Improved Quench Tank Performance and Part Quality Through CFD Analysis

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Motivation

Quenching is a critical part of heat treatment

Quench agitation systems have not necessarily been designed for uniform treatment of the parts

Improvements to these systems would represent a significant improvement in part quality

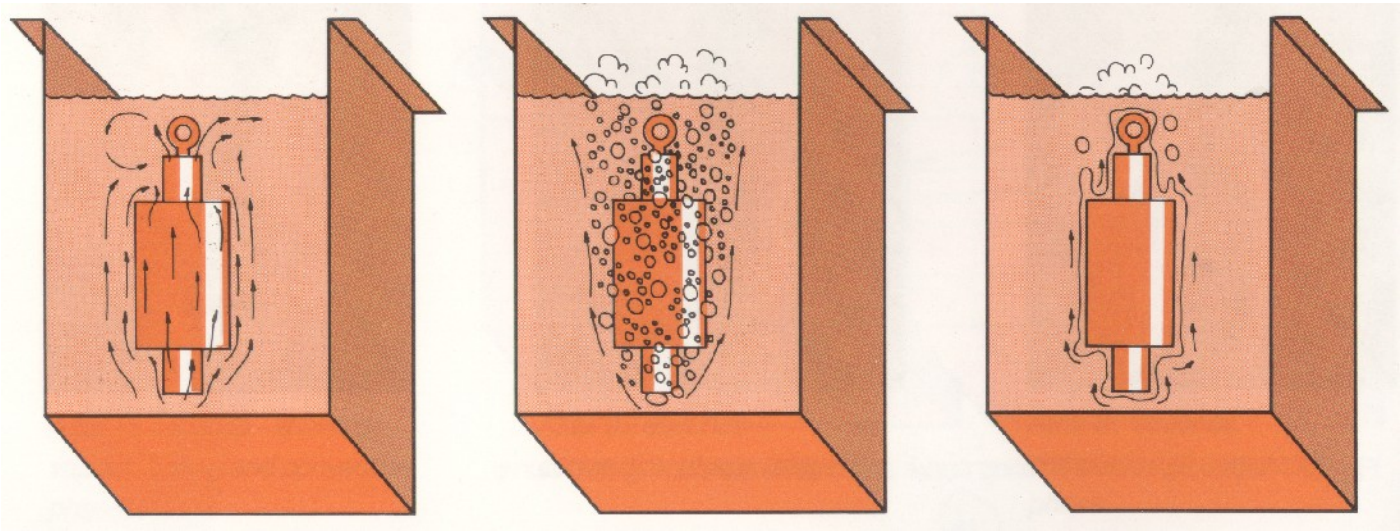
Most effective approach is to modify the installed base

An effective tool is needed to assess potential changes

Approach

Use CFD to investigate design options

Focus on isothermal convection – better flow uniformity should lead to more uniform quenching through all three stages of the quench



Film Boiling Nucleate Boiling Convection

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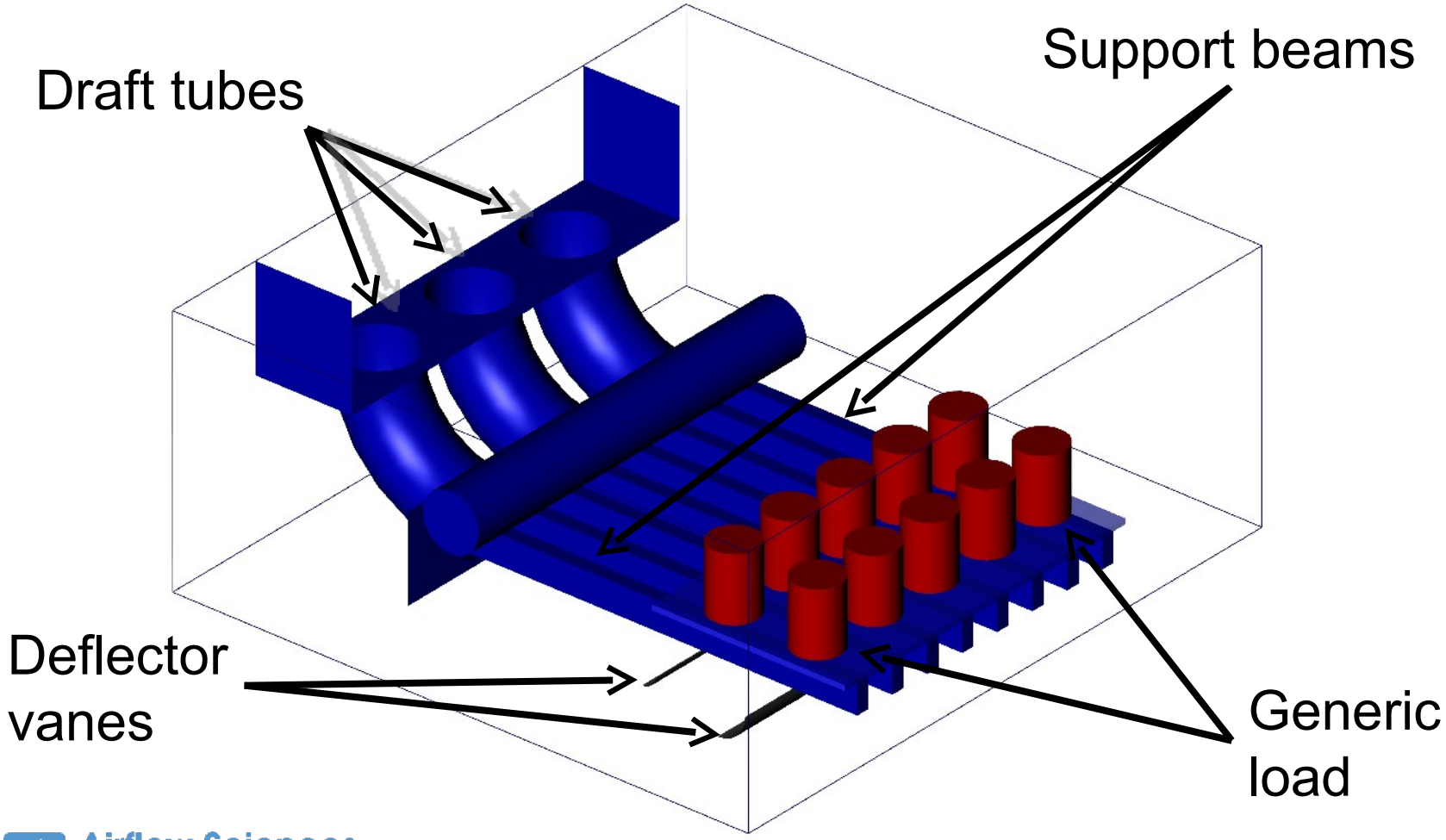
Quench Tank Geometry

Base Case



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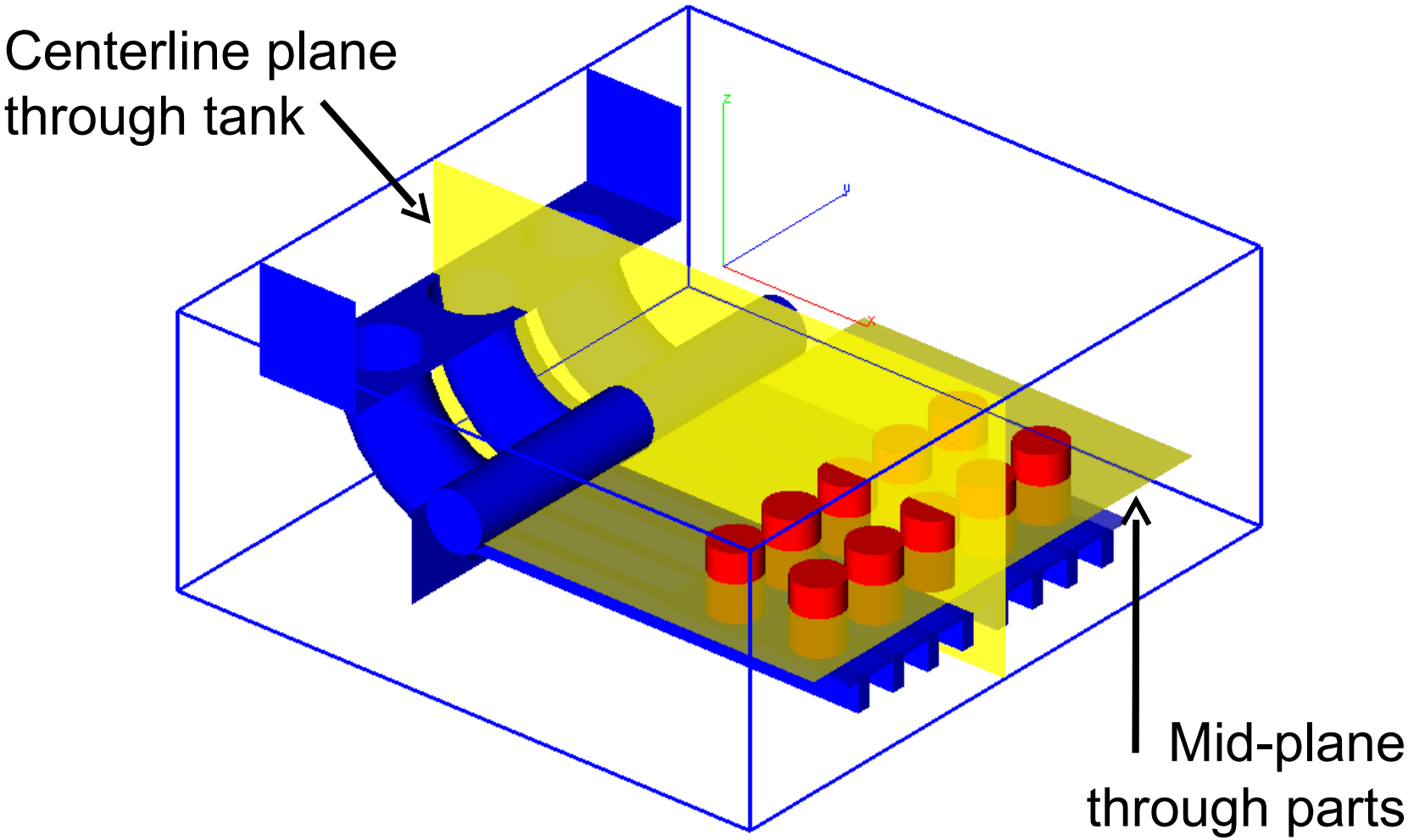
Quench Tank

