# AIR COOLING OF A HPC SERVER CHASSIS WITH VERY HIGH POWER DENSITY

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Next Step Engineering Solutions, LLC

# OVERVIEW

- INTRODUCTION
- APPLICATION
- BACKGROUND – CONVECTIVE COOLING
- ANALYSIS STRATEGY
- ANALYSIS RESULTS
- SUMMARY

# INTRODUCTION

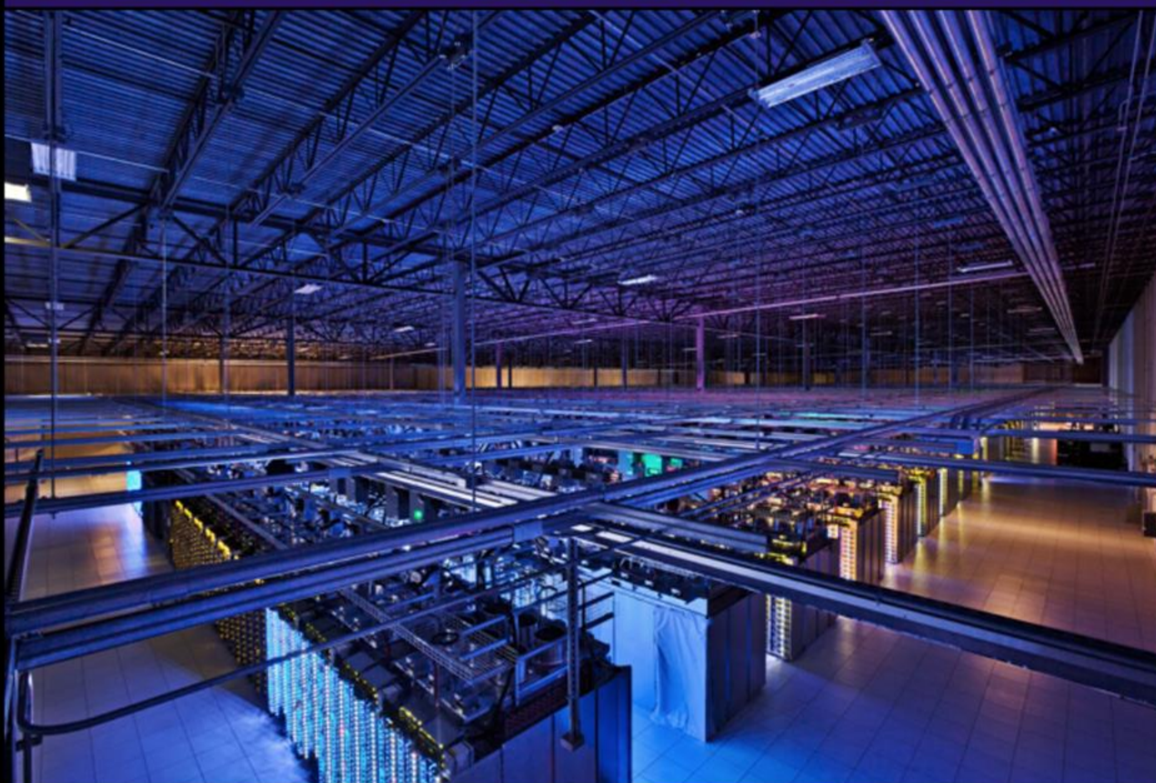
NextStepToTake.com

- In business since 2012
- Mission:  Support of technology start-ups
  - ✓ Technology validation, development strategy, IP development, technical marketing
  - ✓ Engineering services
- Expertise
  - ✓ Mechanical engineering, fluid dynamics, thermodynamics, applied mathematics, simulations (Systems, CFD, FEA)
  - ✓ Test and data acquisition
  - ✓ Software development and scientific computing
- Areas of Specialization
  - ✓ Internal Combustion Engines, Thin Film Lubrication, Image Processing and 3-D Vision, Electronics Cooling

# APPLICATION

## KNUEDGE HIGHLY SCALABLE NEURAL COMPUTING

SCALE ENABLES ARTIFICIAL INTELLIGENCE



KNUEDGE
**130MM**
cores

TaihuLight
**10MM**
cores

Google
**4MM**
cores

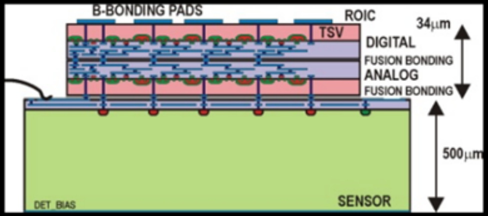
IBM Watson
**720**
cores

All Knuedge related technology is property of Friday Harbor, LLC
For inquiries, please contact Tom Hutton (tom.hutton@axaxl.com)

# MINDSCALE REQUIREMENTS

| **Property** | **Specification** |
|---|---|
| Scatter/gather | > 1 Peta Transfers/Sec |
| N/S Edge processing | 100 racks, WindyPoint API processing |
| Power/LFE "rack" | 125KW |
| Compactness | Comm paths < 50M |
| Cost/ToC | $500M / $100M/Year |
| Streams/Rate | ~100 billion, average data rate ~1 KB/s |
| Storage | NVM, MicroBlade Form Factor |
| MicroBlade Modules | 500K chips, heavy lifting via reconfigurable logic, 64 GB, 10 Tera-Ops, 1.2 TB/s I/O, ~20 pJ/op |
| Latency | < 250 nS PtP, fetch ~400nS |
| Communications | Short: LVDS, Medium: mm optical, Long: DWDM Energy: ~20 pJ/bit |
| Fault tolerance | 1 processor per hour |
| Scraping | Assumption: 90% of scraping performed at edge |


**Vert Multi-Story Concept**

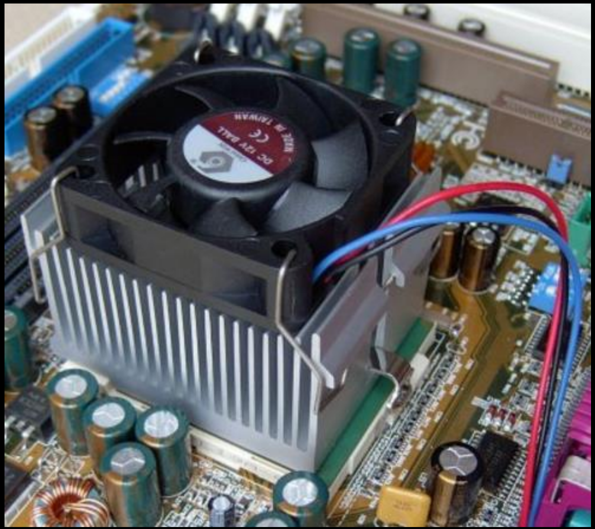



**5.5D stacked architecture**

# BACKGROUND – CONVECTIVE COOLING

- Convective air cooling of electronics is historically very common (both natural and forced convection)
- Heat transfer coefficients (from solid to fluid) depend on boundary layer of heat sink surfaces (far field velocity, turbulence, surface roughness, etc.)
- Given the power dissipation of each electrical component, the analysis goal is to ensure sufficient air flow and to validate max component temperatures
- Altair© AcuSolve© is ideally suited to solve this type of conjugate heat transfer (CHT) problem

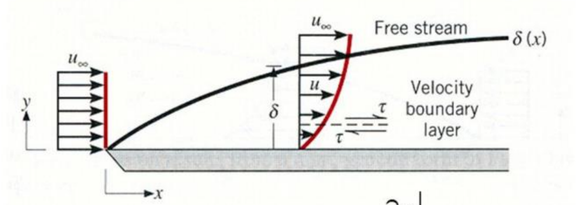
Natural Convection



Forced Convection

# CONVECTIVE COOLING MECHANISM

**Velocity (or momentum) boundary layer**




**wall shear stress:** $\tau_s = \mu \left.\dfrac{\partial u}{\partial y}\right|_{y=0}$

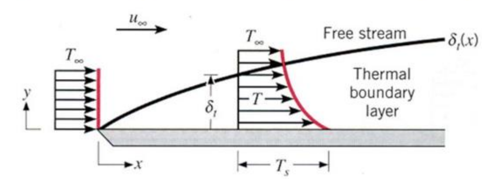
$\mu$: **dynamic viscosity**

**friction coefficient:** $C_f = \dfrac{\tau_s}{\rho u_\infty^2 / 2}$

Same Transport Equations

$$\frac{\partial(\rho\phi)}{\partial t} + div(\rho\phi\mathbf{u}) = div(\Gamma\, grad\,\phi) + S_\phi$$

**Temperature (or thermal) boundary layer**



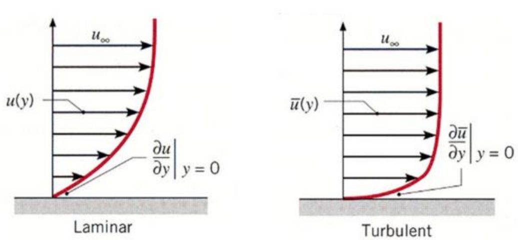

**local heat flux:** $q_s''(x) = -k_f \left.\dfrac{\partial T}{\partial y}\right|_{y=0}$

**local heat transfer coefficient:**

$$h(x) = \frac{-k_f}{T_s - T_\infty} \left.\frac{\partial T}{\partial y}\right|_{y=0}$$

Amplification Effect

**Comparison of laminar and turbulent velocity profile in the boundary layer**




$$\left.\frac{\partial u}{\partial y}\right|_{y=0,\ \text{lam}} < \left.\frac{\partial \overline{u}}{\partial y}\right|_{y=0,\ \text{turb}}$$


**Reference:**

[1] W. Montgomery, http://slideplayer.com/slide/9328881/

[2] http://www.bakker.org/dartmouth06/engs150/03-cnsrv.pdf

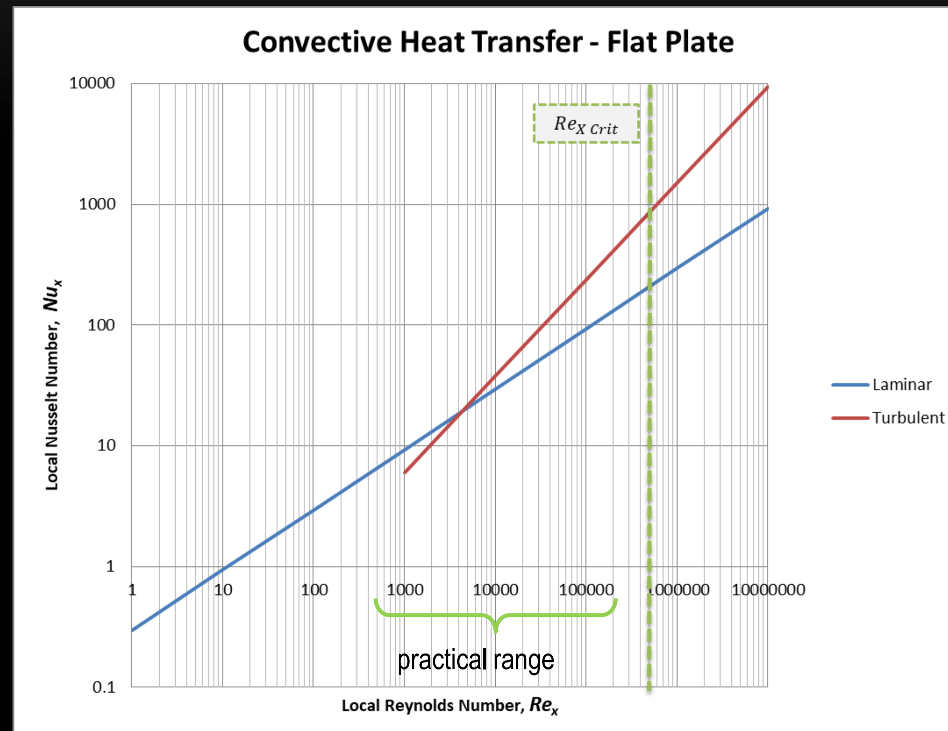
# ROLE OF TURBULENCE

Air flow across flat plate

Laminar flow ($Re_x < Re_{cr}$) $$Nu_x = \frac{0.332\,Re_x^{1/2}\,Pr^{1/3}}{\left[1-\left(\frac{x_o}{x}\right)^{3/4}\right]^{1/3}}$$

Turbulent flow ($Re_x > Re_{cr}$) $$Nu_x = \frac{0.0296\,Re_x^{4/5}\,Pr^{3/5}}{\left[1-\left(\frac{x_o}{x}\right)^{9/10}\right]^{1/9}}$$

(no unheated entry zone: $x_0 = 0$)



