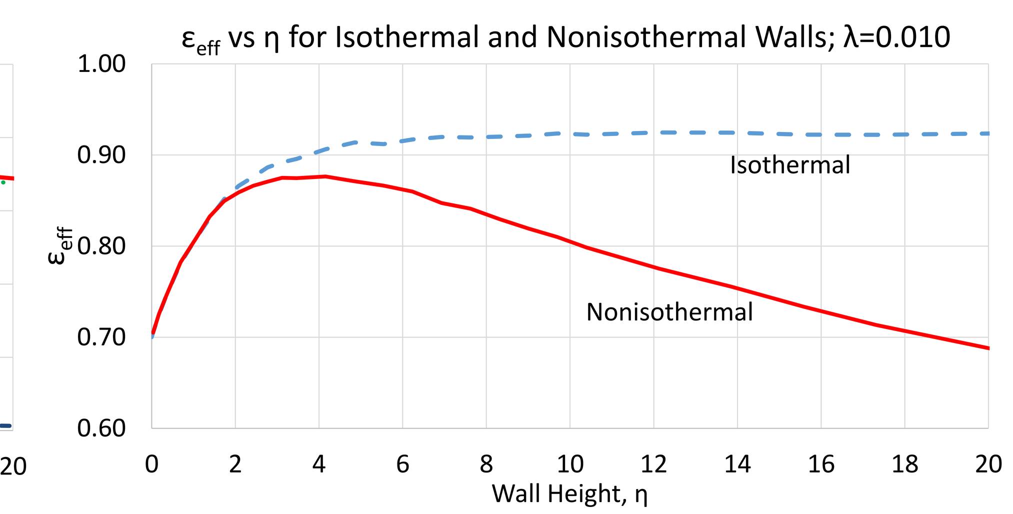
- Region 1: $\varepsilon_{eff} \geq \varepsilon_{surf}$; $d\varepsilon_{eff}/d\eta > 0$
- Region 2: $\varepsilon_{eff} > \varepsilon_{surf}$; $d\varepsilon_{eff}/d\eta \leq 0$
- Region 3: $\varepsilon_{eff} \leq \varepsilon_{surf}$; $d\varepsilon_{eff}/d\eta < 0$



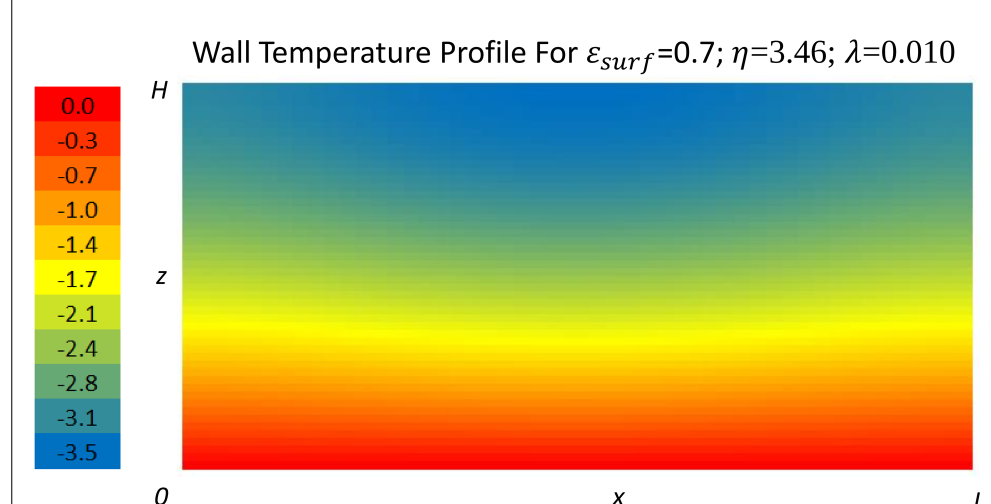
- Higher ε_{surf} leads to higher $\varepsilon_{eff\ max}$
- Higher ε_{surf} leads to greater relative increase in ε_{eff} (higher turndown ratio)
- Higher ε_{surf} leads to lower η_{crit}



