



**Sandia
National
Laboratories**

Wayne L. Staats, PhD
Sandia National Labs
SAND2014-0242C
wstaats@sandia.gov
(925) 294-3307

Heat Transfer and Pressure Drop Performance of the Air Bearing Heat Exchanger

Wayne L. Staats, N.D. Matthew, Ethan S. Hecht,
Terry A. Johnson and Jeff Koplow

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Learning Objectives

- Identify the potential benefits and applications for PCM-based thermal stores.
- Identify the critical parameters affecting compact PCM-based thermal store performance.
- Explain how air conditioning can be improved in hot and humid climates
- Describe how hybrid solar collectors can be used to drive air conditioning applications
- Describe the impact of fin surface wettability on the performance of dehumidifying heat exchangers.
- Explain how the wettability impact is dependent on the compactness of the heat exchanger.
- Describe how under yard and under slab EAHX perform in a heating dominated climate
- Distinguish when to select an under yard versus an under slab EAHX
- **Describe the operation of the Air Bearing Heat Exchanger**
- **Explain the performance tradeoff associated with setting the air bearing thickness in the Air Bearing Heat Exchanger**

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- Sandia Laboratory Directed Research & Development (LDRD) program

Outline/Agenda

- The Air Bearing Heat Exchanger
- Experiments
 - Fan curve measurement
 - Heat transfer measurement
- CFD Simulations
- Ongoing Work
- Conclusions

Motivation

1. Energy savings

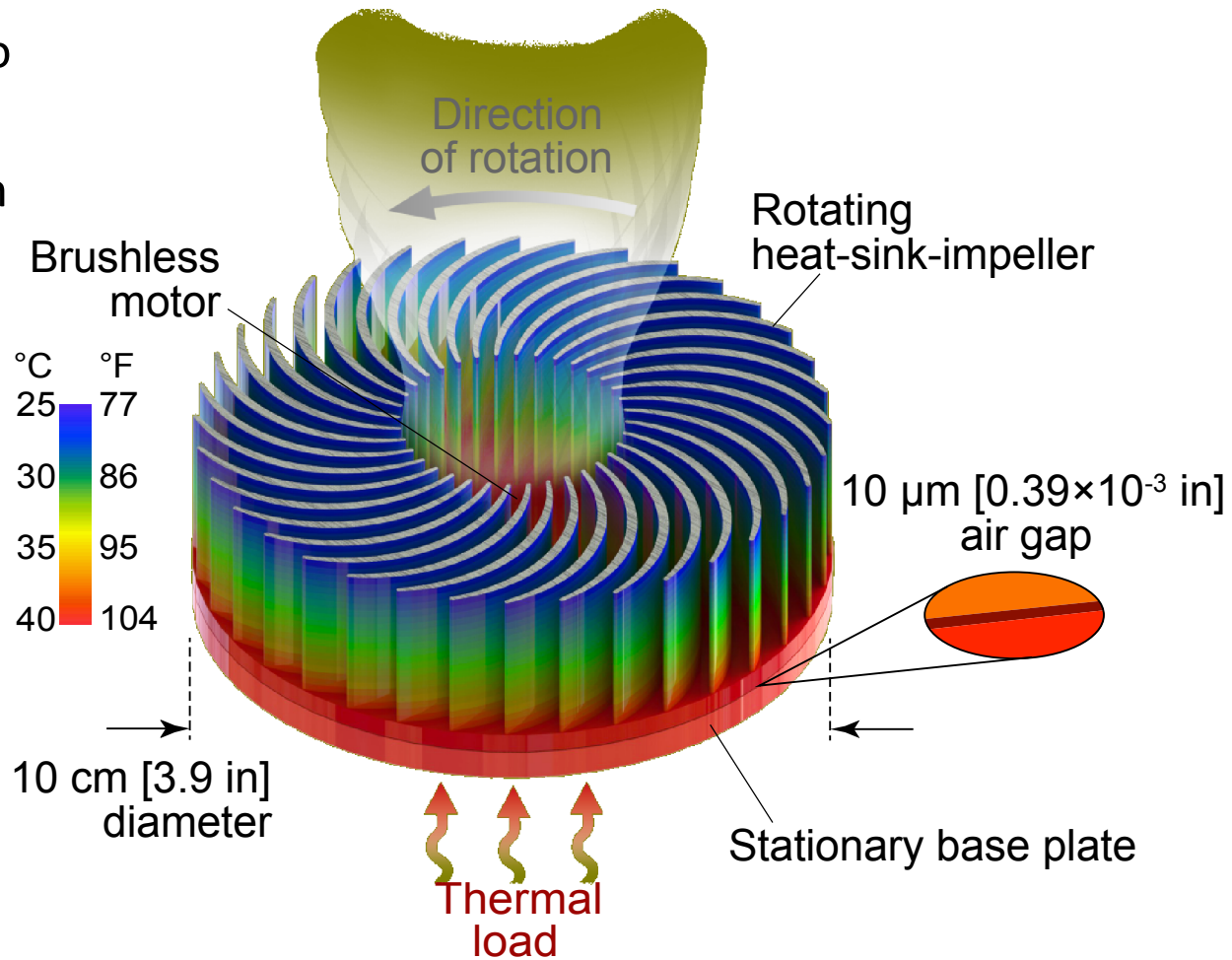
- Data centers: 1.5% of worldwide electricity use (50% of which is used for cooling systems)
- Lighting: 14% of US electricity use (could reduce to 7% with solid-state lighting, which currently requires high-performance thermal management)
- HVAC&R
- Heat exchangers play an important role across the energy sector