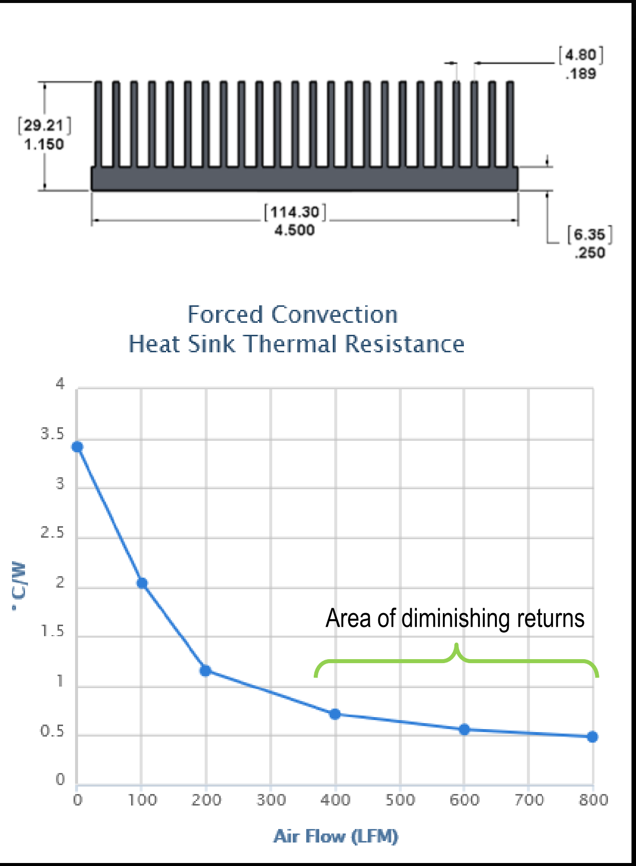

Note: When flow interacts with heatsink, oftentimes turbulence intensity already > 0 (e.g. fans)

**Reference:**
[1] Equations taken from http://www.pathways.cu.edu.eg/ec/text-pdf/part%20b-9.pdf

# PRACTICAL CONSIDERATIONS

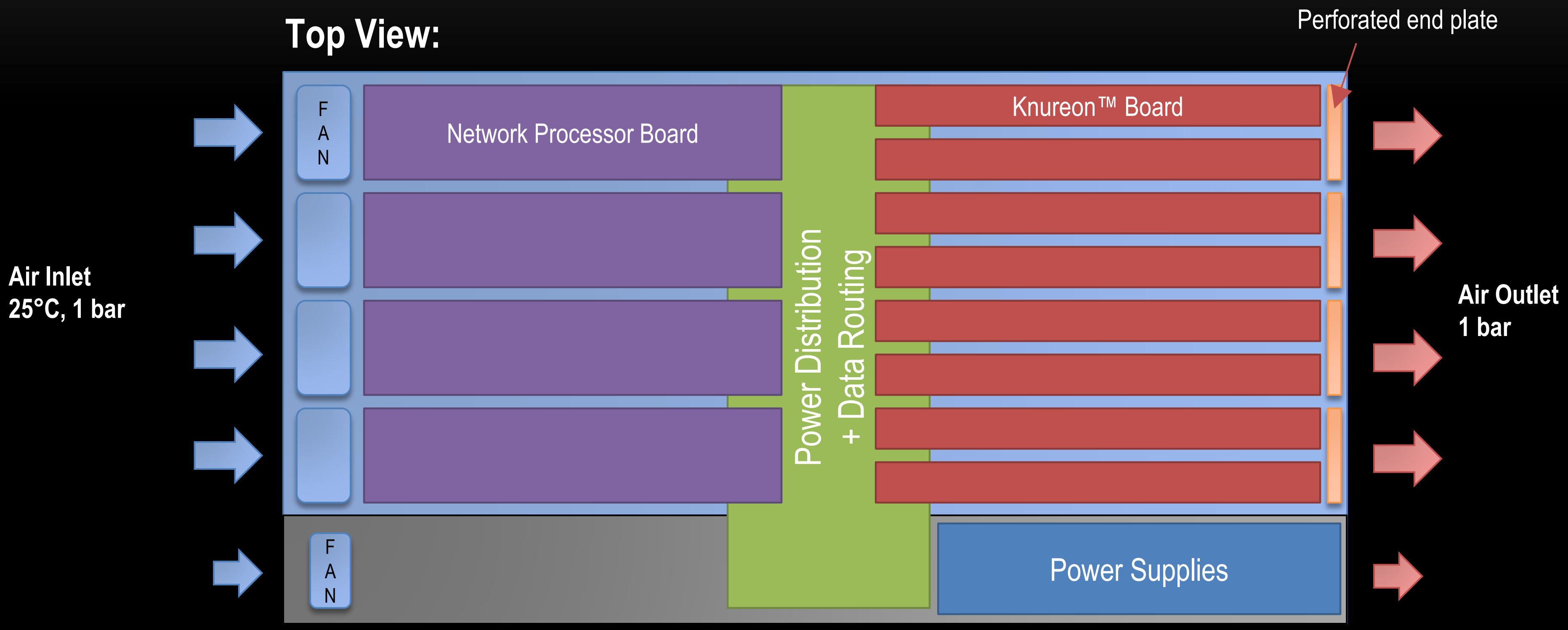
- Classical trade-offs:
  - Heat transfer not linear with flow velocity
  - Flow velocity vs. backpressure
  - Surface area vs. friction/drag
- Advantages of air cooling:
  - Simplicity and reliability
    (no liquids/no leaks/no plumbing)
  - More space efficient for cooling multiple components on PCB
- Specific challenges:
  - Need to carefully engineer flow through entire enclosure
  - Need to carefully engineer heatsinks
  - Max heat transfer coefficients more limited (compared to liquid cooling)

Example of non-linear heat transfer:



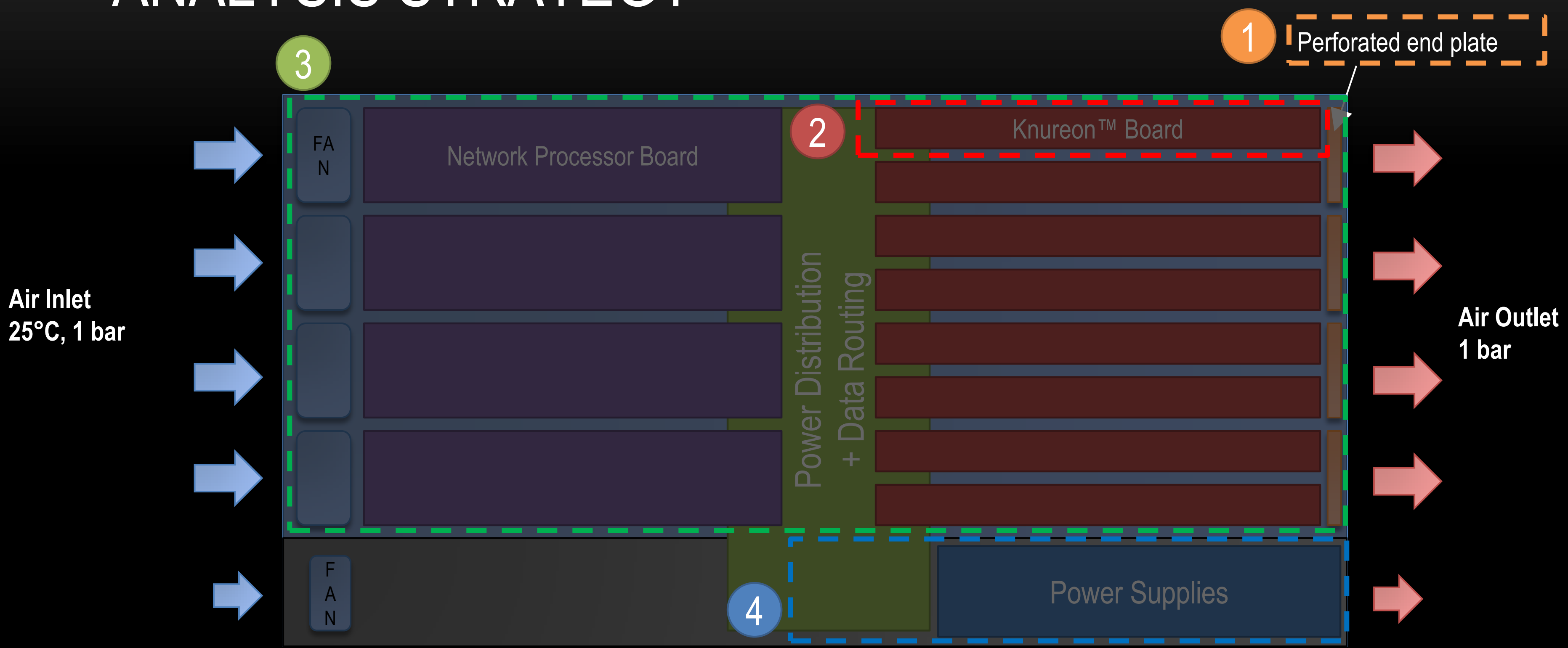

**Reference:**
[1] Heatsink information: [http://thermocoolcorp.com/product/tcp7670/](http://thermocoolcorp.com/product/tcp7670/)

# LAYOUT OF HPC SERVER CHASSIS




Chassis divided into two separate compartments (large compartment contains 4 Network Processor Boards and 8 Knureon™ Boards, small compartment contains 5 Power Supplies) -> each compartment can be analyzed separately.

# ANALYSIS STRATEGY

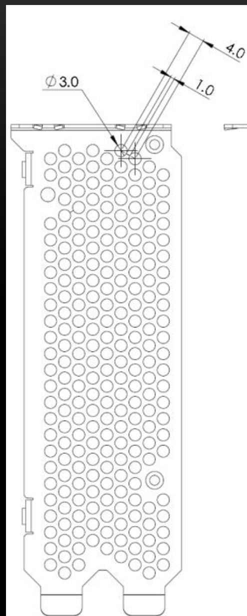


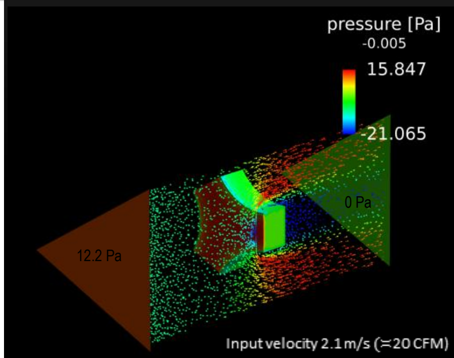

**Step-by-step escalation of analysis complexity:**

1. Perforated end plate -> P&Q curve
2. Knureon™ Board
3. Compartment with all processor boards
4. Compartment with power supplies