Model Display Planes



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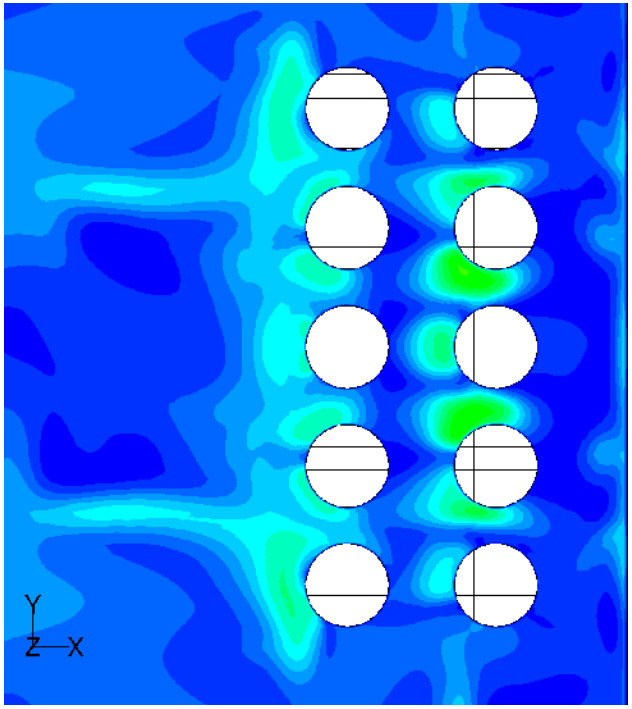
Velocity Distribution

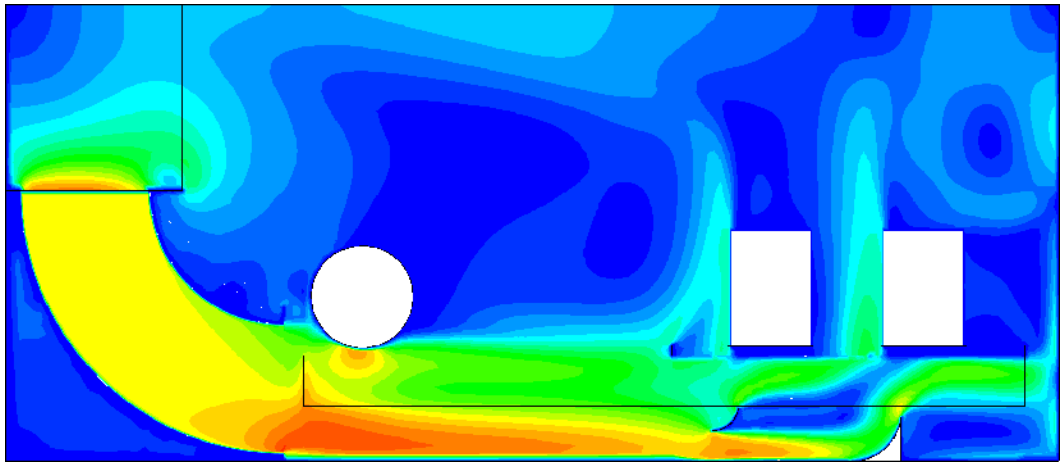
Base Case



Deflector vanes create localized jets of flow

A portion of the flow bypasses the load entirely

Presence of support beams creates low velocity areas



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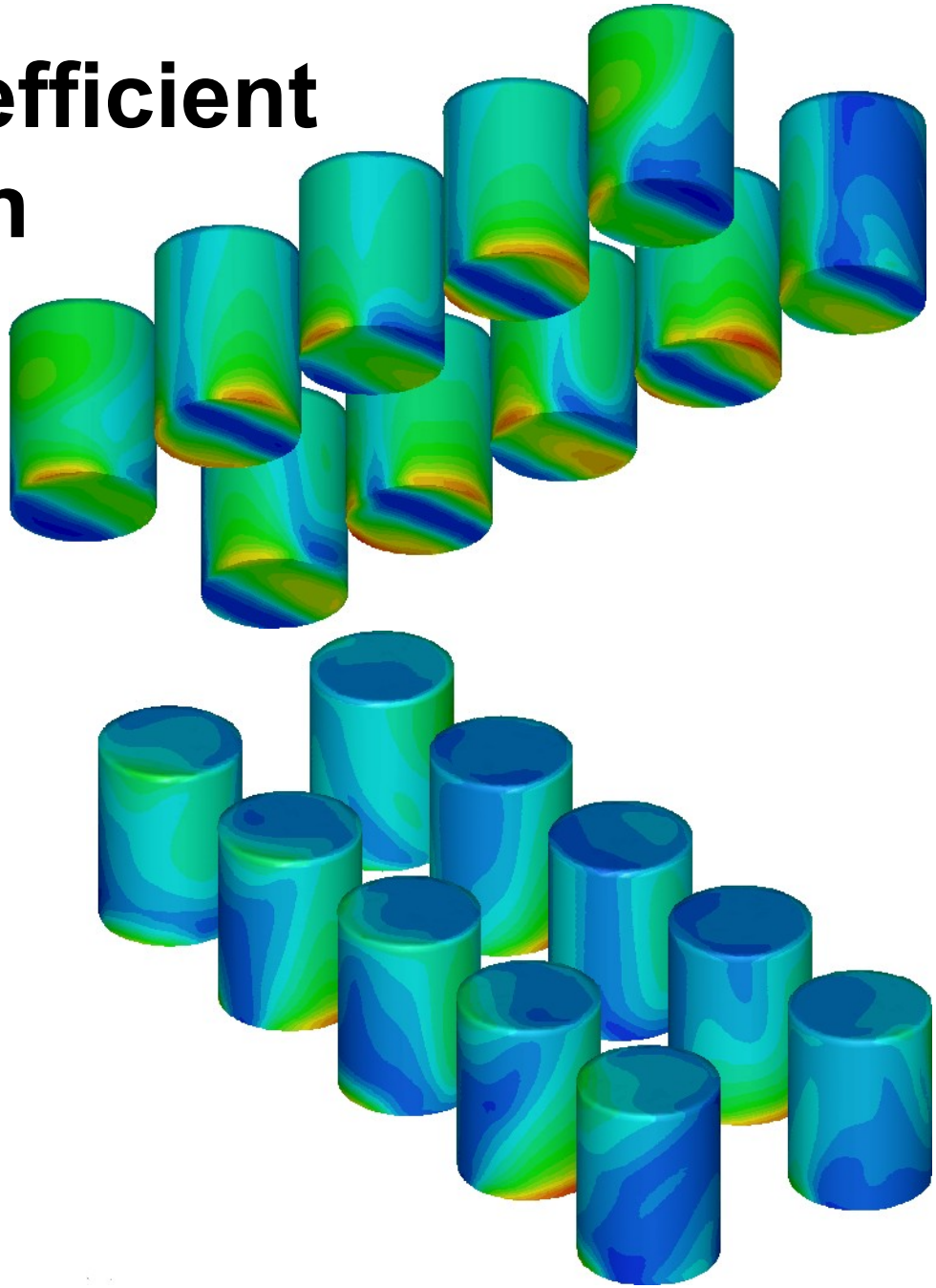
Heat Transfer Coefficient Distribution