2. Increased computing performance (clock speed)

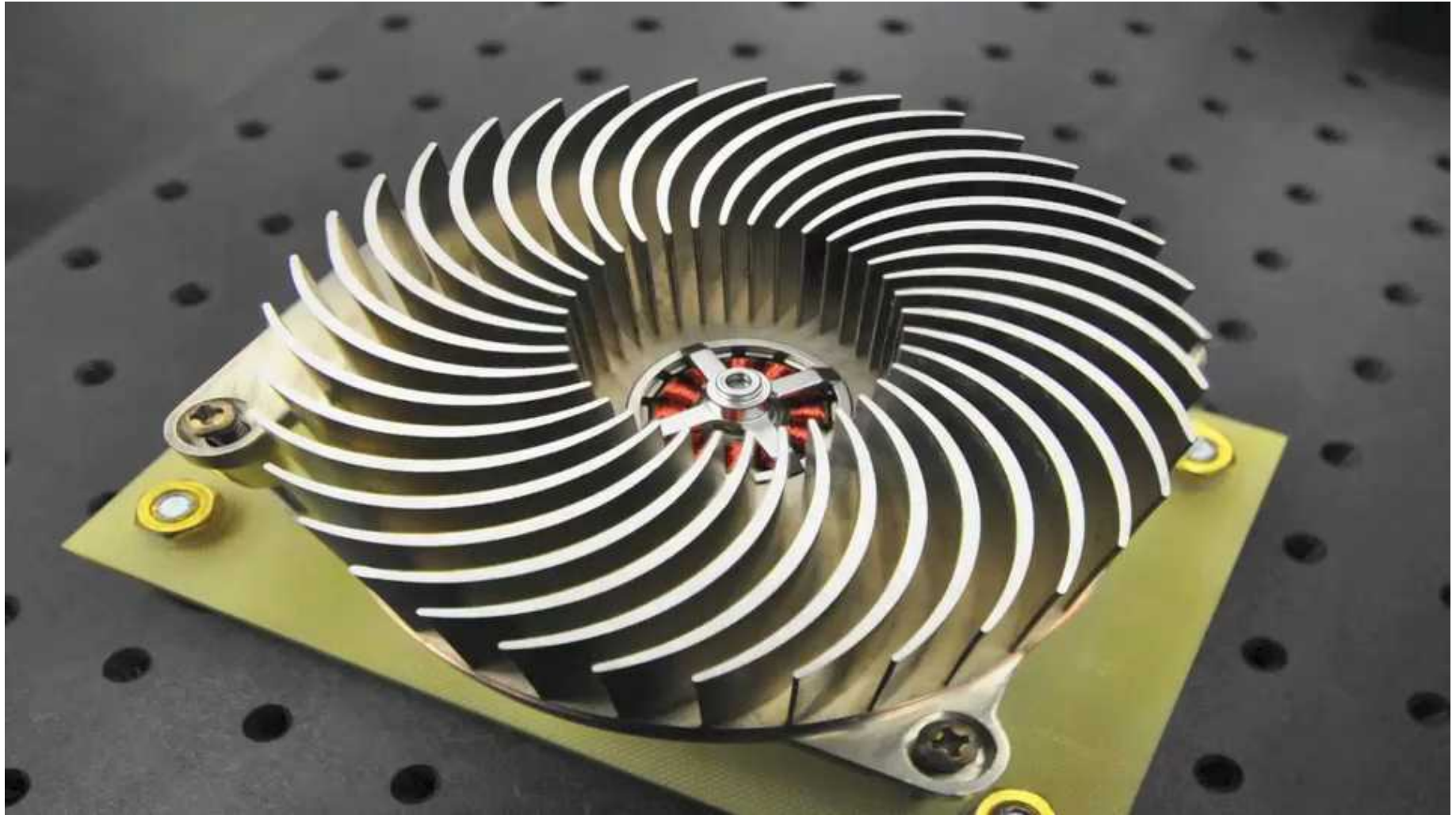
- CPU speed is limited by inadequate performance of conventional heat sinks

Air Bearing Heat Exchanger Operating Principles

1. Thermal load is applied to stationary base plate
2. Heat transfer occurs from base plate to rotating heat-sink-impeller across ~10 micron air gap
3. Rotating heat-sink-impeller acts as a centrifugal fan, drawing cool air in axially and discharging it radially
4. Convective heat transfer to the air occurs in **rotating frame**, resulting in enhanced heat transfer coefficient