# BACKPRESSURE FROM PERFORATED END PLATES

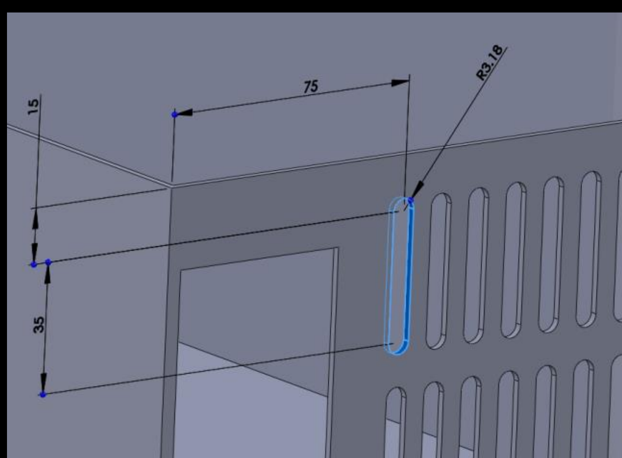
**Holes:**



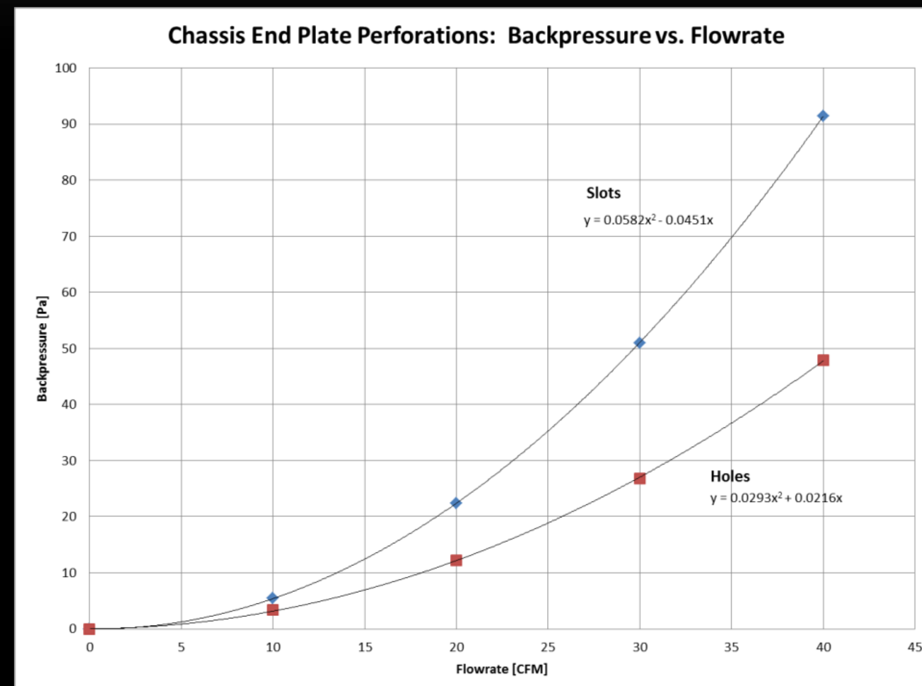




Wall thickness: 0.91 mm
Area ratio for holes: 51%

**Slots:**

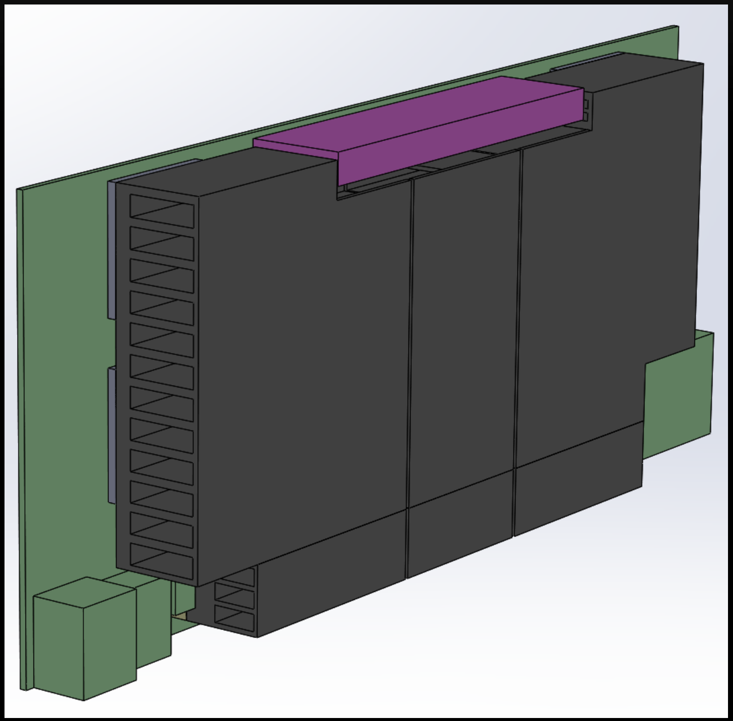


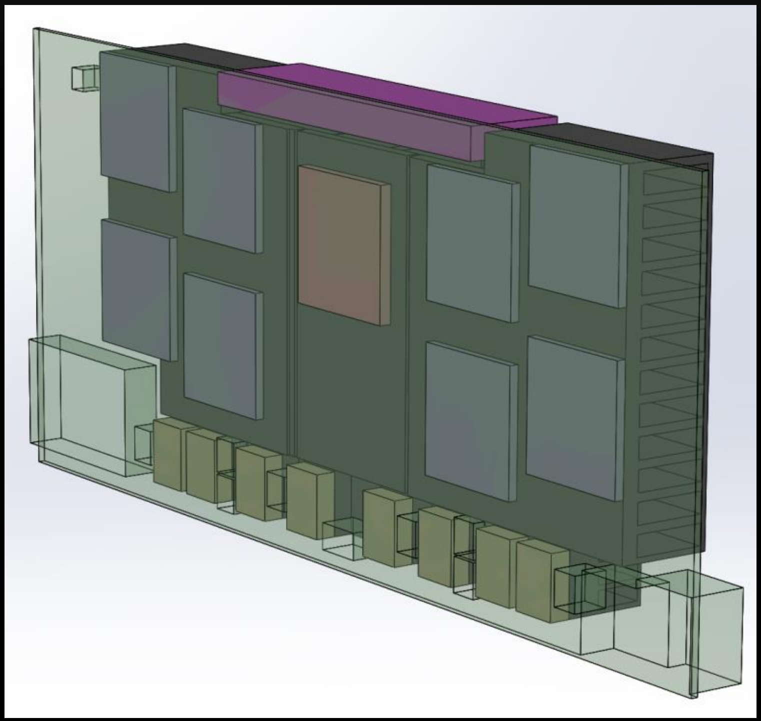

Wall thickness: 1.98 mm
Area ratio for slots: 42.4%




‘Holes’ chosen for subsequent analysis

# KNUREON™ BOARD

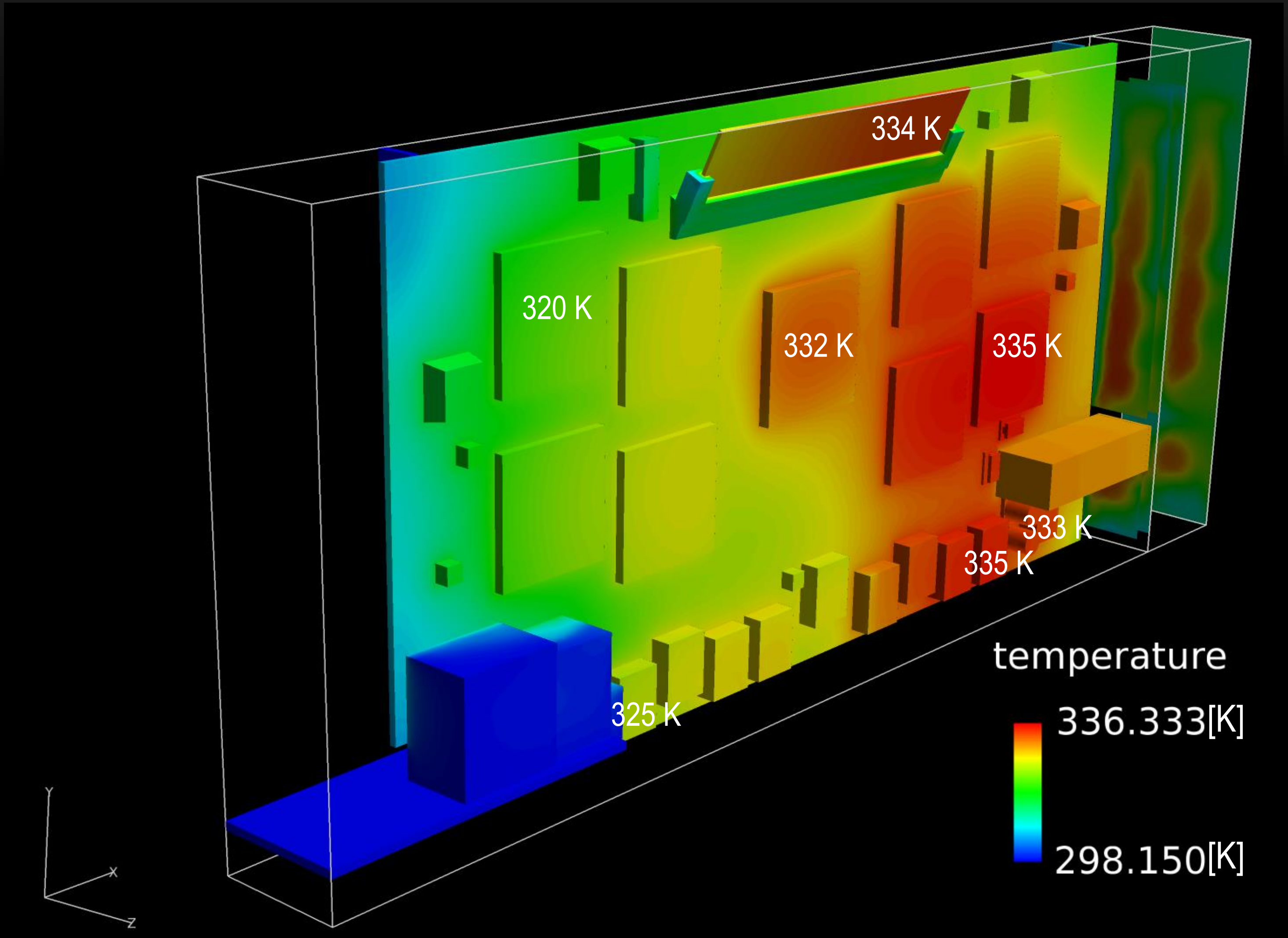




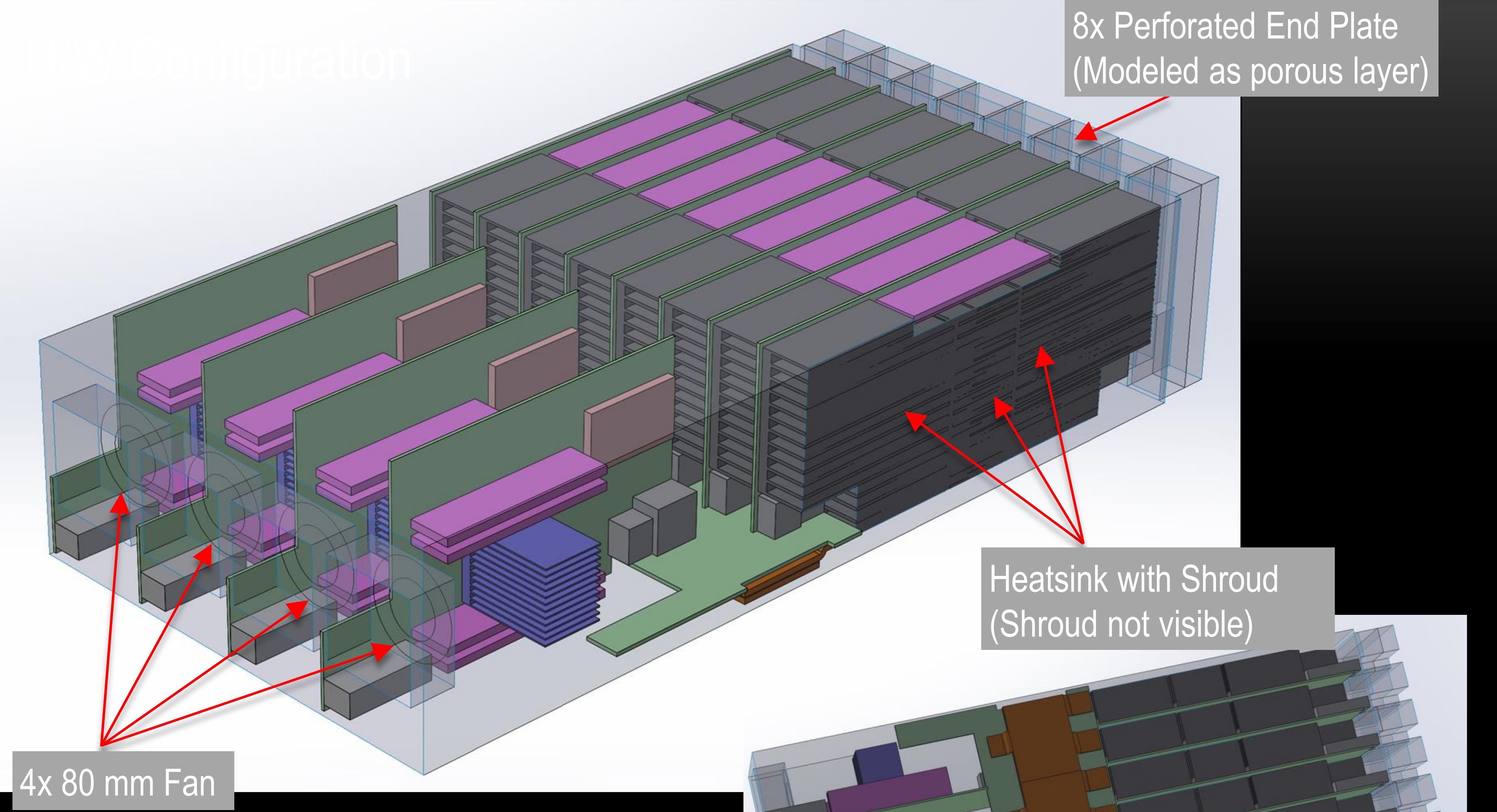
View Thru Transparent PCB

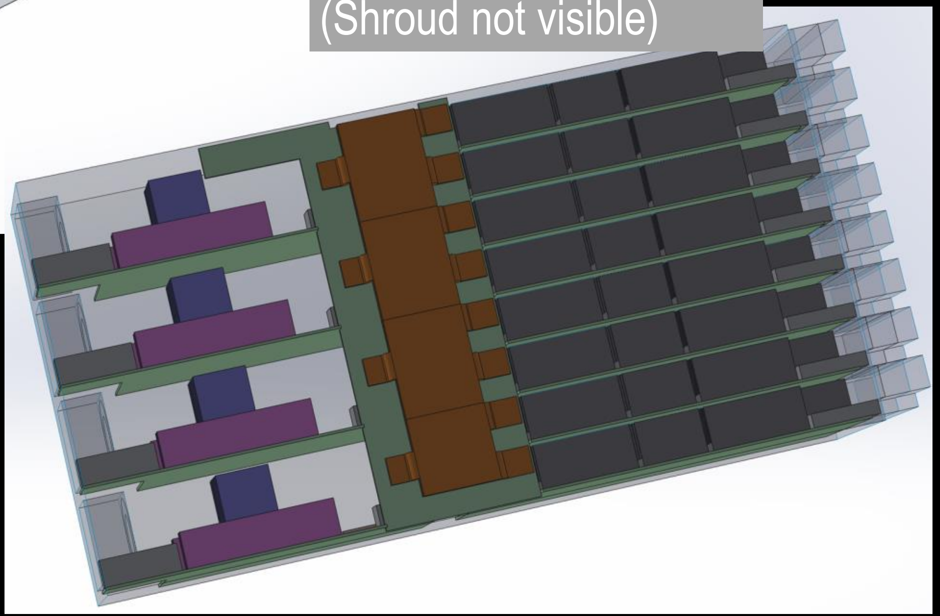
- Modeled only high-powered components (≥1 W) contacting heat sink
- Total power dissipation per board:  477 W