Base Case



"Shadows" from support beams create low heat transfer areas

Vanes cause front side of parts to have higher heat transfer than rear

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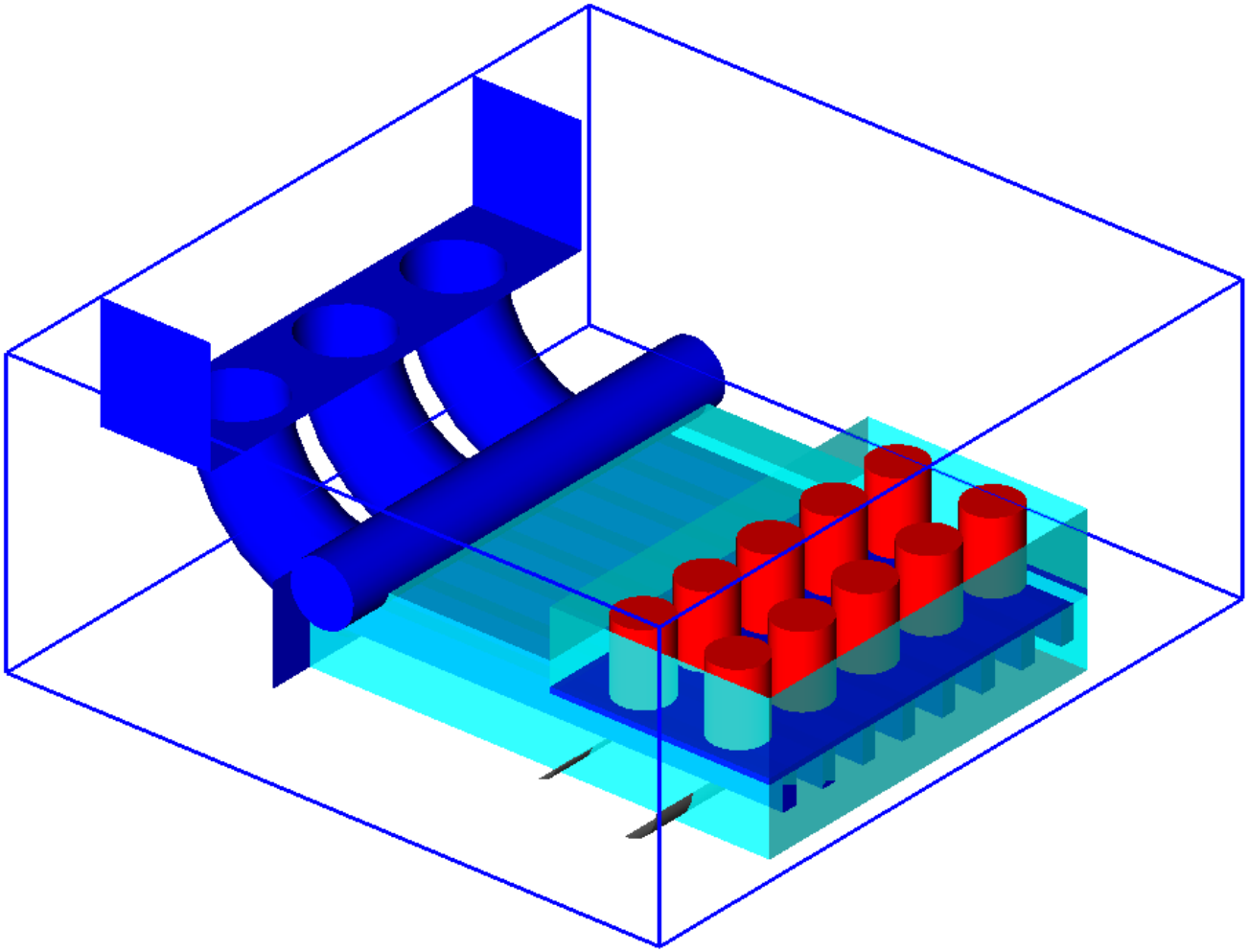
Quench Tank Geometry

Option 1 – Add Flow Baffles

Prevent flow bypass

Channel flow through load



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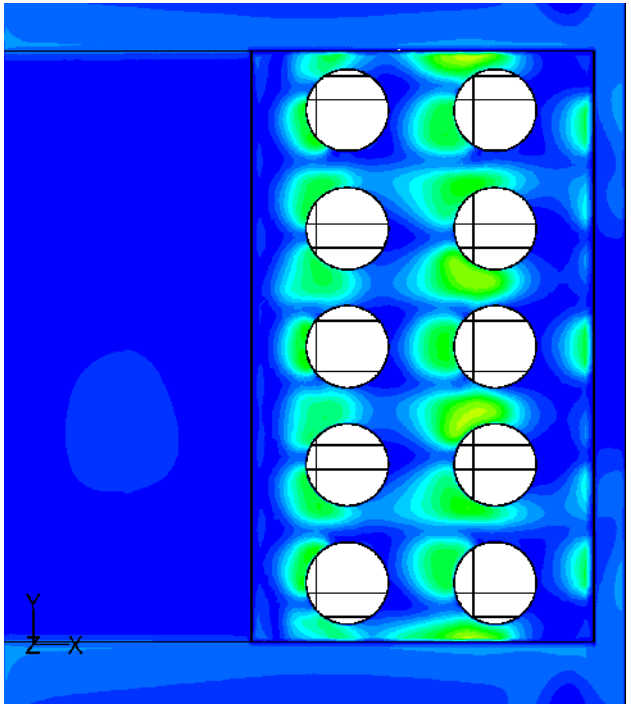
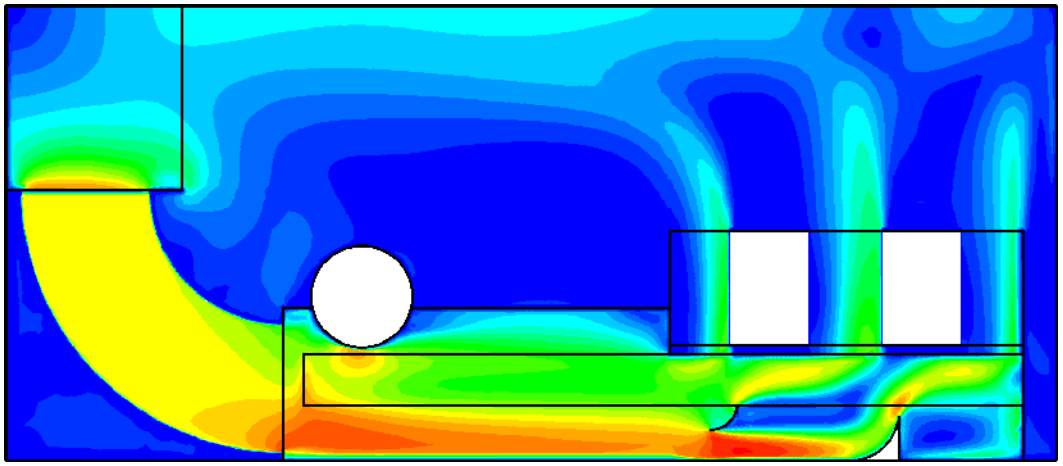
Velocity Distribution

Option 1 – Add Flow Baffles

Average velocity through load is increased (no bypass)