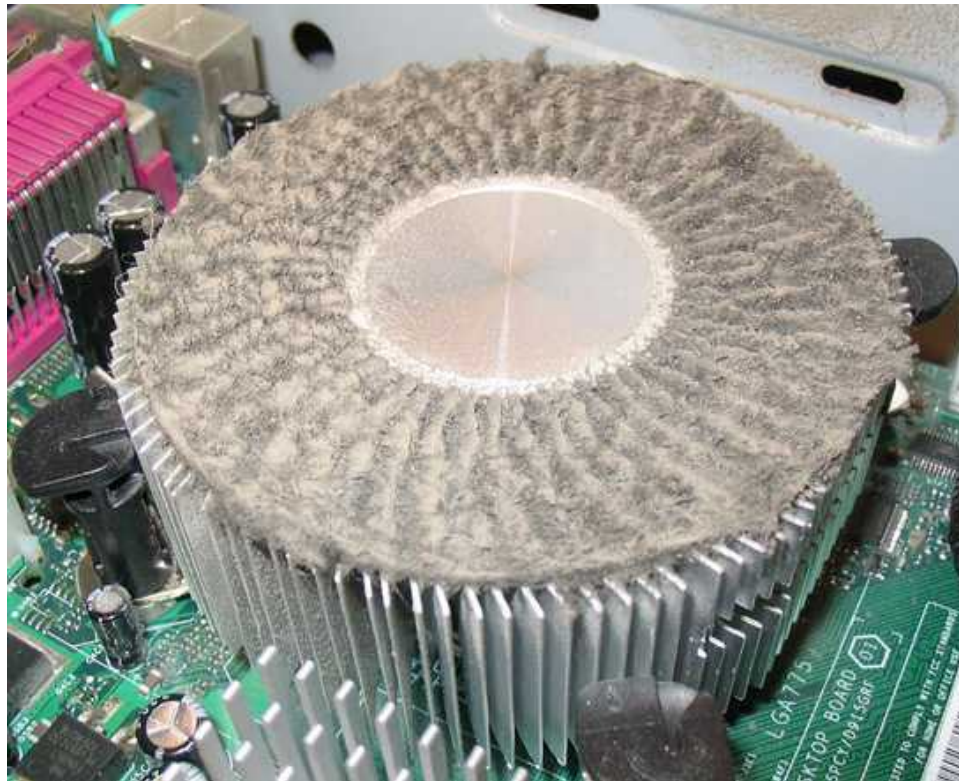


The Air Bearing Heat Exchanger

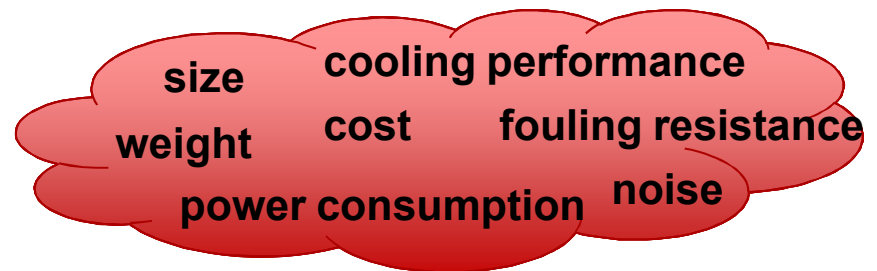
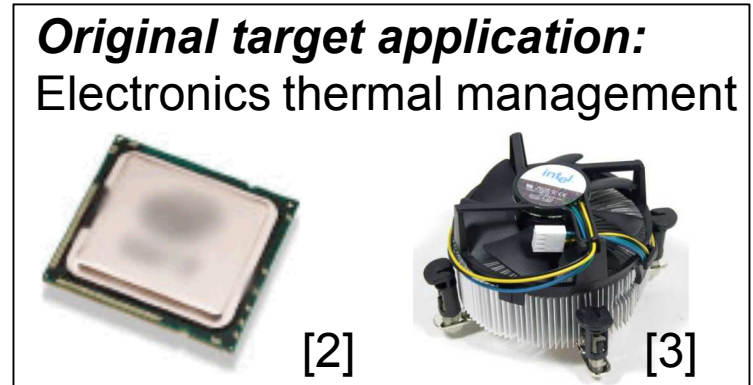


Design Advantages of the ABHE

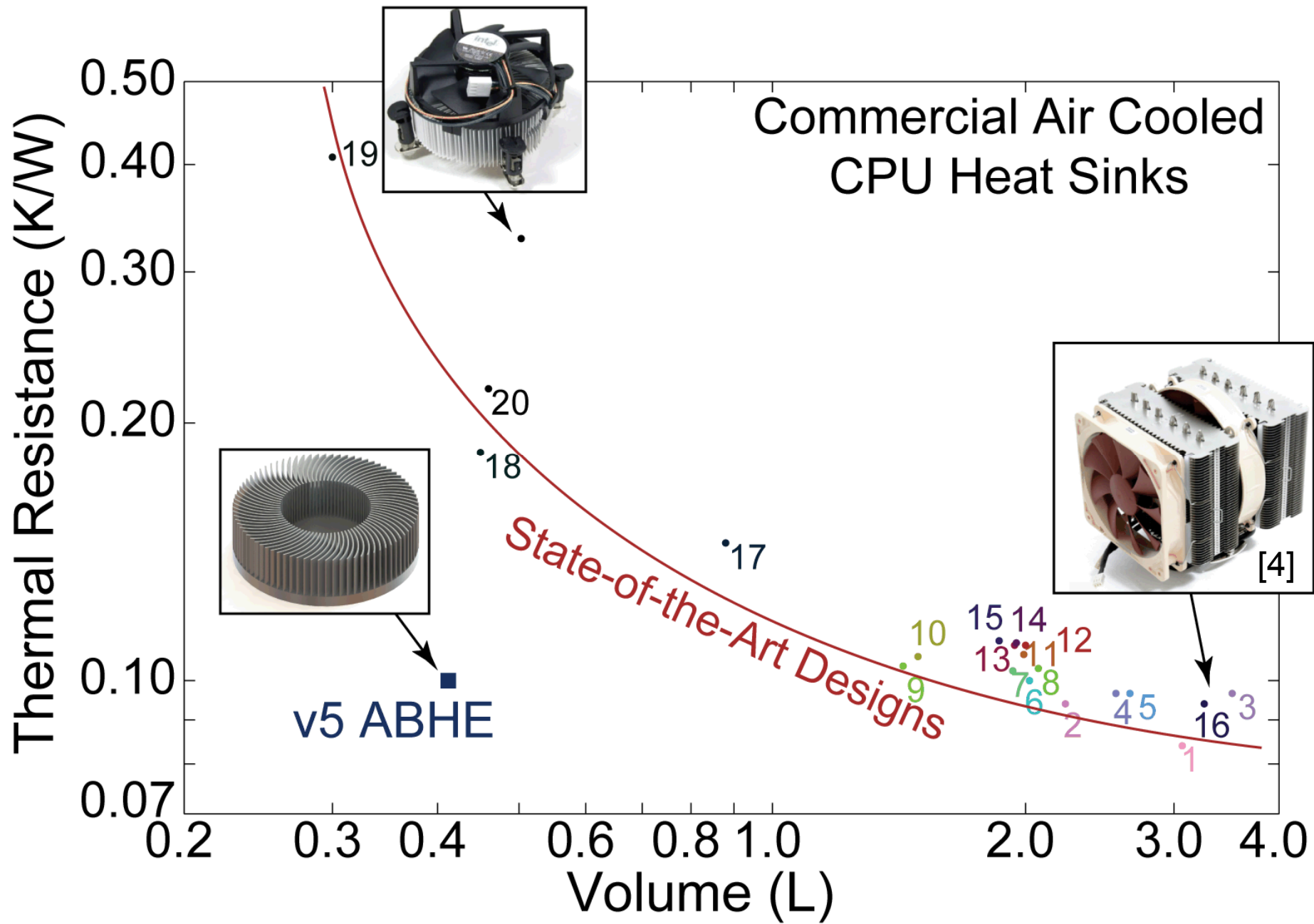
- Low thermal resistance without large power consumption or volume
- Low noise (nearly inaudible at 2000 rpm)
- Excellent resistance to dust fouling