# Typical Component Temperatures



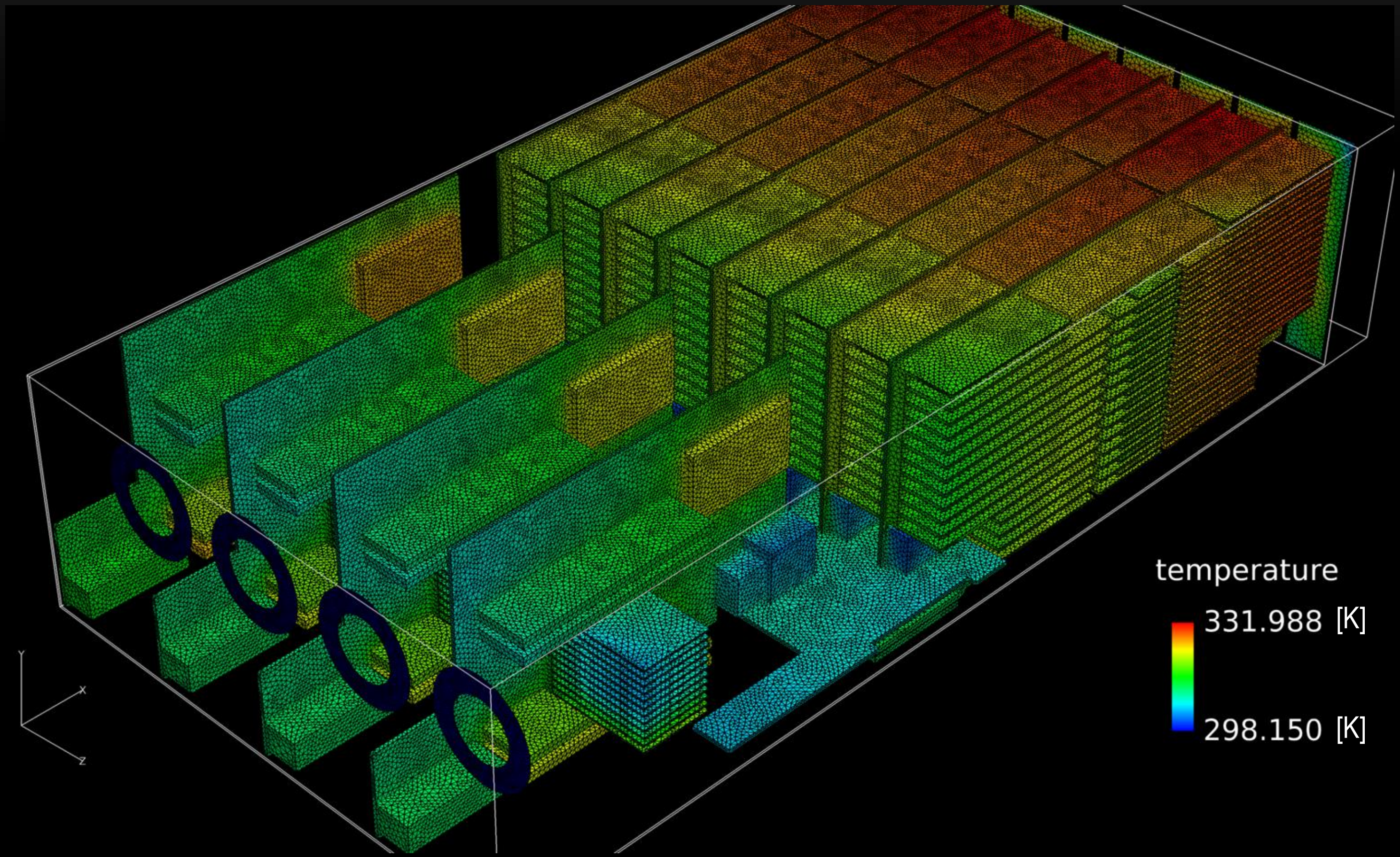
# H/W Configuration



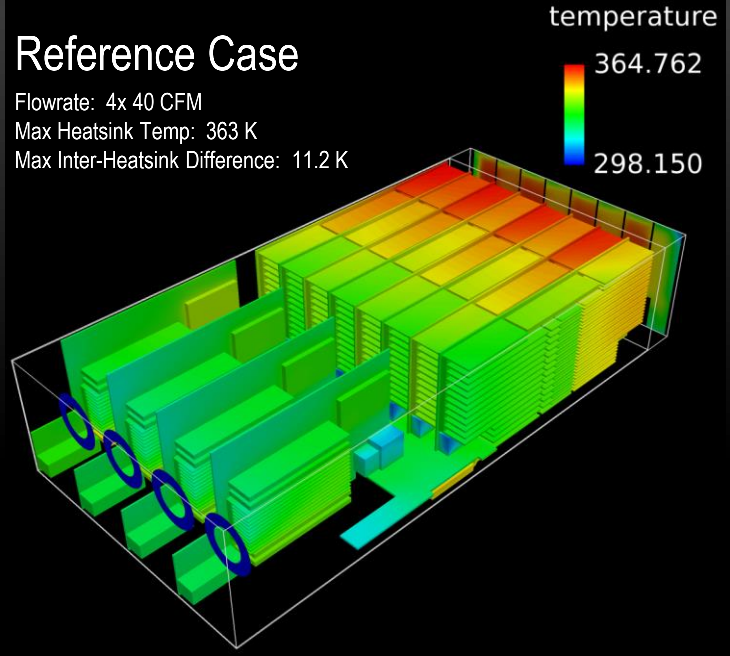



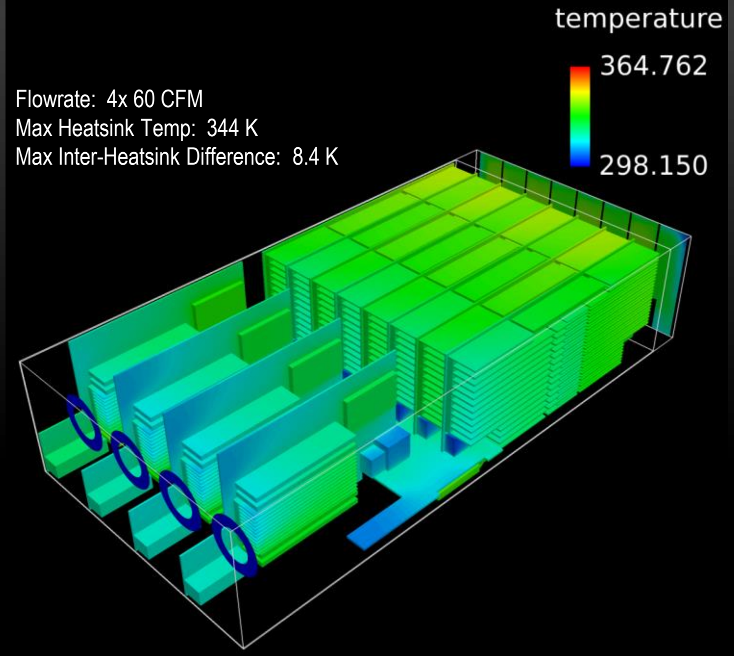
Input temperature: 298.15 K (25°C)
Total heat dissipation: 4442 W

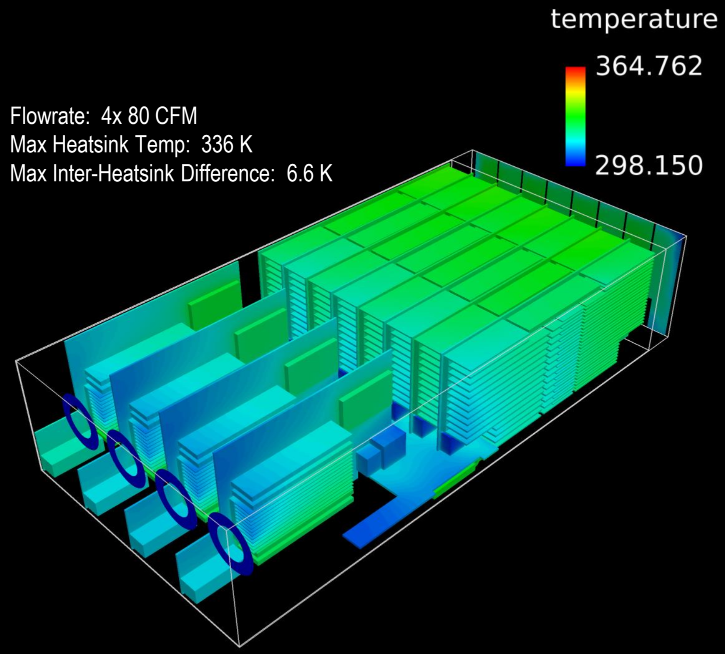
# DISCRETIZATION OF SOLID SURFACES

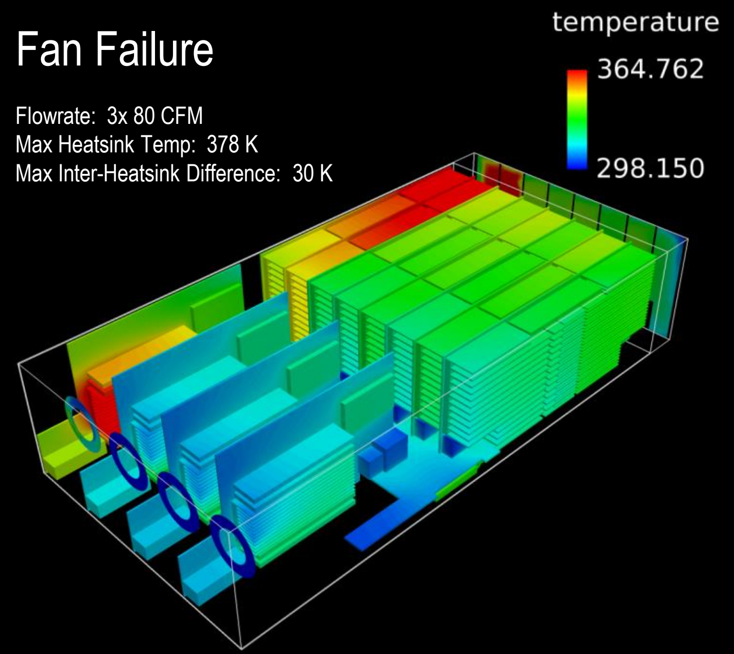



Simulation is computationally intensive (8 M nodes, 15.4 hours runtime on 8 cores)