Effect of vanes and beams still present





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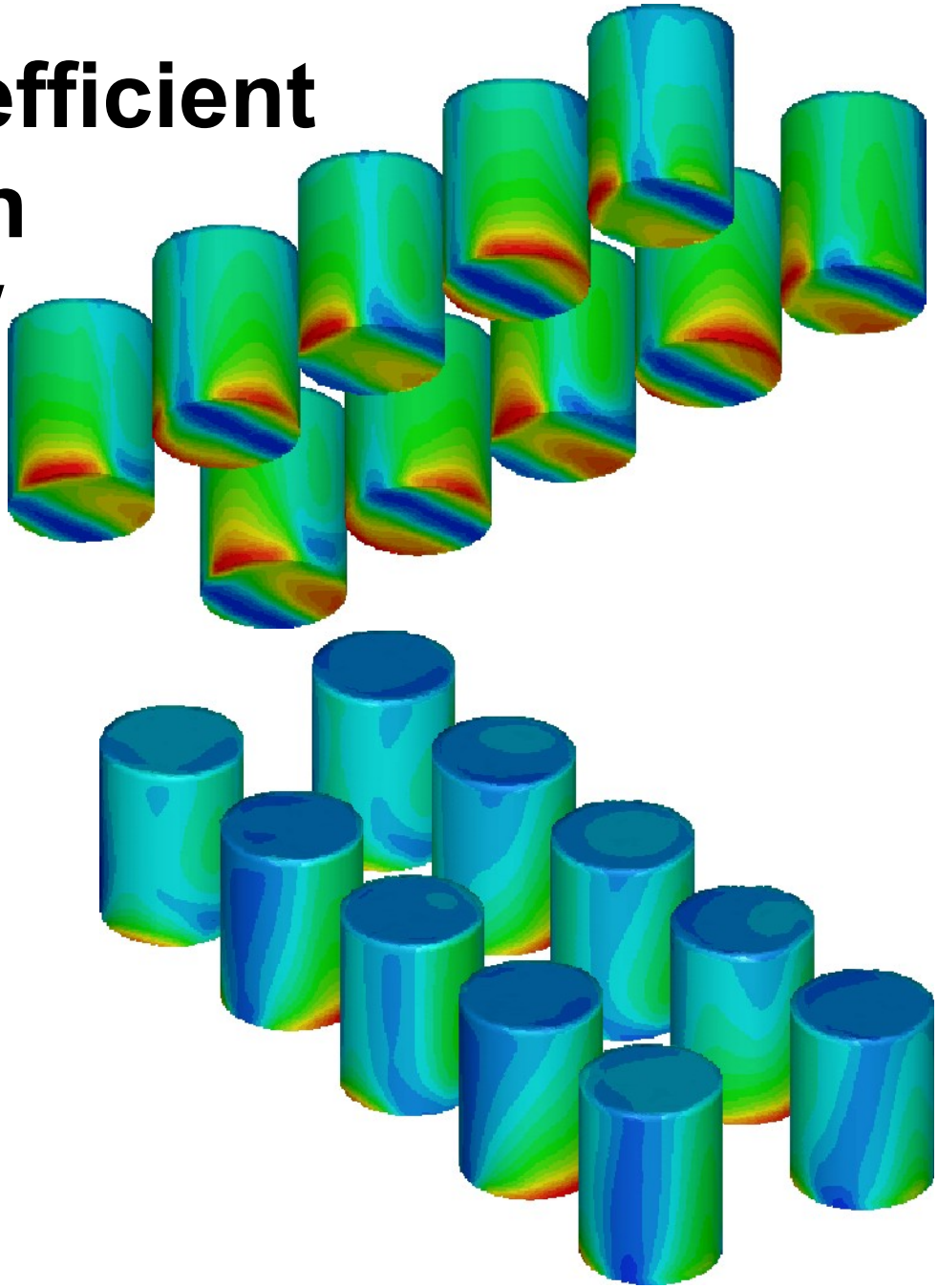
Heat Transfer Coefficient Distribution

Option 1 – Add Flow Baffles



Peak heat transfer rates are increased over base case

Pattern remains largely unchanged

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How good can it get?

CFD allows for the exploration of idealized cases that are not necessarily practical

Quick and easy on the computer – difficult to try things out in hardware

Overall flow concept is to bring flow in from bottom

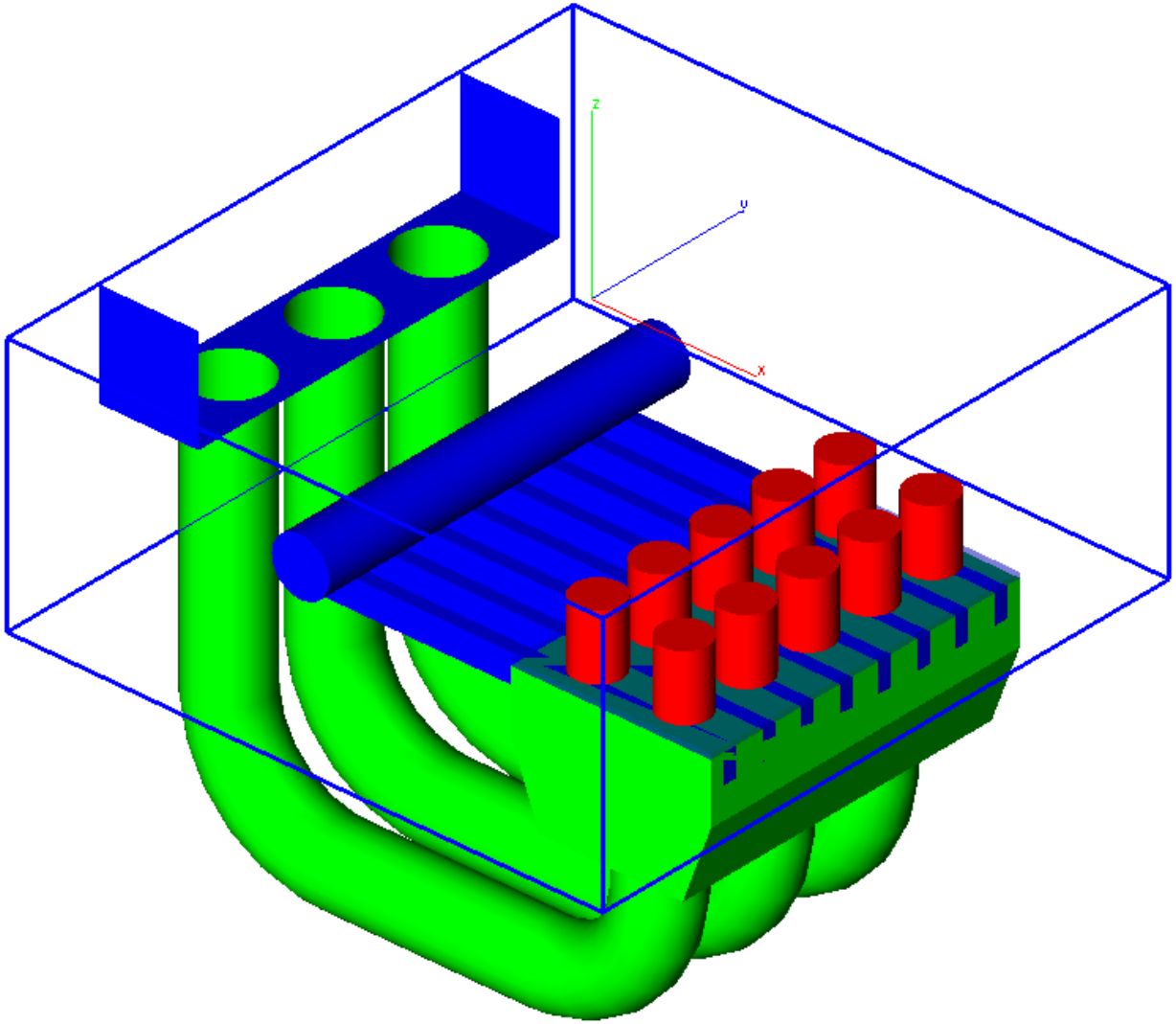
Try an idealized version of that concept to see if it works

Quench Tank Geometry

Option 1 - Idealized Flow Entrance

External flow loop presents uniform flow to load

Not practical as a retrofit or even a new design



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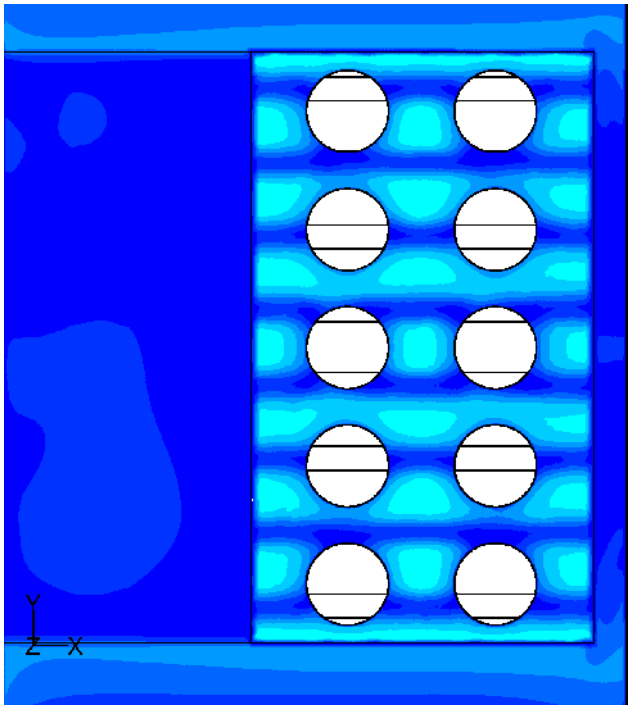
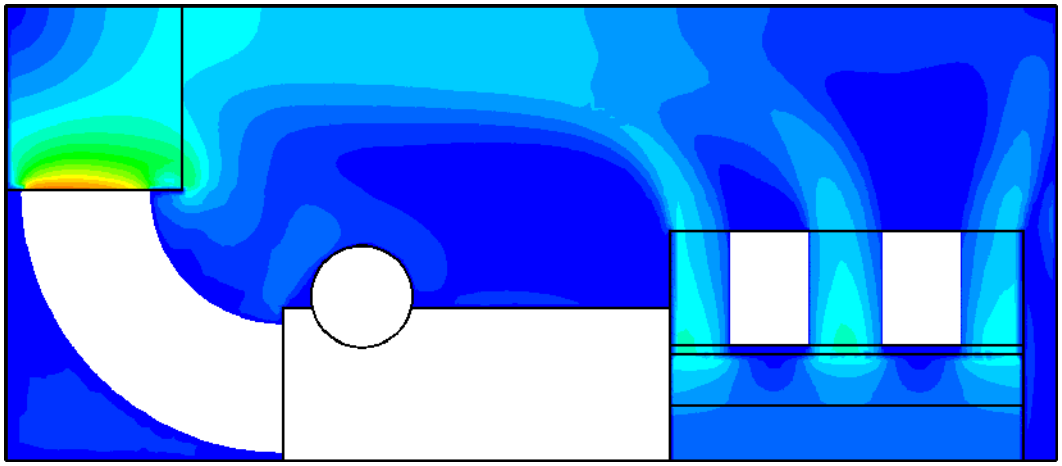
Velocity Distribution