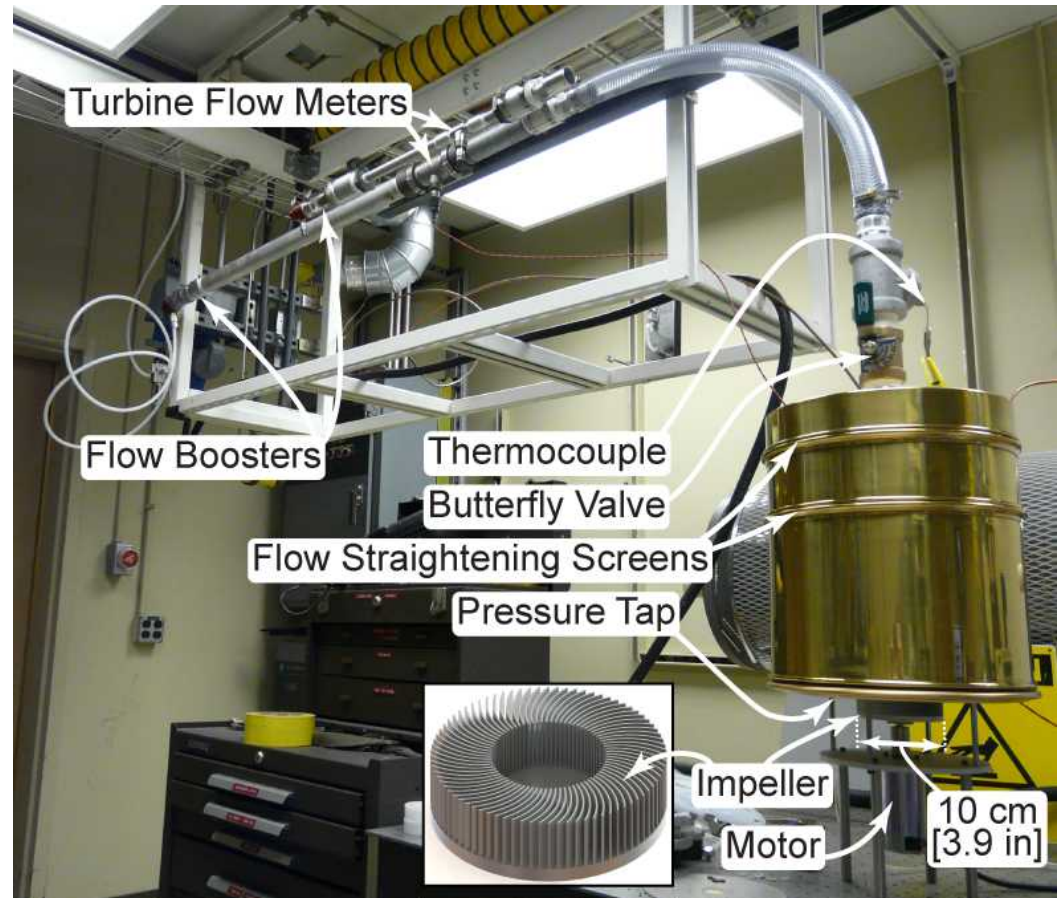
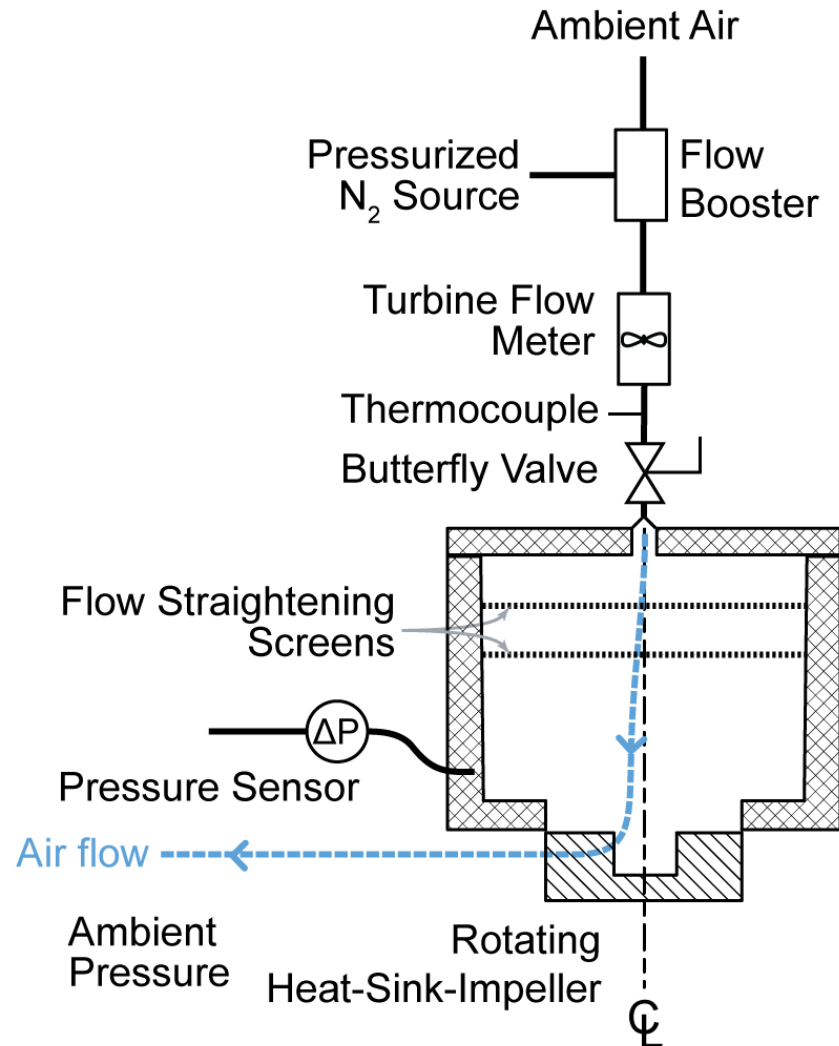
Dust fouling of a conventional CPU heat sink [1]