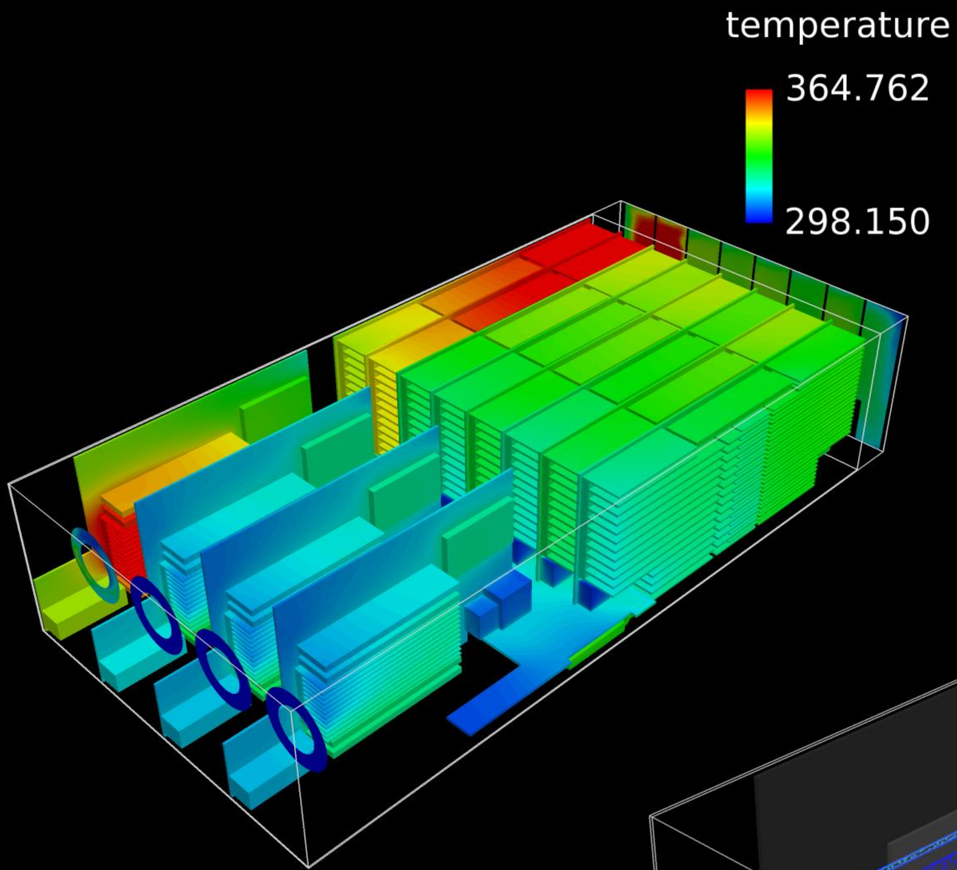


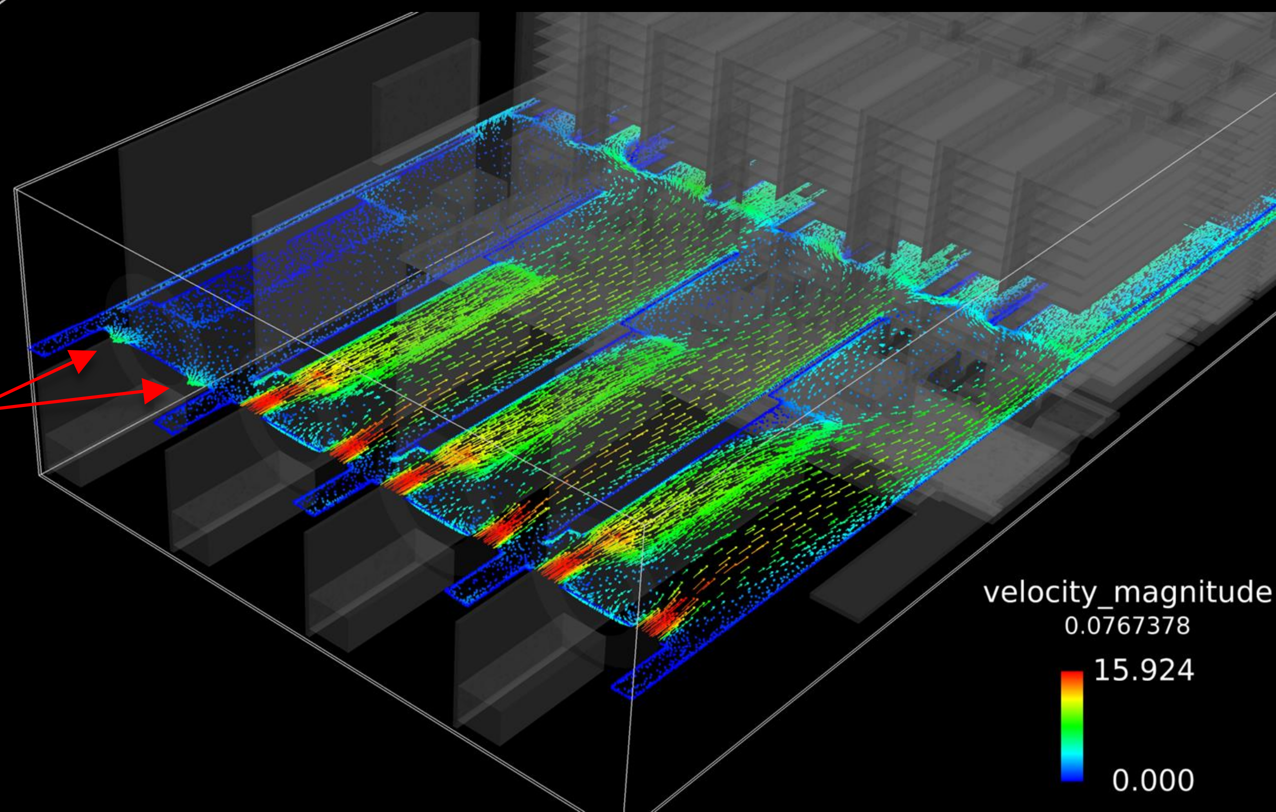

Please note that the temperature legend is identical in all cases




# Fan Failure

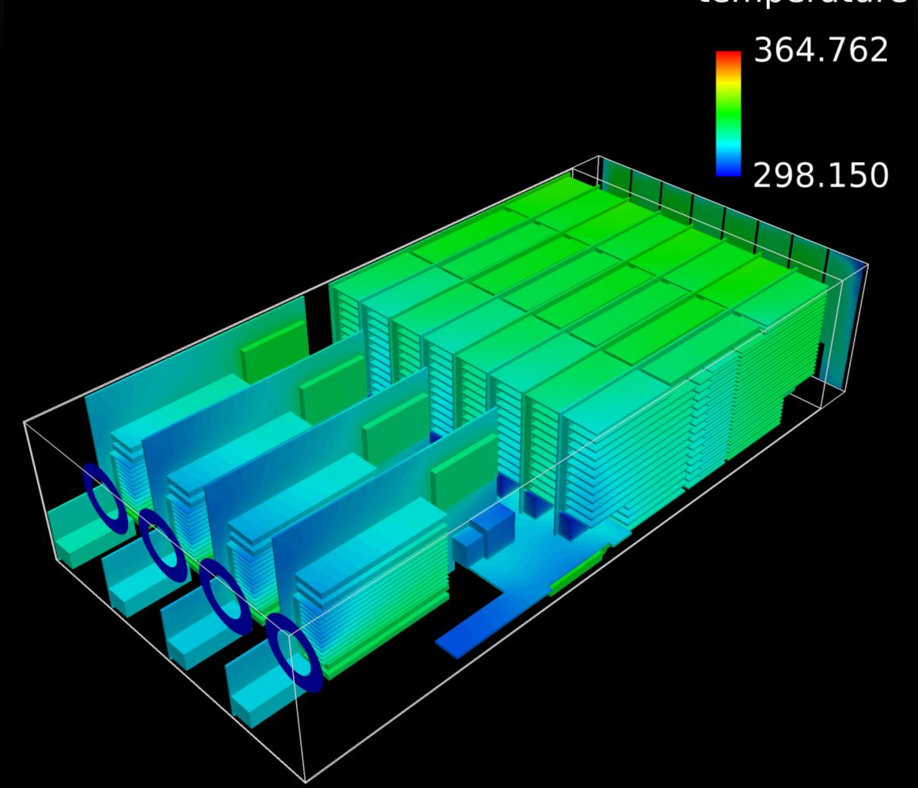
Flowrate: 3x 80 CFM
Max Heatsink Temp: 378 K
Max Inter-Heatsink Difference: 30 K

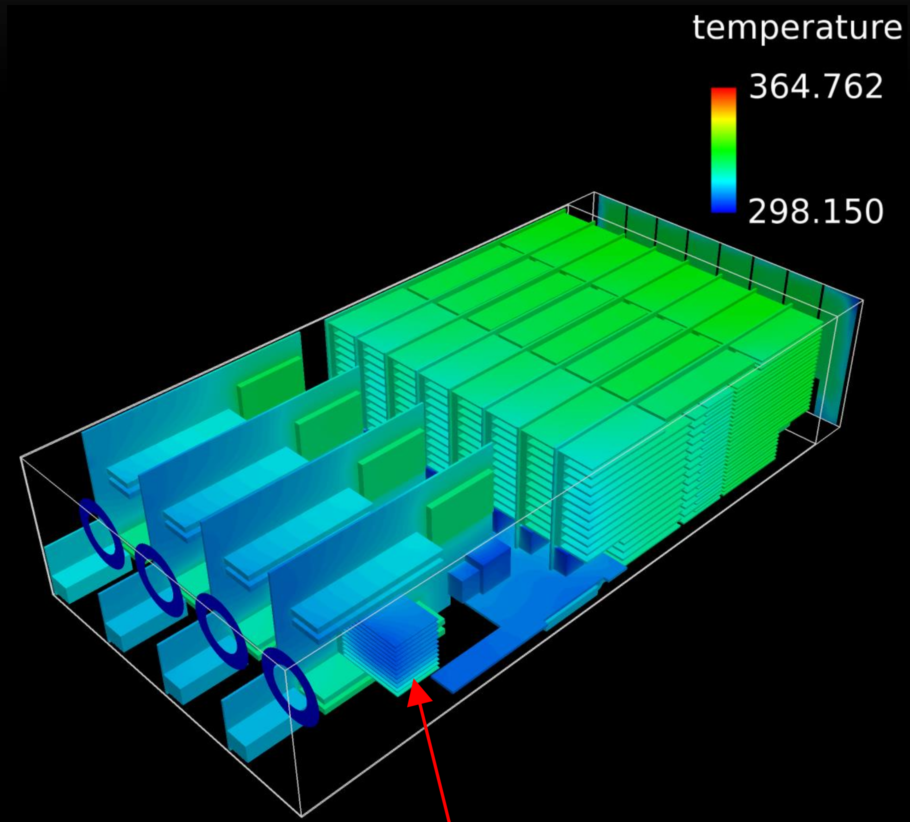
Backflow through inlet of failed fan



# HEATSINK DESIGN ITERATION

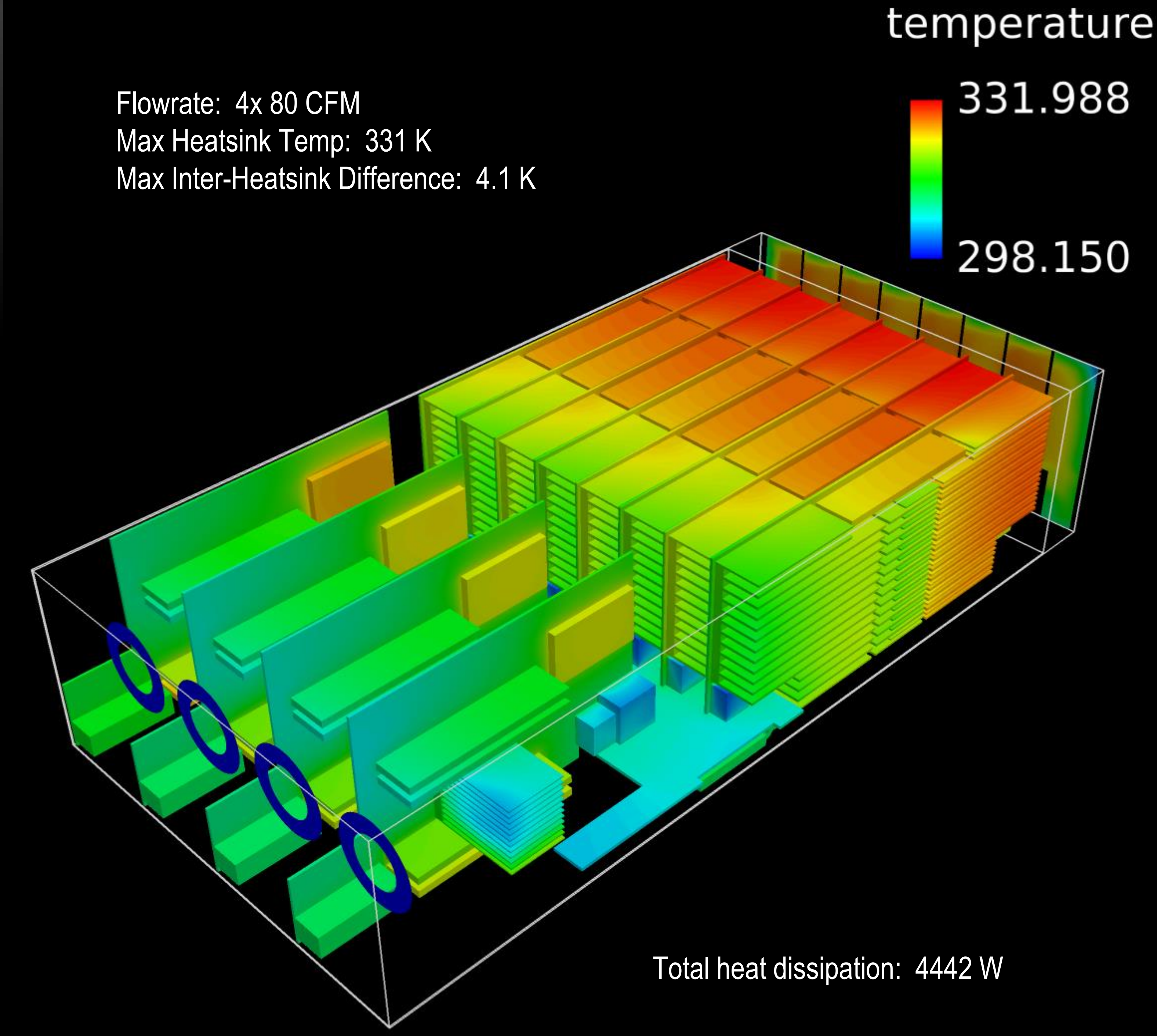
Temperature contours relative to Reference