Option 2 – Idealized Flow Entrance



Good front to back flow uniformity

Presence of support beams prevents better uniformity



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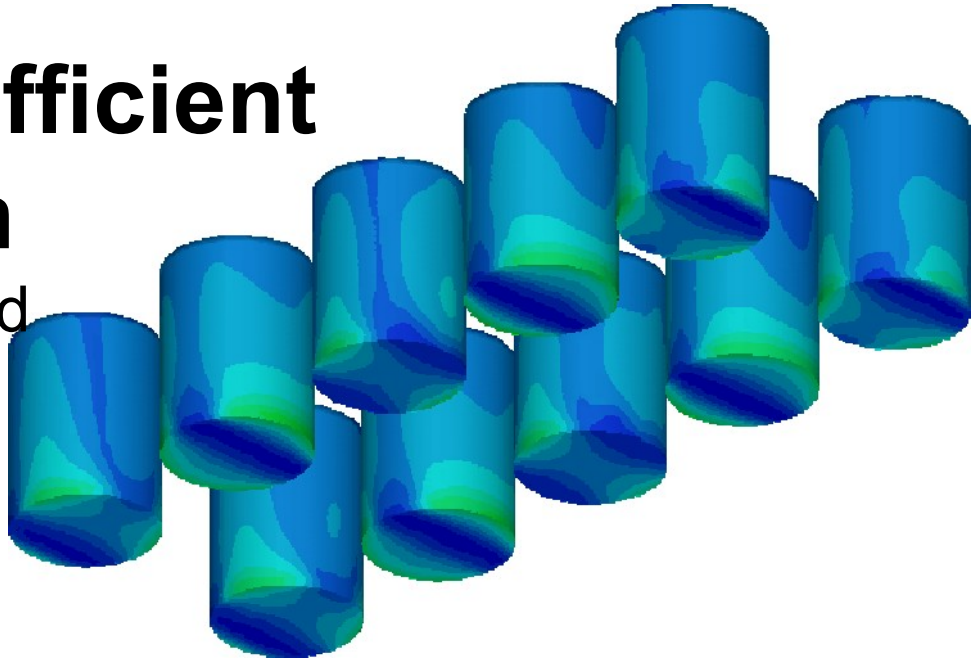
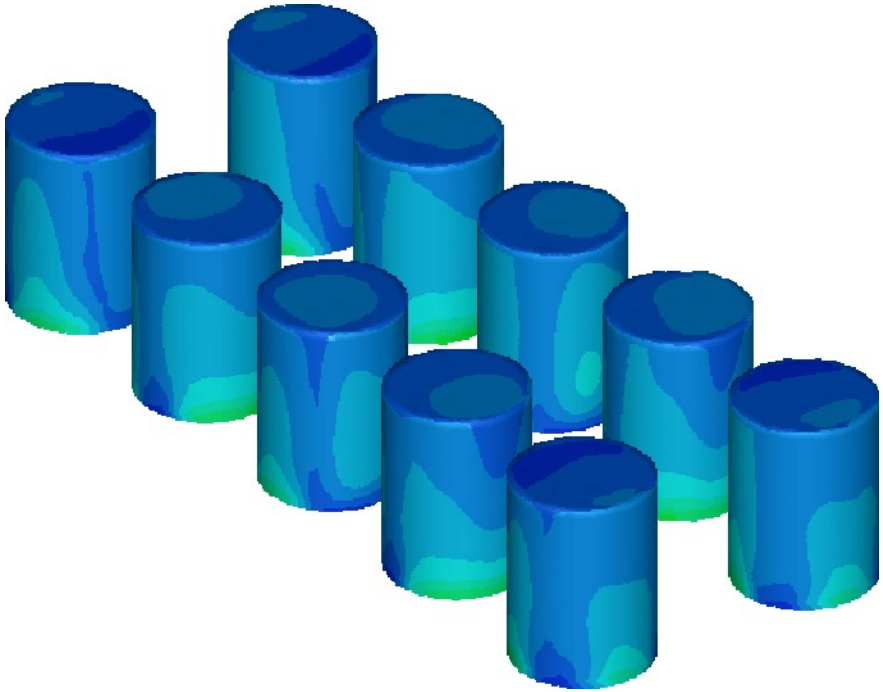
Heat Transfer Coefficient Distribution

Option 2 – Idealized flow entrance





Lower overall heat transfer rates than baseline

Good front to back uniformity

Flow around beams creates high and low heat transfer zones

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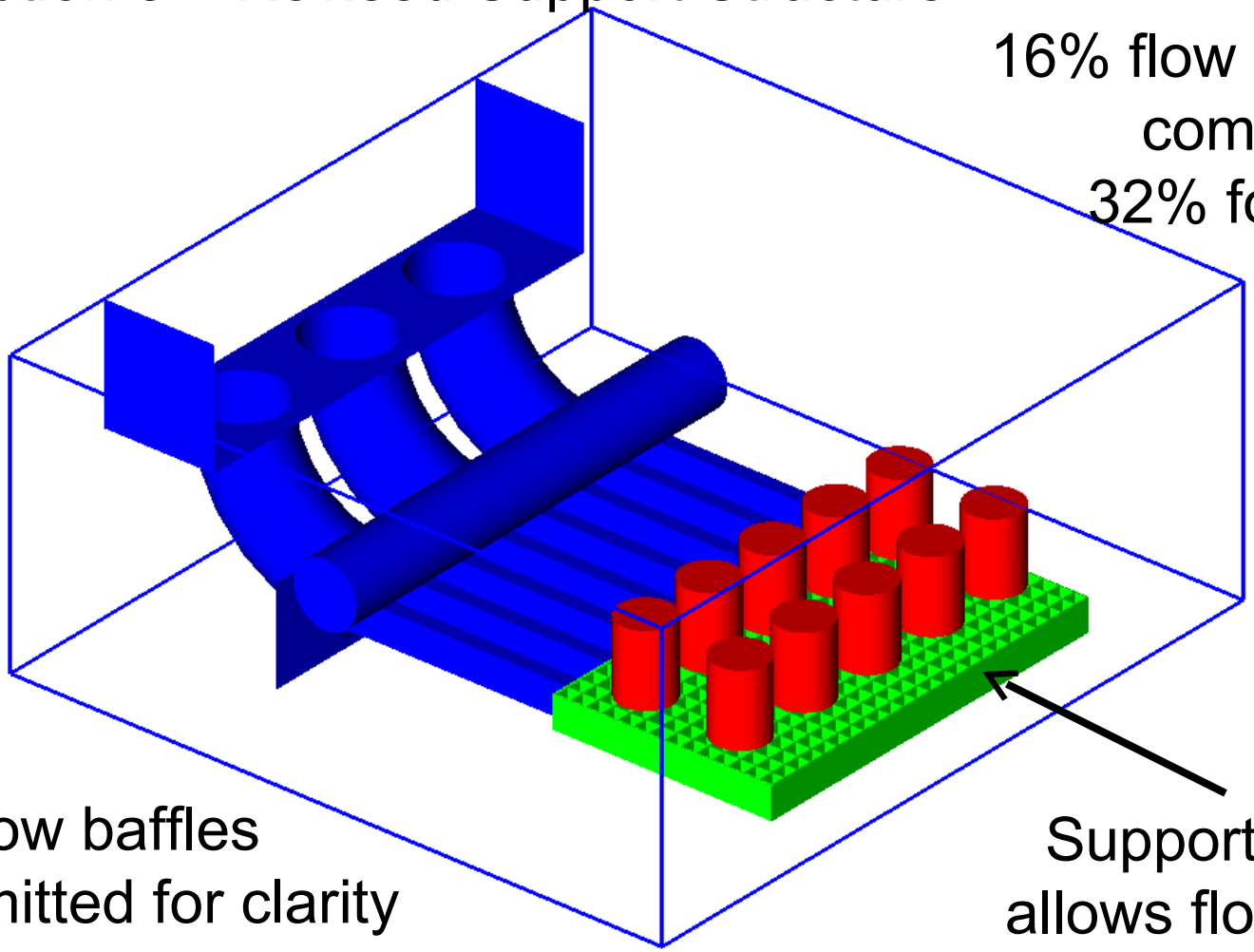
Quench Tank Geometry