performance trade space

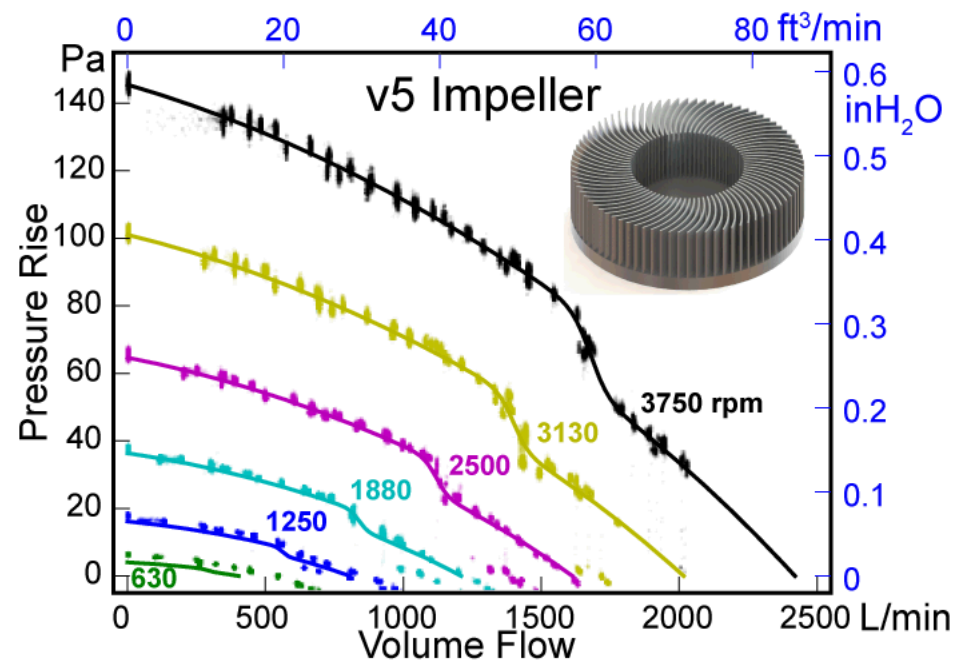
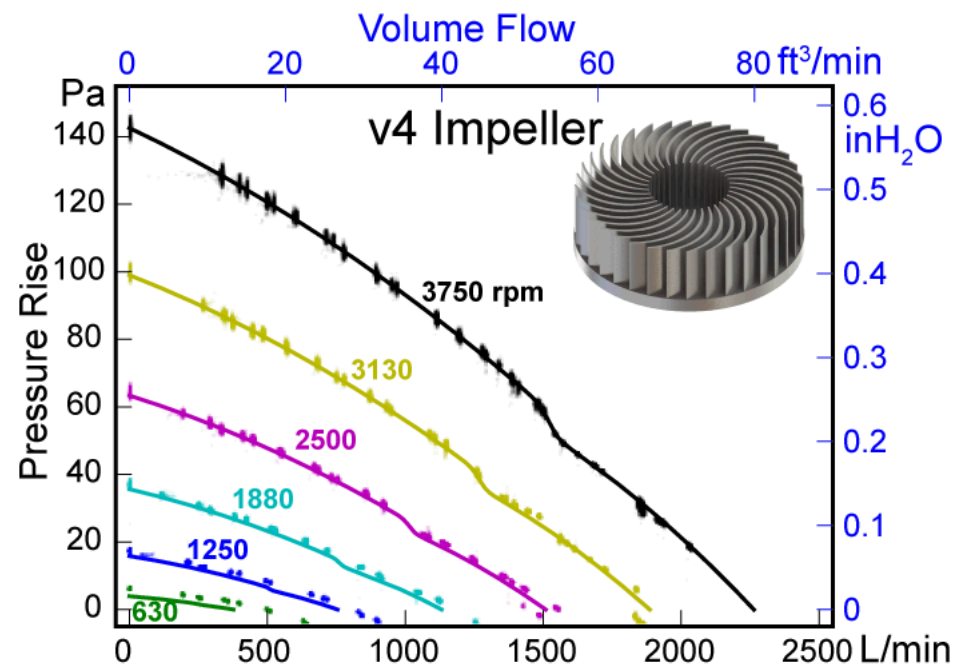