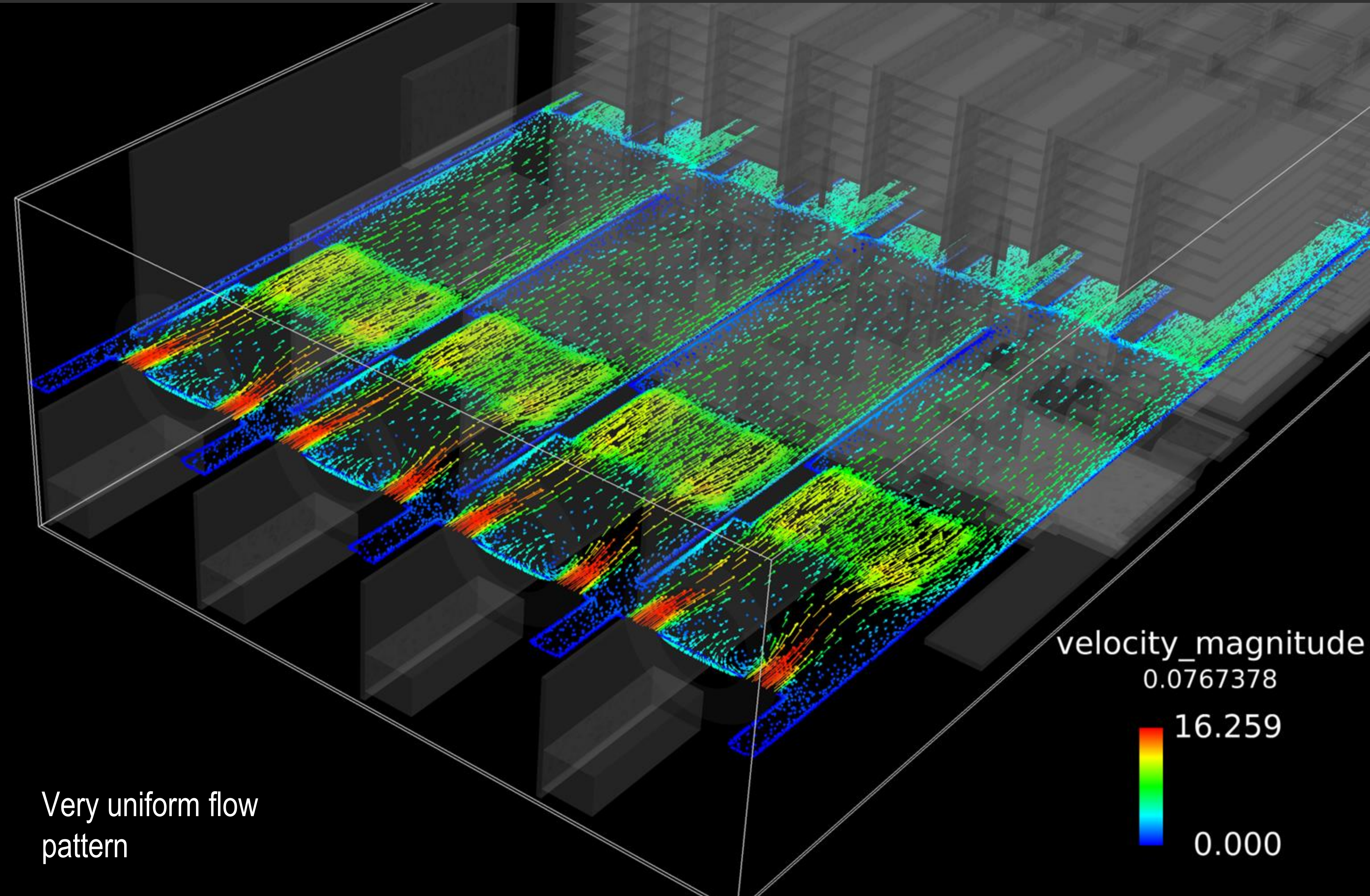


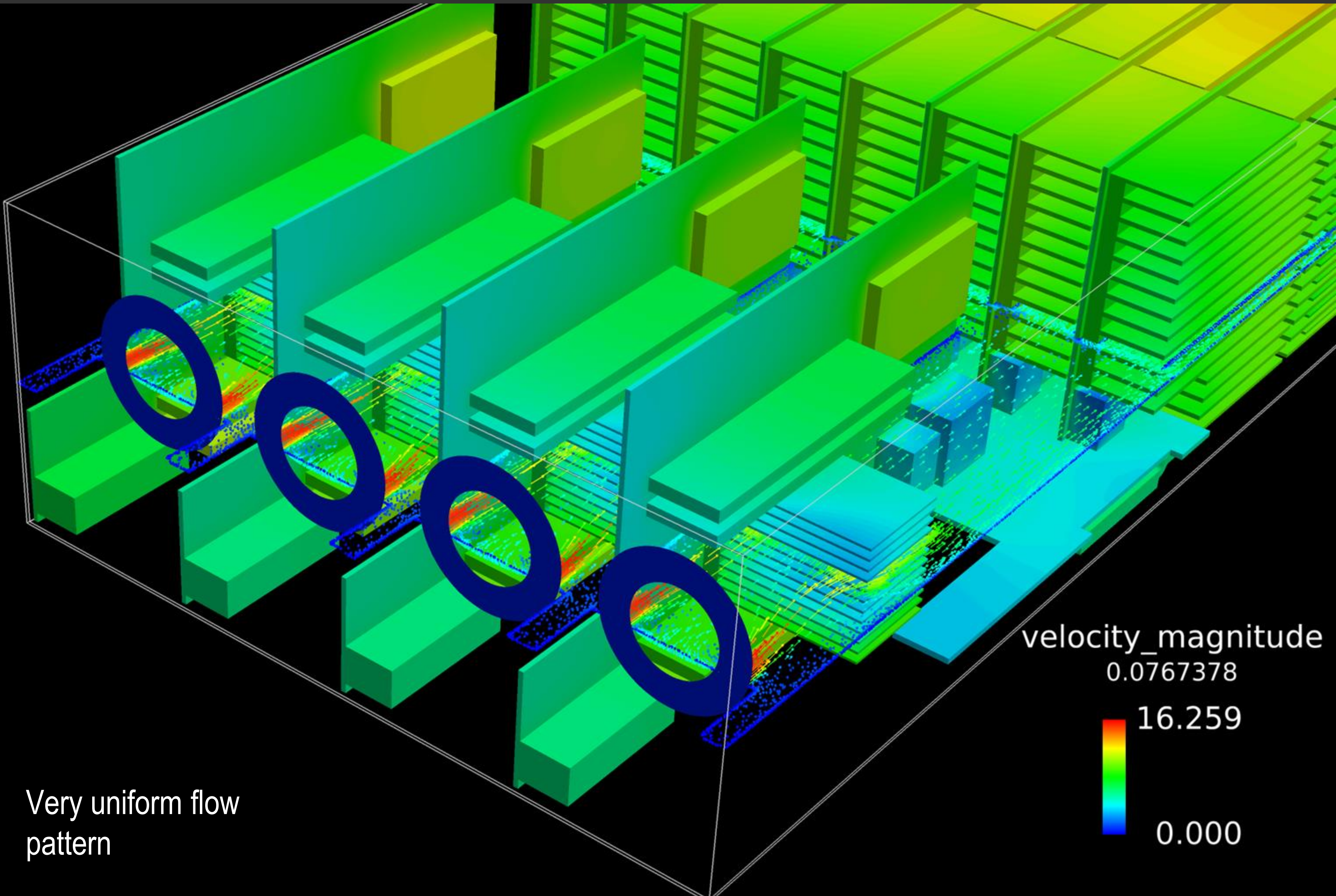

Shortened heatsink with taller fins

2nd design better has better cooling and more favorable flow pattern for downstream boards

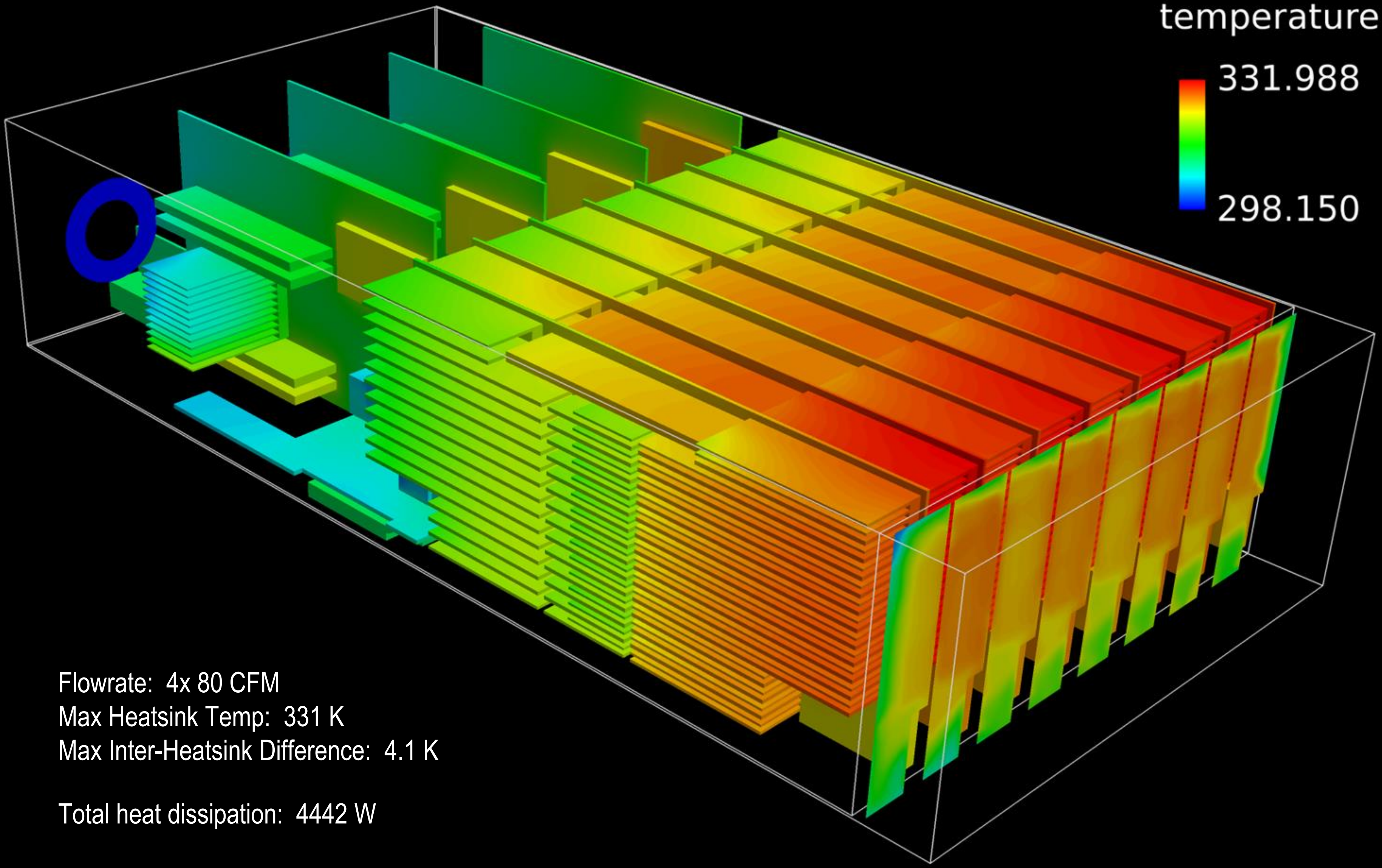

Flowrate: 4x 80 CFM
Max Heatsink Temp: 331 K
Max Inter-Heatsink Difference: 4.1 K
temperature
331.988
298.150
Total heat dissipation: 4442 W