Option 3 – Revised Support Structure



16% flow blockage compared to 32% for beams

Egg crate Support structure allows flow to pass 1/2” web, 6” spacing, 12” tall

Flow baffles omitted for clarity

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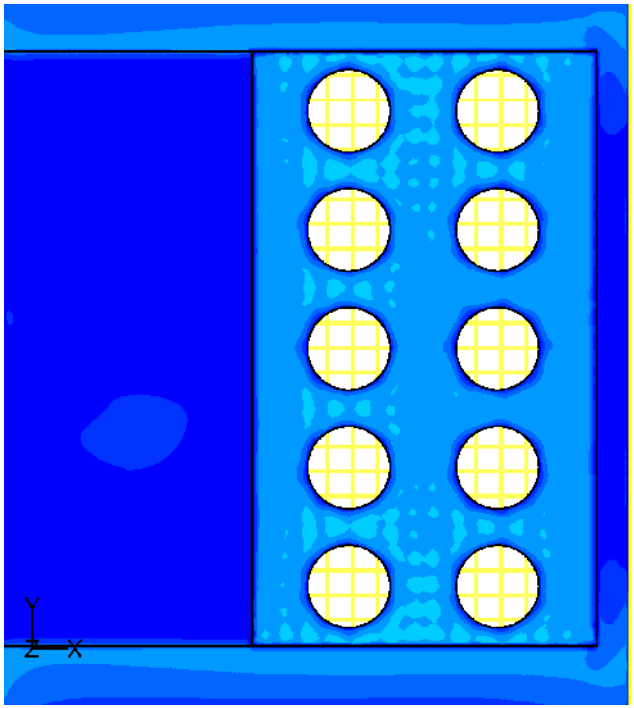
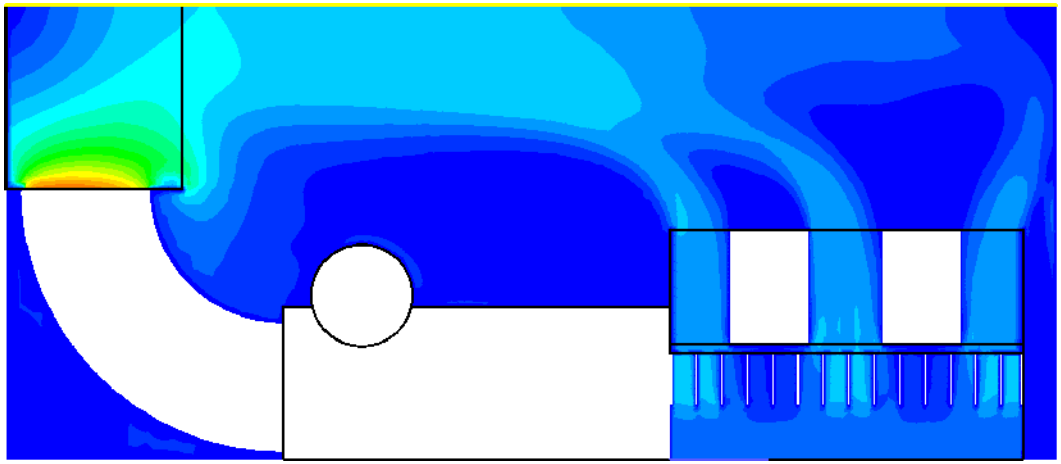
Velocity Distribution

Option 3 – Bottom Inlet, Egg-Crate Support Structure



Very uniform flow throughout the load



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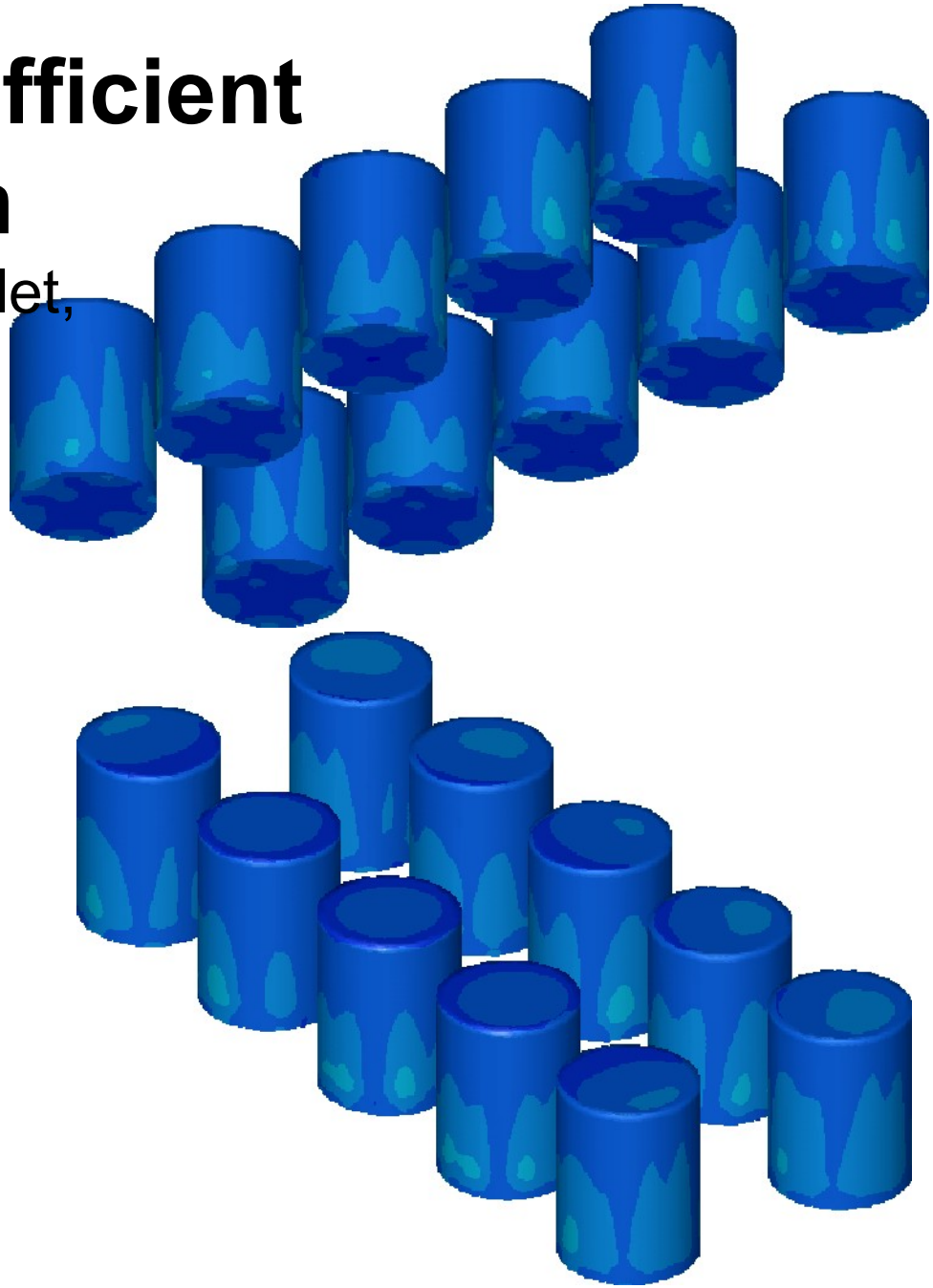
Heat Transfer Coefficient Distribution