Fan Curve Measurement

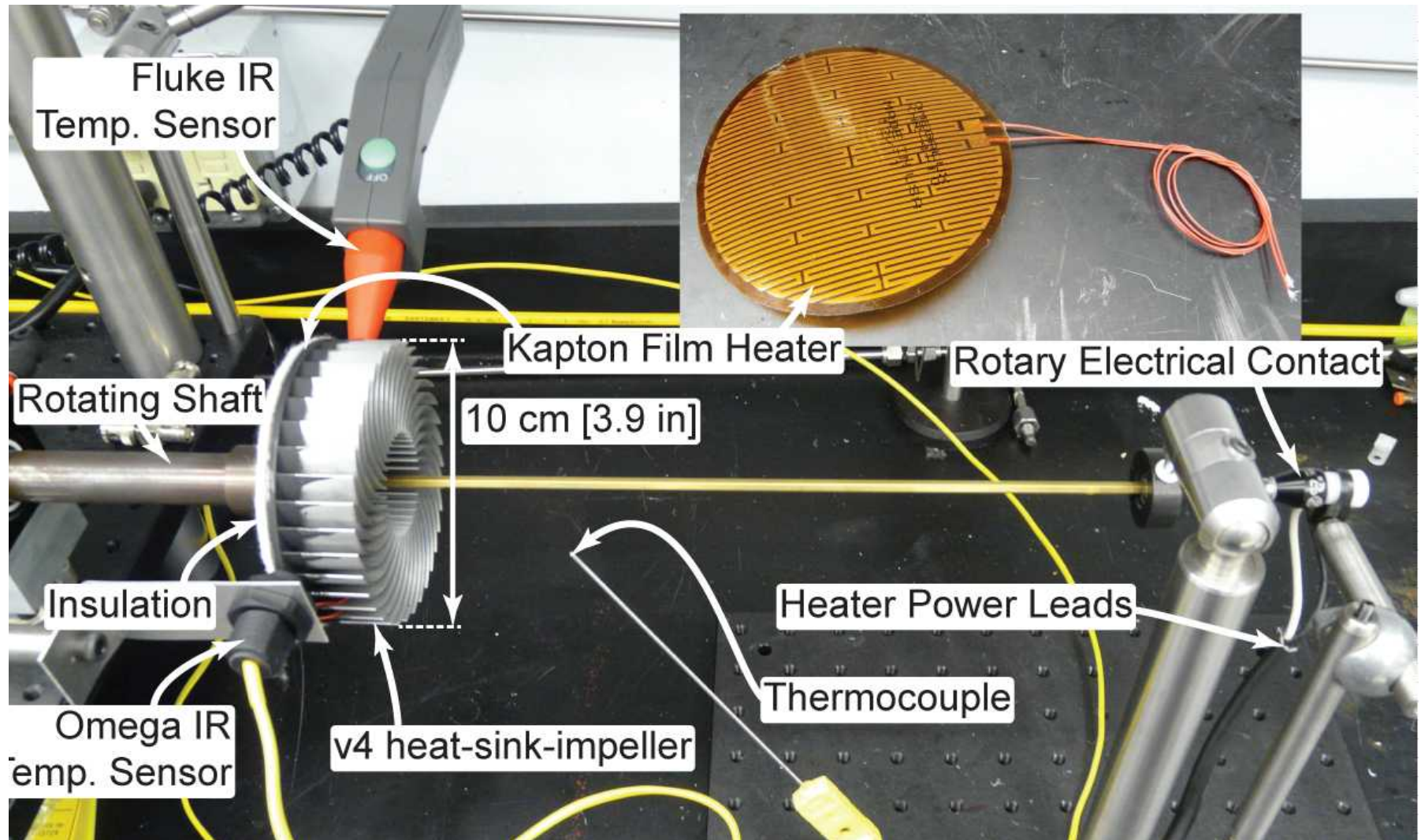


Fan Curves

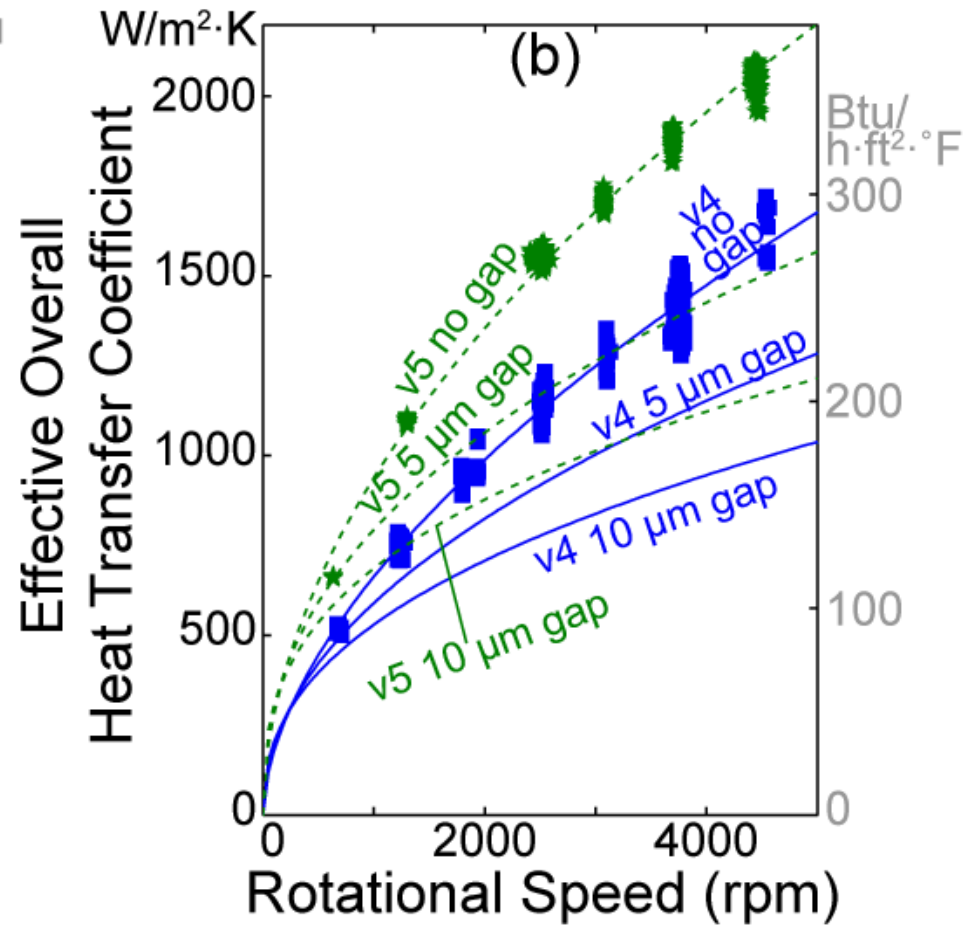
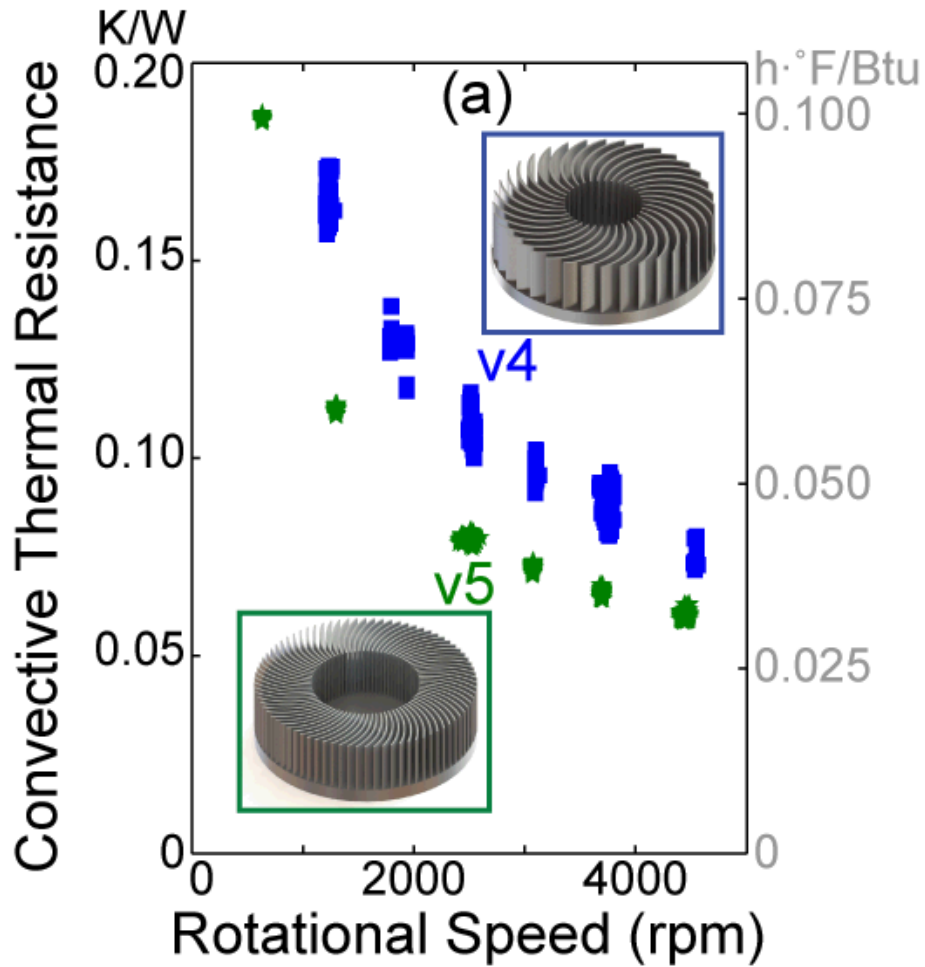
- Fan performance (shut-off pressure and free delivery flow rate) is comparable to COTS fans
- However, the ABHE operates at the free delivery flow rate, since it normally operates without inlet restriction
 - In contrast, traditional finned heat sinks force fans to operate in a restricted regime
- v4 and v5 impellers have very similar fan performance