Very uniform flow pattern

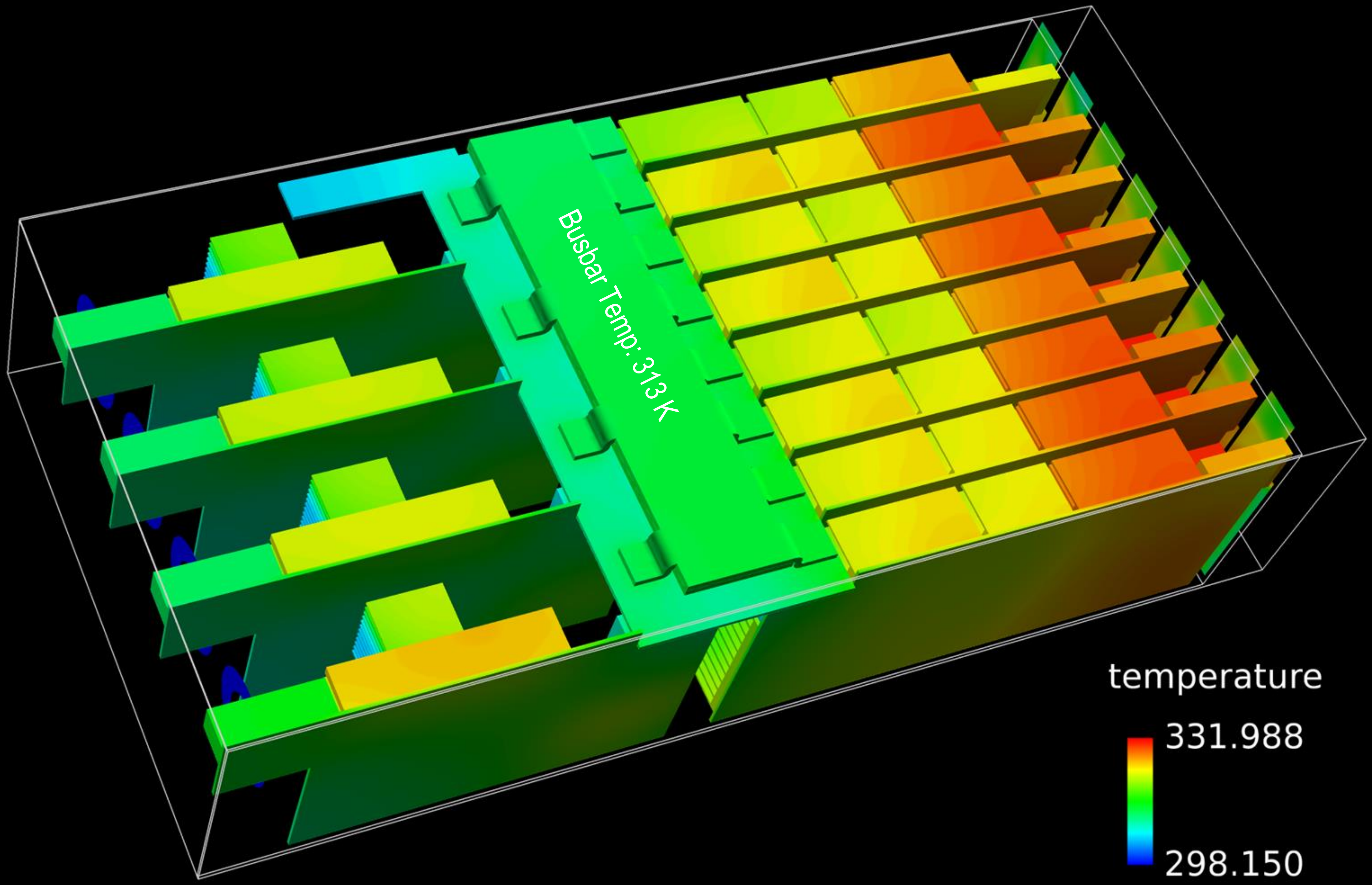



Very uniform flow pattern

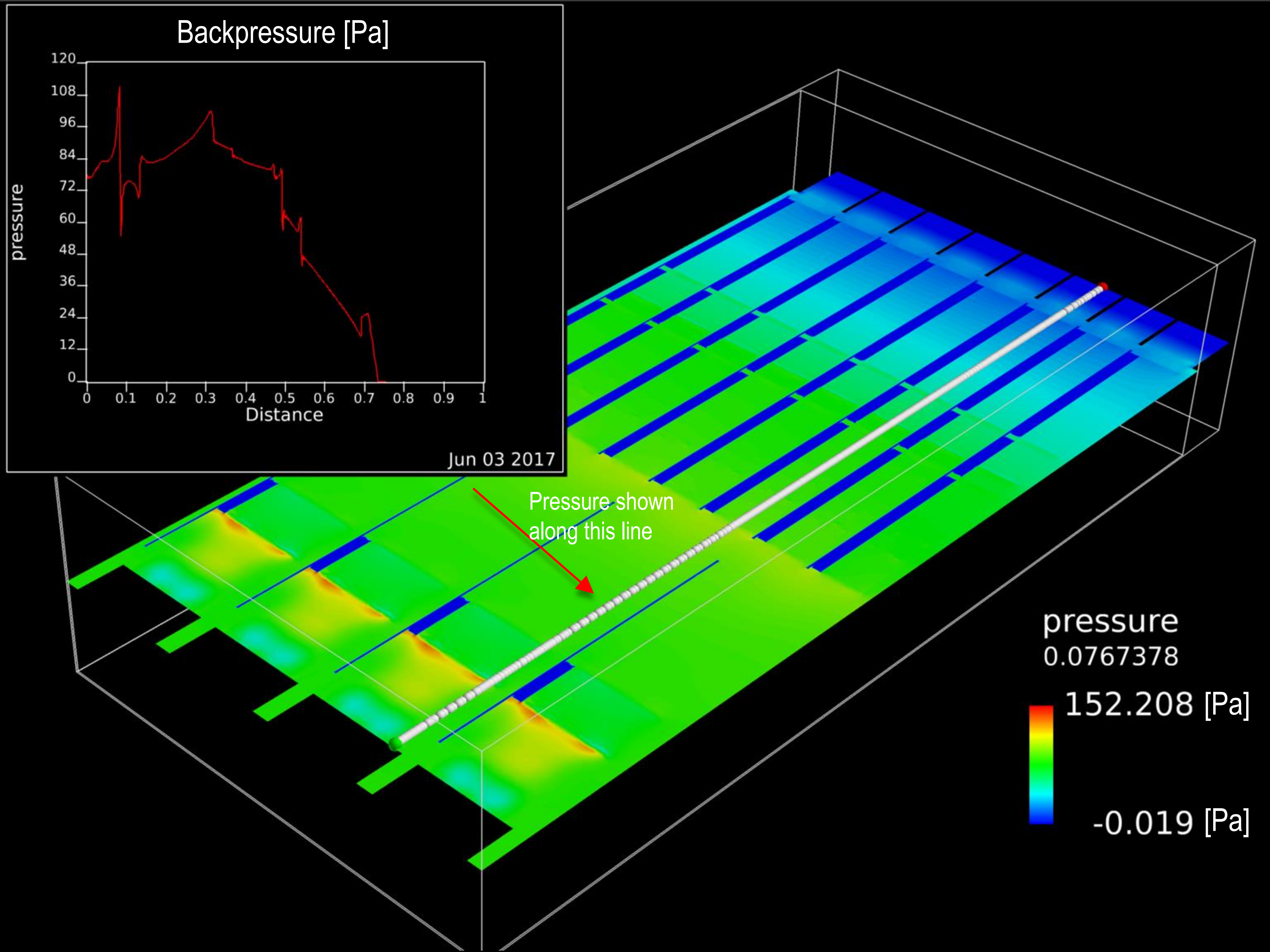


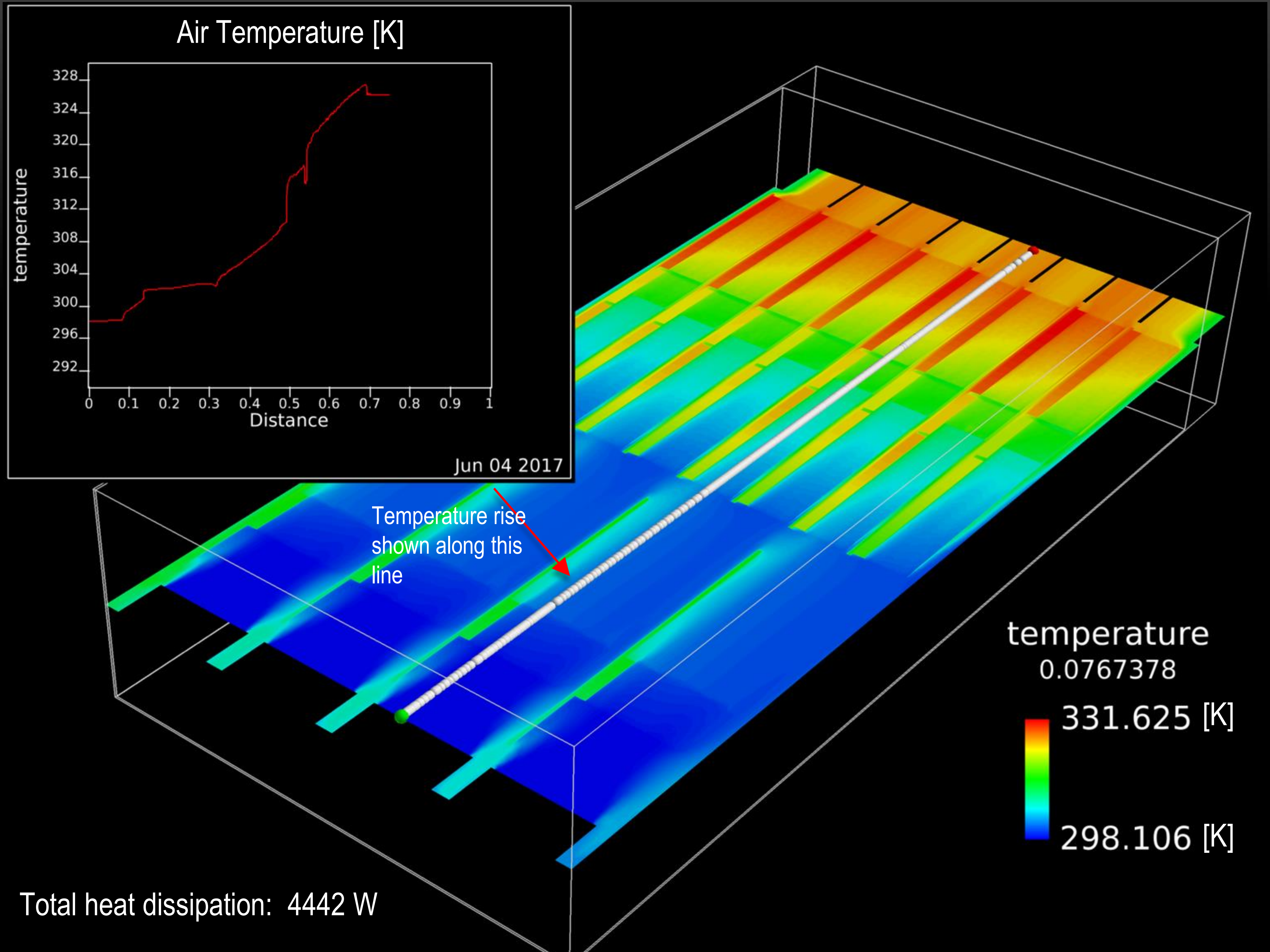

Flowrate: 4x 80 CFM
Max Heatsink Temp: 331 K
Max Inter-Heatsink Difference: 4.1 K

Total heat dissipation: 4442 W



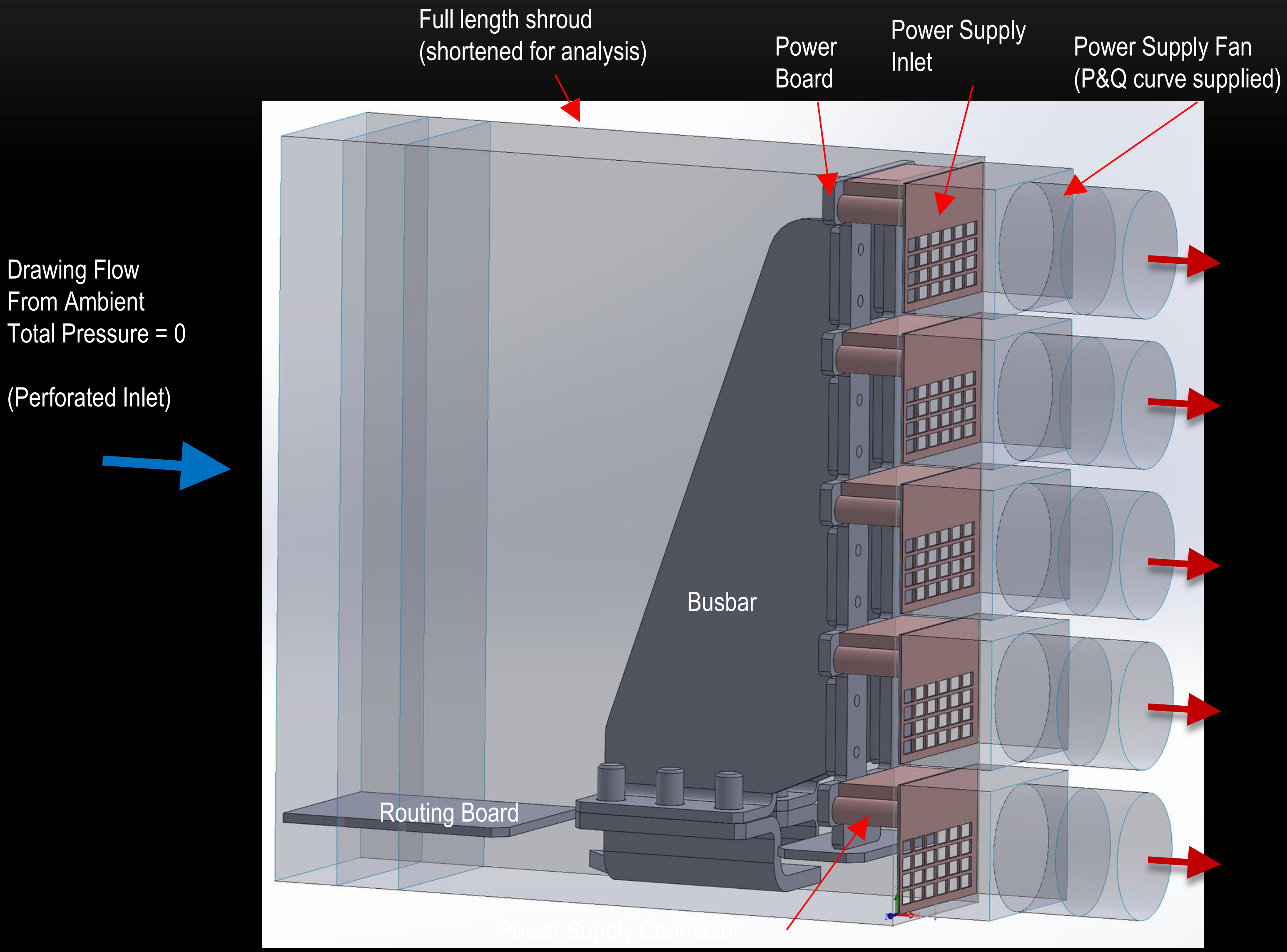

Busbar dissipates 2x 15 W at full power


Backpressure [Pa]
120
108
96
84
72
60
48
36
24
12
0
pressure
0
0.1
0.2
0.3
0.4
0.5
0.6
0.7
0.8
0.9
1
Distance
Jun 03 2017
Pressure shown
along this line
pressure
0.0767378
152.208 [Pa]
-0.019 [Pa]