Option 3 – Bottom inlet, egg-crate support structure



Lower overall heat transfer coefficient

Very good uniformity

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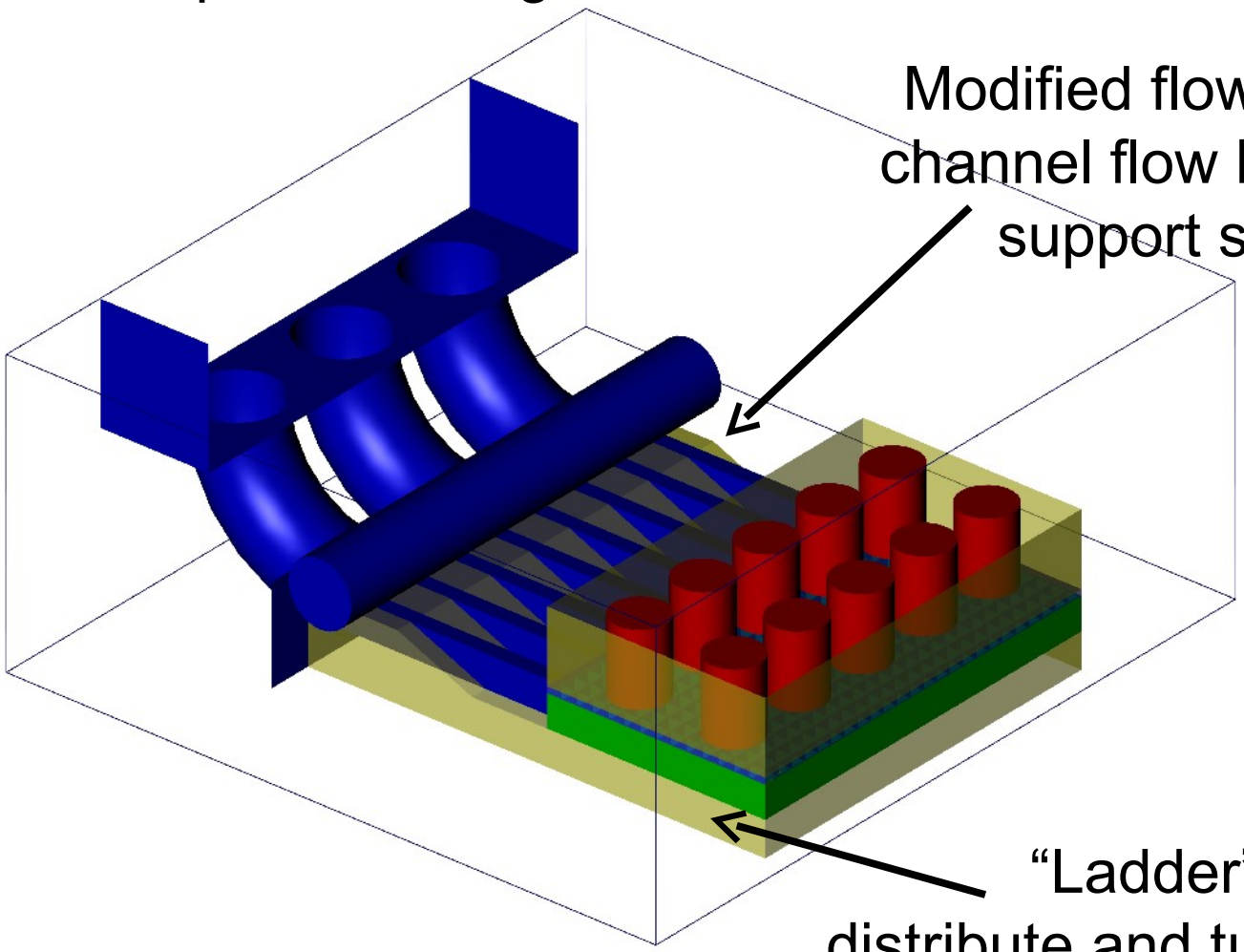
Quench Tank Geometry

Option 4 Design



Modified flow baffles channel flow beneath support structure

"Ladder" vanes distribute and turn flow up into the load

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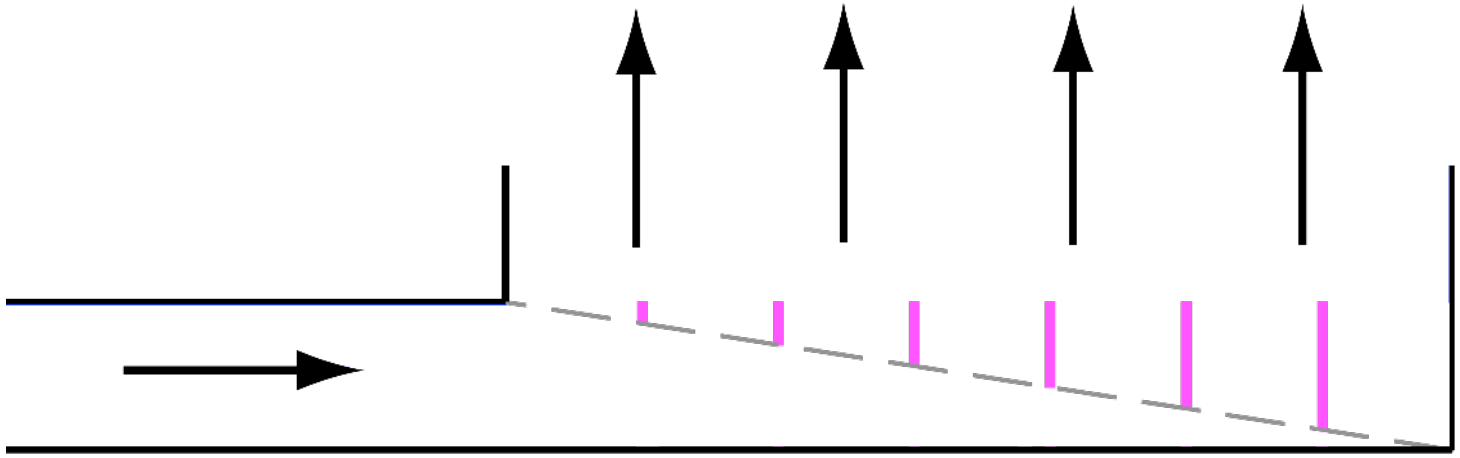
Ladder Vane Detail



Evenly spaced vanes along diagonal of 90 degree elbow evenly splits and turns flow

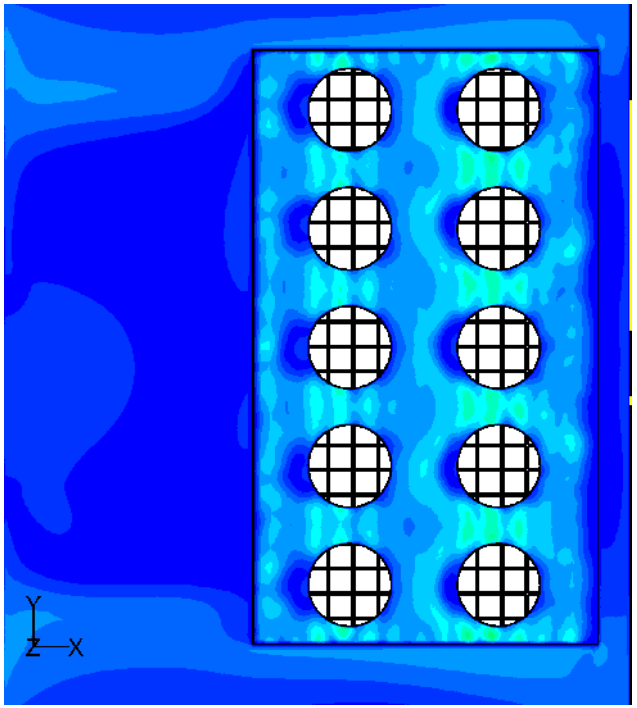
Requires even incoming flow

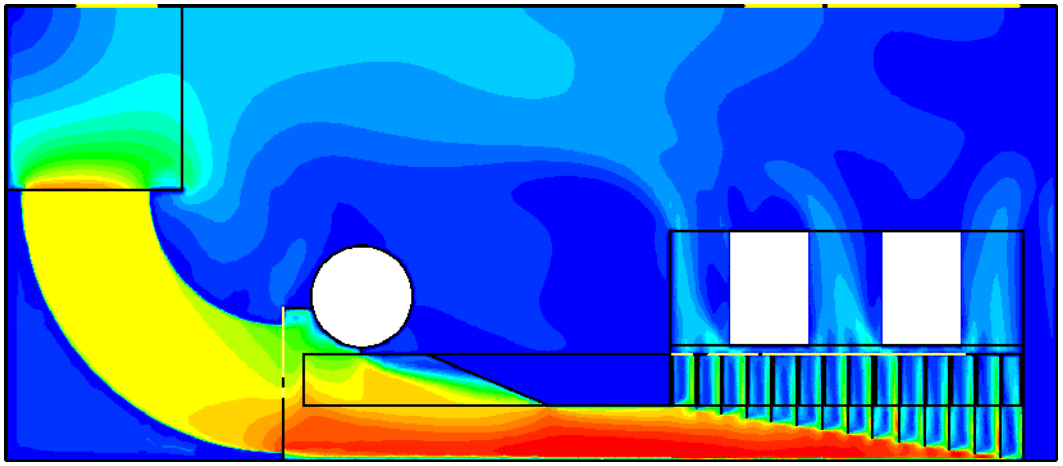
Velocity Distribution

Option 4 – Final Design

Spacing of ladder vanes matches spacing of egg-crate support.