Thermal Resistance Measurement

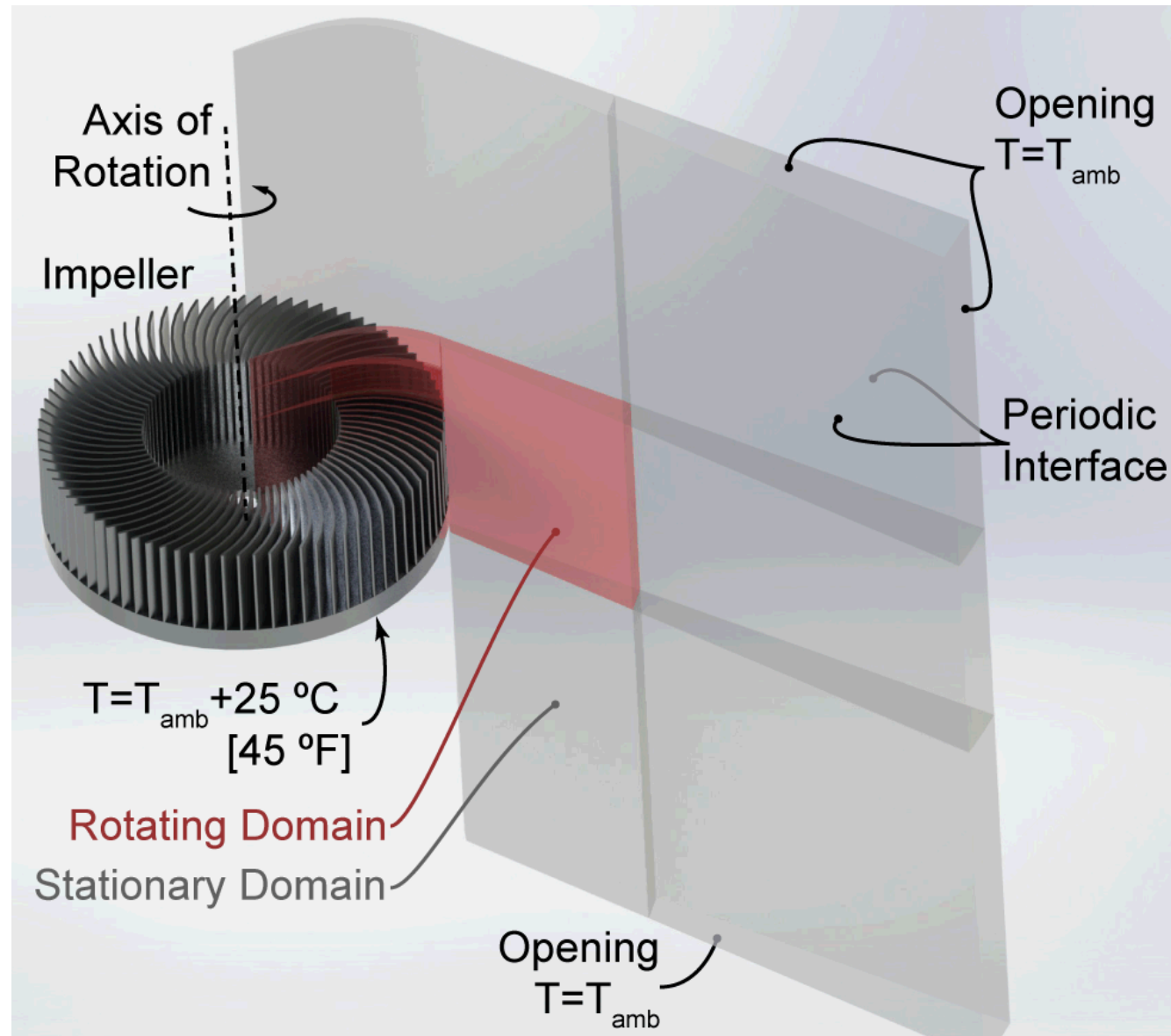


Thermal Performance



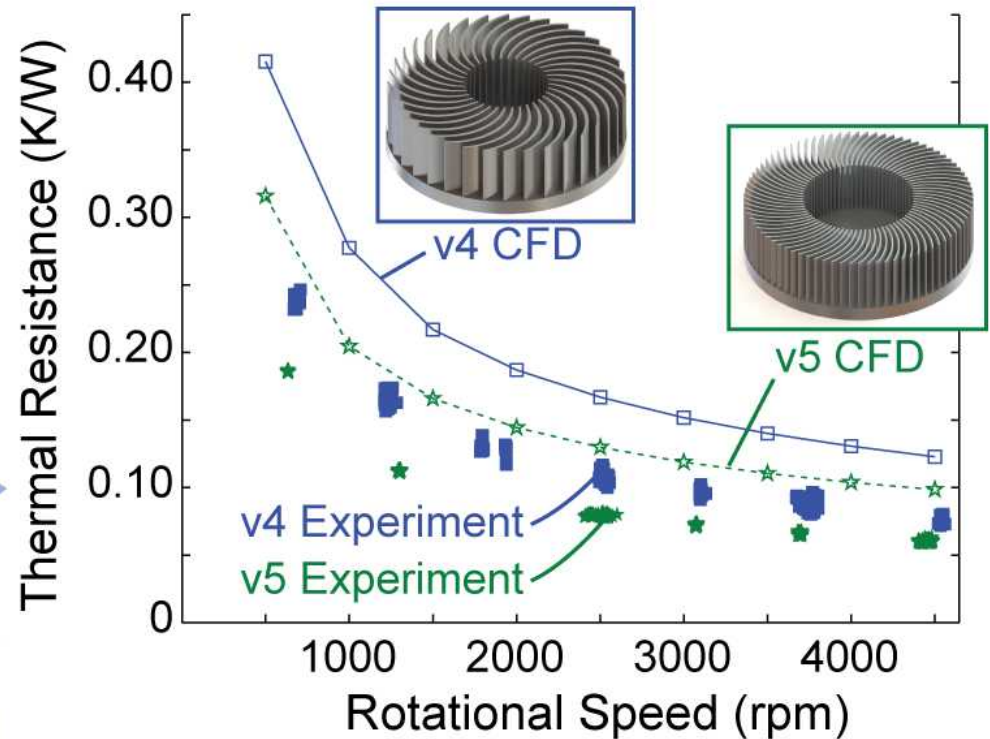
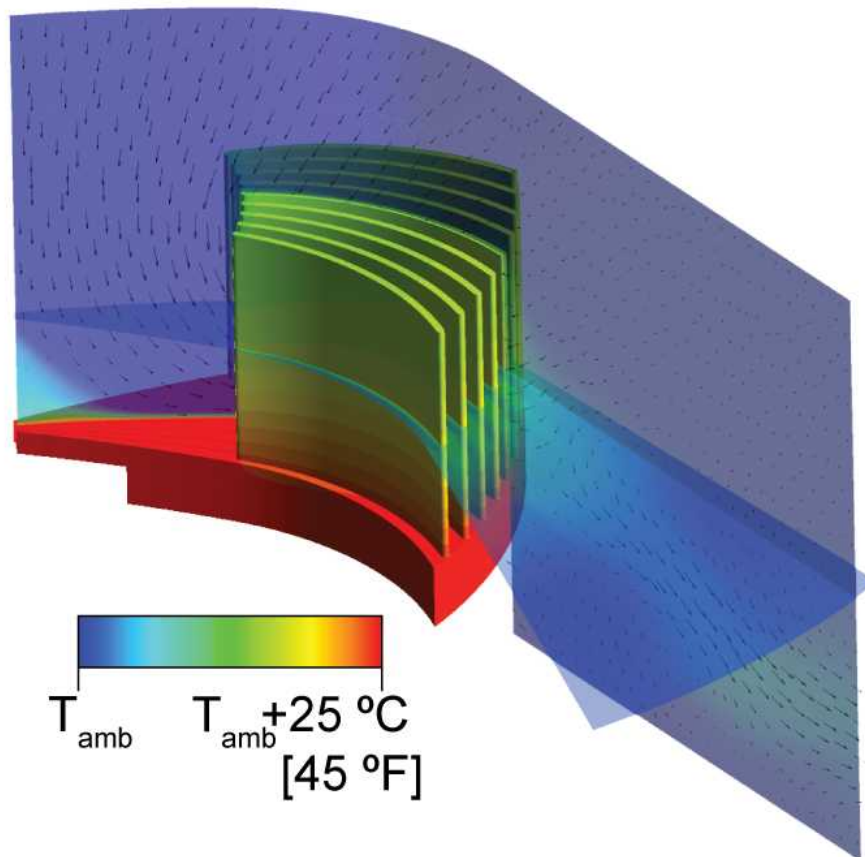
CFD Simulations

- Goal: develop a simple CFD model that can be used for parametric optimization of heat-sink-impellers
- SST turbulence model
- Conduction in aluminum impeller simulated with conjugate heat transfer
- Frozen rotor frame-change model
- Opening boundary condition mimics unrestricted operation



CFD Simulation Results

- Estimates of free delivery flow rate and power consumption were within 20% of experimental results
- Thermal resistance estimates followed experimental trends with rotational speed and impeller geometry



Ongoing Work

- Fabricating 10 “v5” demo units for independent testing
- Applying the ABHE to refrigerator condenser application
- Applying a variant of the ABHE to solid-state lighting
- Developing an axial-flow architecture
- Constructing a 4 kW air conditioning / heat pump demo
- Performing scalability analysis
- Developing low-cost, high-volume manufacturing techniques

Conclusions

- The Air Bearing Heat Exchanger excels in volume-constrained air cooling applications