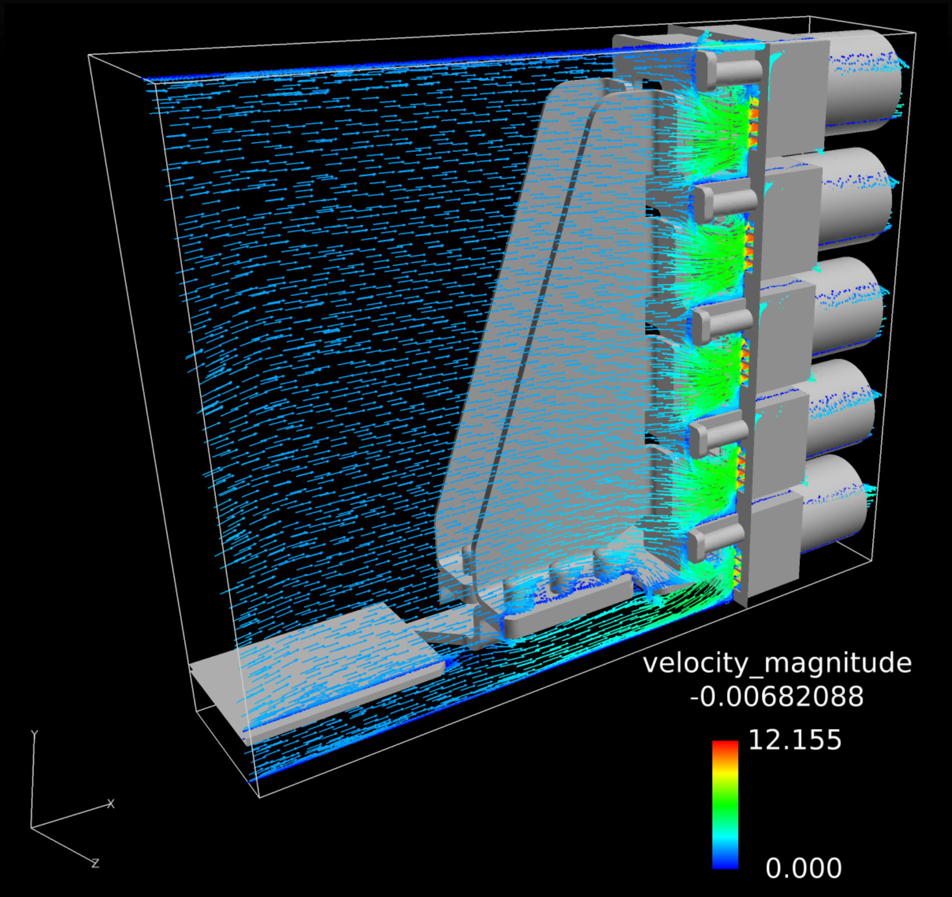


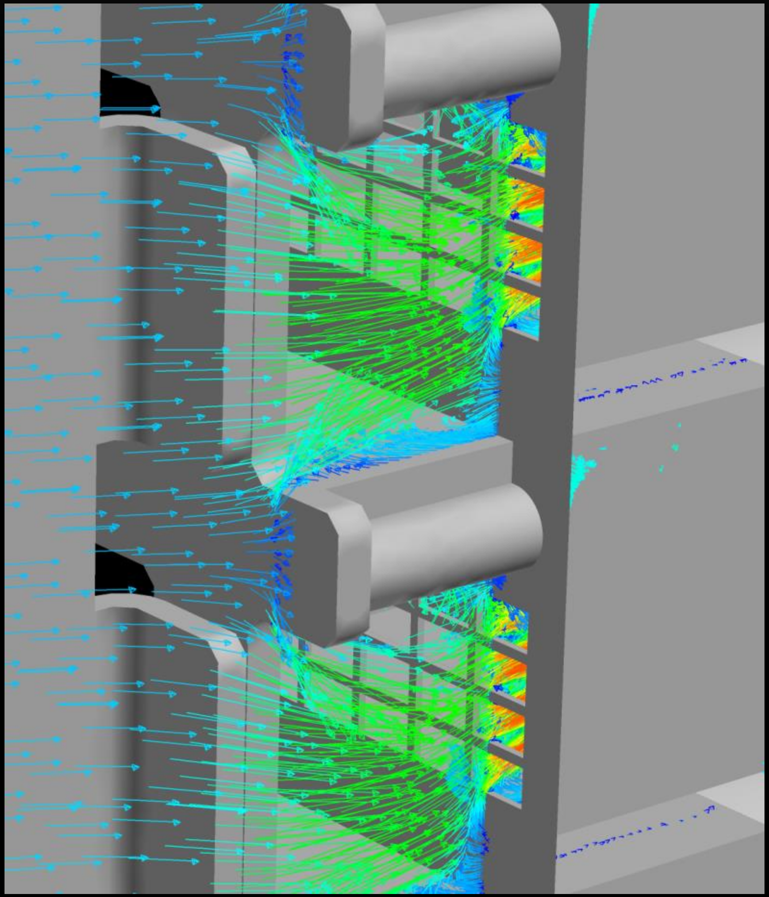
Air Temperature [K]
temperature
328
324
320
316
312
308
304
300
296
292
0
0.1
0.2
0.3
0.4
0.5
0.6
0.7
0.8
0.9
1
Distance
Jun 04 2017
Temperature rise shown along this line
temperature
0.0767378
331.625 [K]
298.106 [K]
Total heat dissipation: 4442 W

# FLOW SIMULATION MODEL

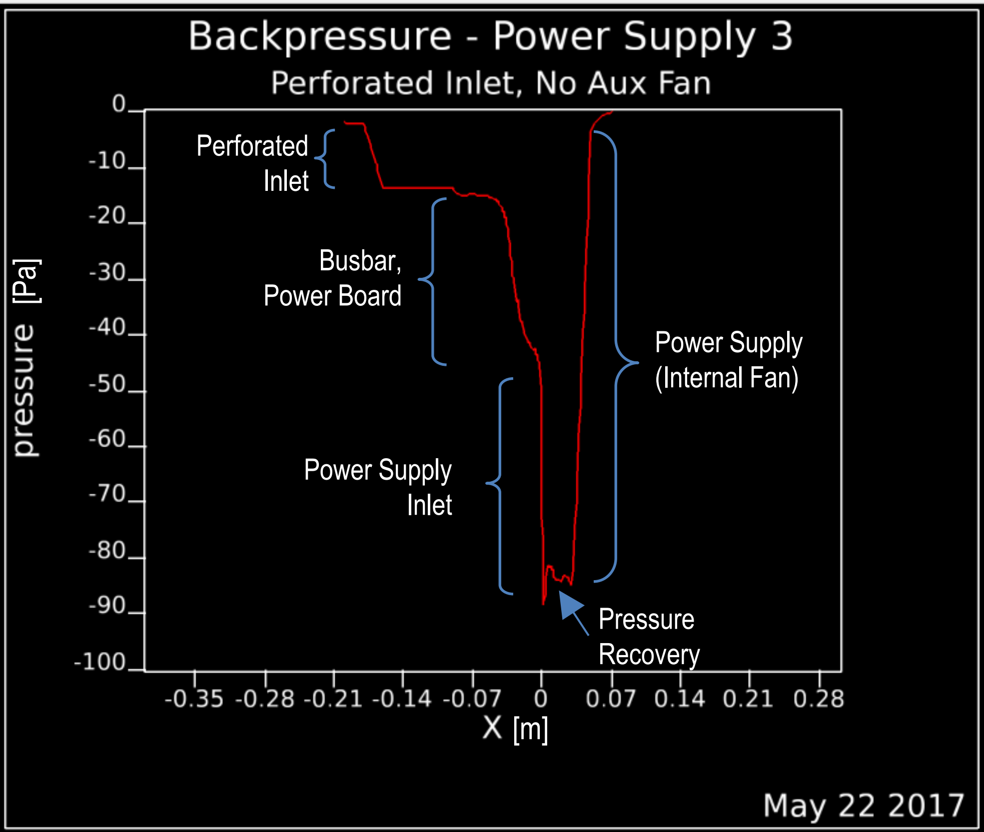


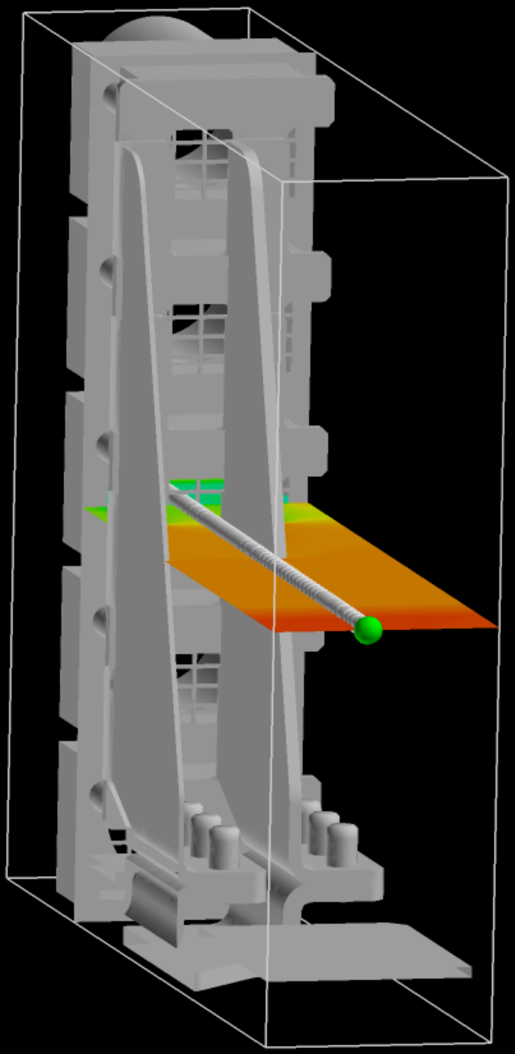
# FLOW INTO POWER SUPPLIES



# BACKPRESSURE CURVE



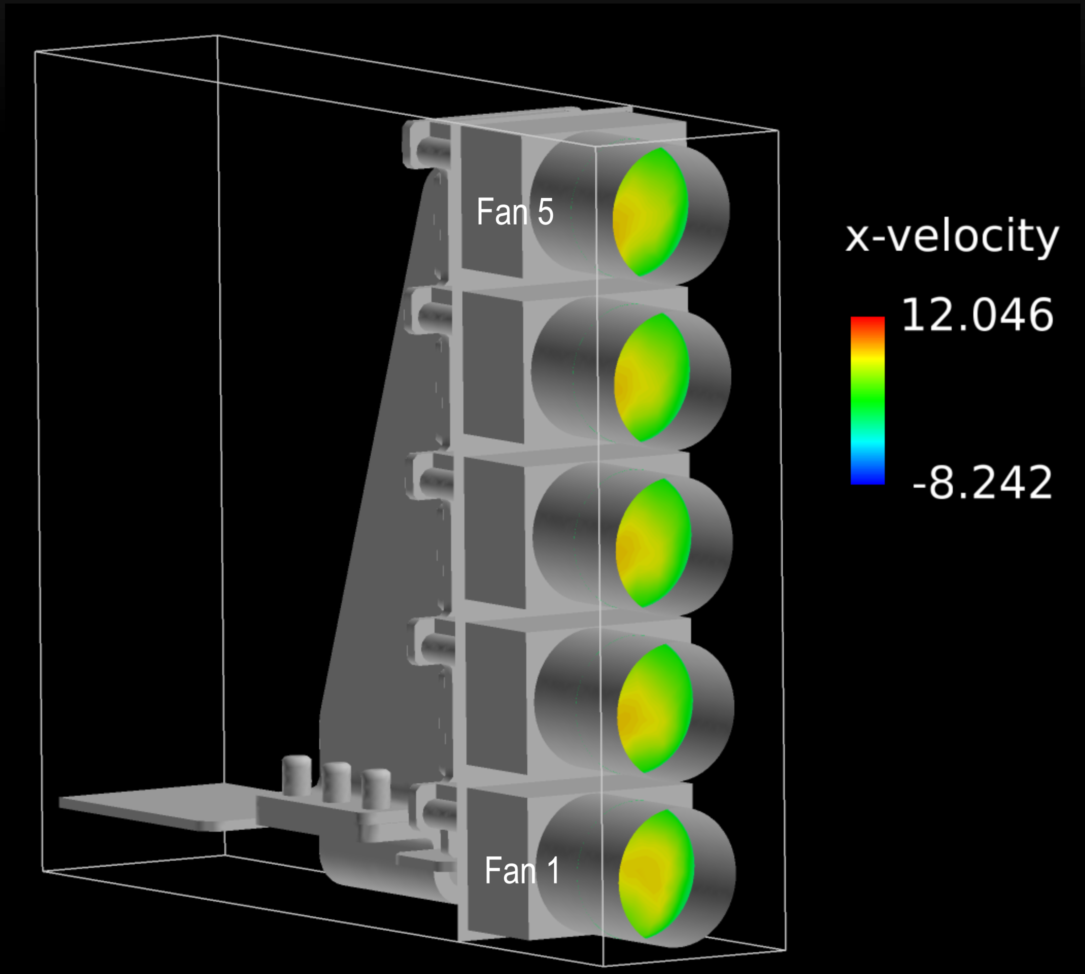
Drawing Flow
From Ambient,
Total Pressure = 0

(Perforated Inlet)

$V_{Avg} = 1.92\ ^{m}/_{s}$

$\dot{Q} = 51.7\ CFM$

# FLOW DISTRIBUTION




| | PS Flowrate (fan outlet) | | |
|---|---|---|---|
| | [m^3/s] | [CFM] | % variation |
| Fan 1 | 0.00495147 | 10.99 | 1.23 |
| Fan 2 | 0.004861 | 10.79 | -0.62 |
| Fan 3 | 0.00487939 | 10.83 | -0.25 |
| Fan 4 | 0.00488969 | 10.85 | -0.04 |
| Fan 5 | 0.00487602 | 10.82 | -0.32 |
| Average | 0.00489151 | 10.85 | |

Flow balance within +/- 1.25 %

# SUMMARY

- The CHT analysis performed for this study indicates that nearly 5 kW of waste heat can be removed from the chassis via air cooling using off-the-shelf computer fans while keeping all electrical components well below their temperature limits
- Particular emphasis was placed on the heatsink designs to ensure low back pressure and uniform flow patterns
- The AcuSolve© CFD solver appeared to be very efficient. All analyses could be performed on a system running a single 8-core AMD Ryzen™ 7 1800X

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Contact: Michael@NextStepToTake.com

- Special thanks to KnuEdge Inc., San Diego, for giving permission for this presentation.