Good flow uniformity





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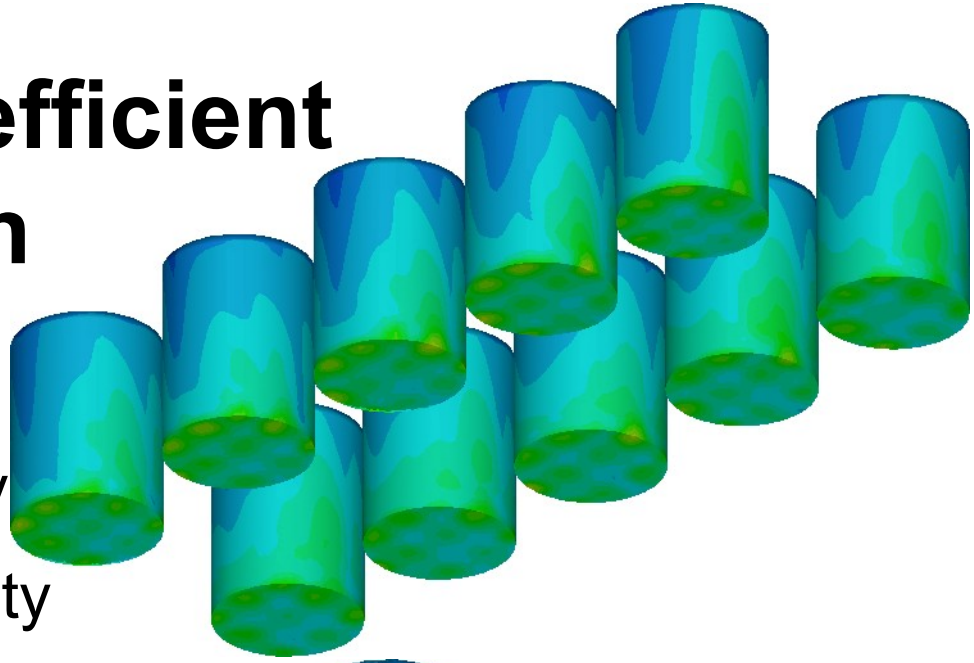
Heat Transfer Coefficient Distribution

Option 4 - Final Design

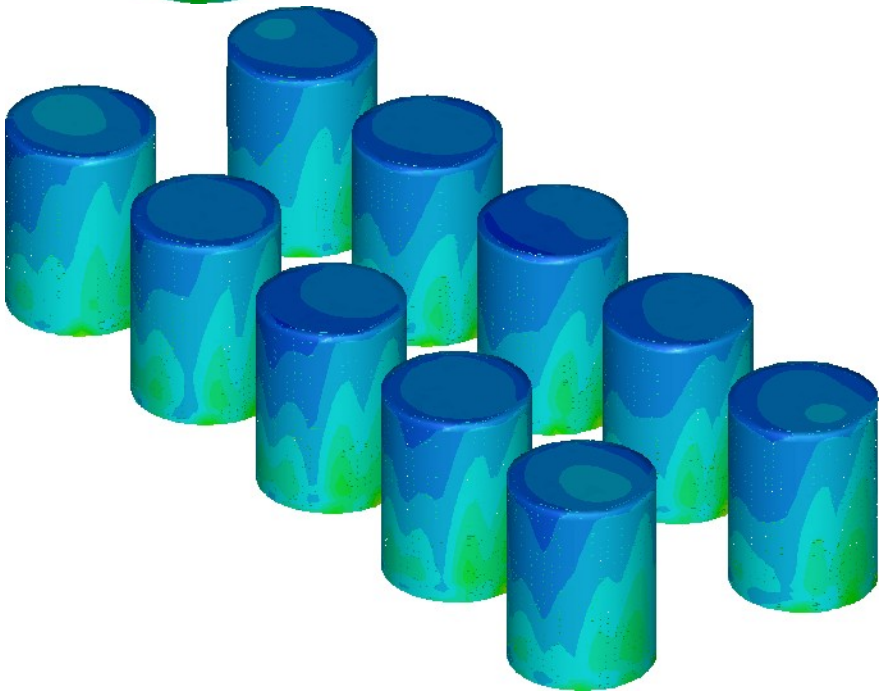


Good part to part uniformity

Good front to back uniformity

Higher heat transfer coefficient on bottom than on top

Overall heat transfer coefficient slightly less than baseline



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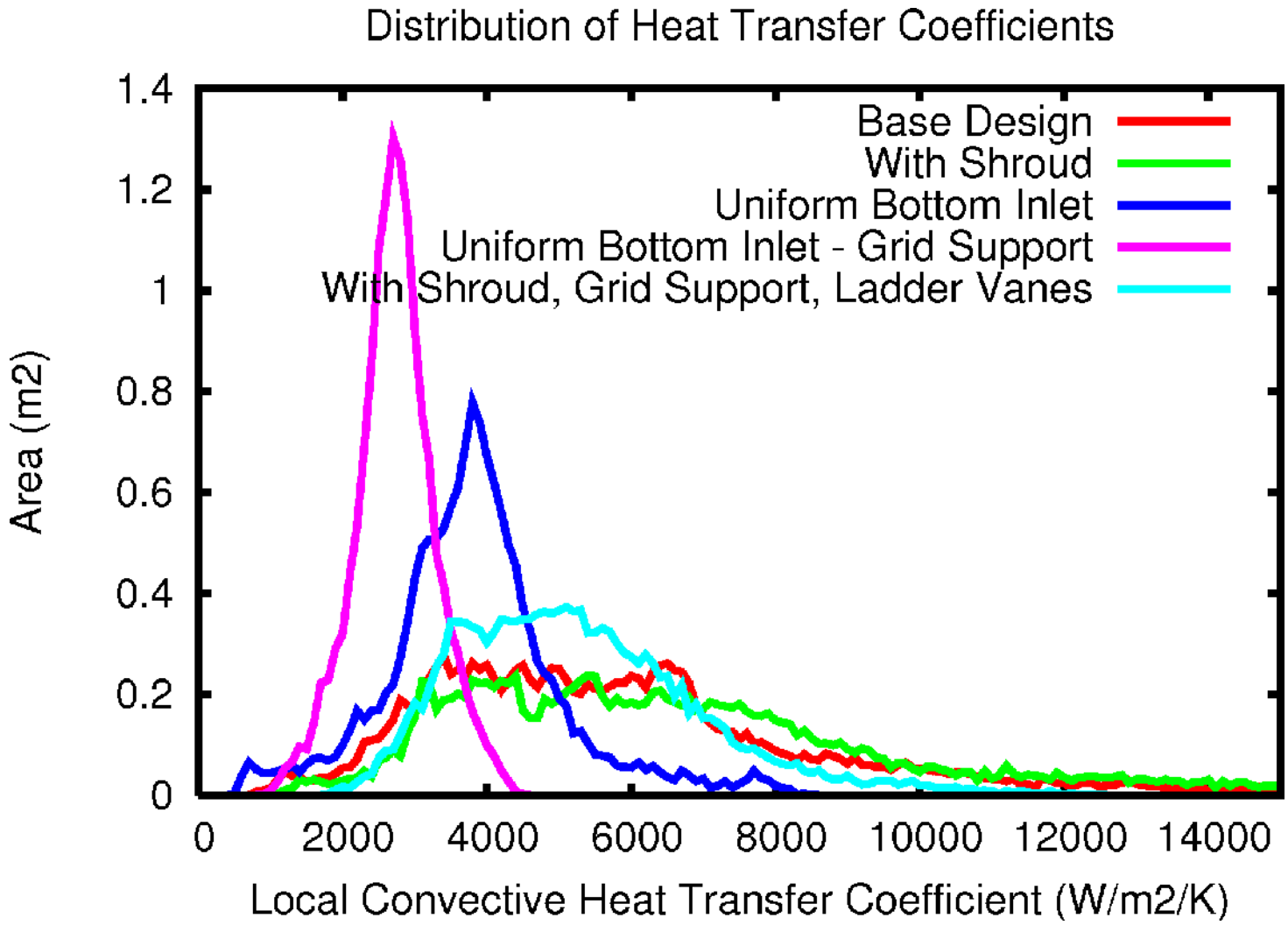
Comparison of Cases



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Comparison of Cases

Heat Transfer Coefficient Statistics ($W/m^2/K$)

Case	Min Value	Average Value	Max Value	Standard Deviation (% of mean)
Baseline	758	5896	18996	47.0%
Option 1	1076	6930	22395	50.8%
Option 2	526	3815	8607	31.6%
Option 3	931	2725	4598	20.2%
Option 4	1807	5259	12604	31.7%

Summary

Four alternatives to initial quench tank design were investigated

Final design had:

- 11% reduced overall heat transfer coefficient
- 33% reduced variation in heat transfer coefficient

Baffles and flow control devices require 2.7 times as much pumping power (6 ➔15.7 HP)

Overall quench rate could be increased by increasing quench flow rate

Modifications could be incorporated in existing quench tank

Questions?

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