- We tested two 10 cm [3.9 in] diameter prototypes
 - At 3750 rpm, v5 had a 150 Pa [0.60 inH₂O] shut-off pressure and a 2370 L/min [83.7 ft³/min] free delivery flow rate
 - At 4500 rpm, with a 10 μm air bearing gap, the effective heat transfer coefficient was 1200 W/m²-K (overall thermal resistance of 0.1 K/W, significantly lower than comparable air cooled CPU heat sinks)
- We also performed CFD simulations
 - CFD results agreed with experimentally observed flow rate and power consumption (within 20%)
 - CFD estimates of thermal resistance followed the experimentally observed trends
 - The CFD model provides a platform for parametric optimization

Bibliography

Conference Paper:

Wayne L. Staats, N.D. Matthew, Ethan S. Hecht, Terry A. Johnson and Jeff Koplw. 2013. Heat Transfer and Pressure Drop Performance of the Air Bearing Heat Exchanger. *ASHRAE Papers CD: 2014 ASHRAE Winter Conference*. Atlanta: ASHRAE.

Images:

1. http://2.bp.blogspot.com/-T1cVjtCx7p0/UjRiPWf-KnI/AAAAAAAAACjU/4G7iGxp14tM/s1600/dusty_cooler.jpg
2. <http://ic.tweakimg.net/ext/i/1294043445.jpeg>
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Questions?

Wayne Staats
wstaats@sandia.gov

Backup Slides

Dimensionless Fan Curves