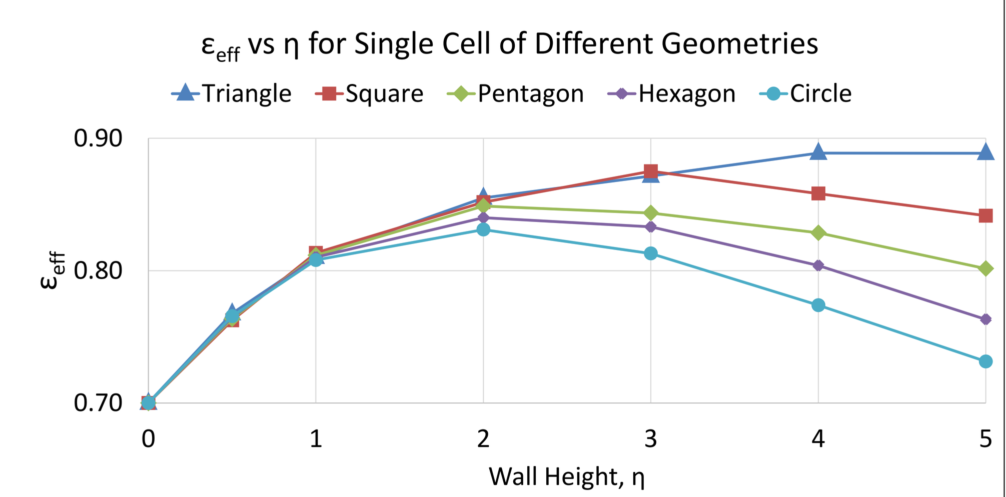
- At $\eta = 0$, $Q_{walls} = 0$ and $Q_{total} = Q_{base}$
- As η increases, Q_{base} decreases
- As η increase, Q_{walls} initially increases before reaching a maximum and decreasing
- As $\eta \to \infty$, $Q_{base} \to 0$ and $Q_{total} = Q_{walls}$



- For small η, Isothermal ≈ Nonisothermal
- For large η, Isothermal > Nonisothermal
- As $\eta \to \infty$, Isothermal > ε_{surf}, Nonisothermal < ε_{surf}



- Highest temperature along $z = 0$ at prescribed base temperature T_b
- Lowest temperature at $x = \frac{L}{2}, z = H$
- ΔT between $z = 0$ and $z = H$ increases with increasing wall height H



- For small η, all geometries have same ε_{eff}
- As η increases, Triangle > Square > Pentagon > Hexagon > Circle
- Triangle has the largest perimeter/area ratio
- For a given η: larger P/A → smaller H → lower ΔT → larger ε_{eff}

Conclusion

The ε_{eff} of a nonisothermal isogrid cavity is highly dependent on the cavity's geometric dimensions, especially the wall height (η). The effect of η on the ε_{eff}, and the mechanisms behind this effect, are summarized below.

$\eta < \eta_{crit}$

- Low thermal resistance up the short walls, cavity walls ≈ isothermal
- Cavity base has large view factor to space
- ε_{eff} increases with η

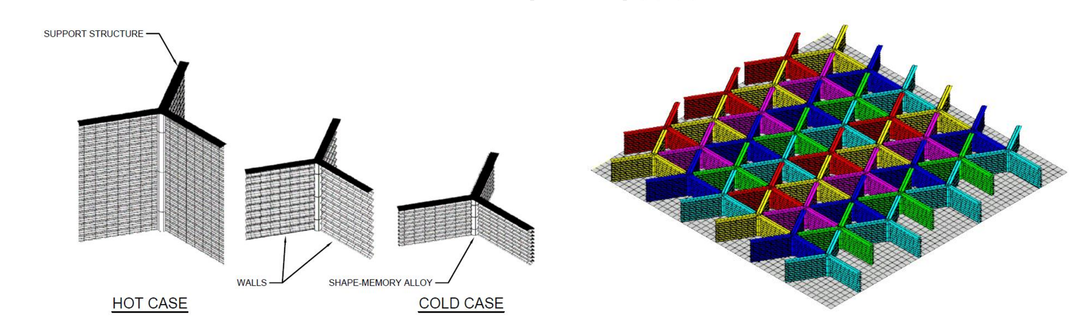
$\eta = \eta_{crit}$

- ε_{eff} reaches maximum value of $\varepsilon_{eff\ max}$

$\eta > \eta_{crit}$

- Increased thermal resistance leads to large gradients up the walls
- Cool top of the walls radiate less effectively to space
- Warm cavity base has small view factor to space
- ε_{eff} monotonically decreases with η
- When $\eta \geq \eta_{equiv}$, $\varepsilon_{eff} \leq \varepsilon_{surf}$

A passive variable emissivity isogrid radiator may be constructed by exploiting the effect of η on ε_{eff}. The wall height may be varied via bimetallic strips, shape-memory alloys, or similar, based on the temperature. Like a louver, a desired setpoint temperature can be maintained by varying the ε_{eff}. Care should be taken to ensure that $\eta \leq \eta_{crit}$ at all times.



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