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Sandia National Laboratories

The Sandia Cooler
A breakthrough in air cooling

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U.S. DEPARTMENT OF ENERGY

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NNSA National Nuclear Security Administration

Air cooling is fundamental to a broad range of products but has changed little in decades

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- Air cooled heat exchangers are ubiquitous:
  - Residential and commercial HVAC&R
  - Residential and commercial electronics
  - Lighting
  - Distributed power and storage

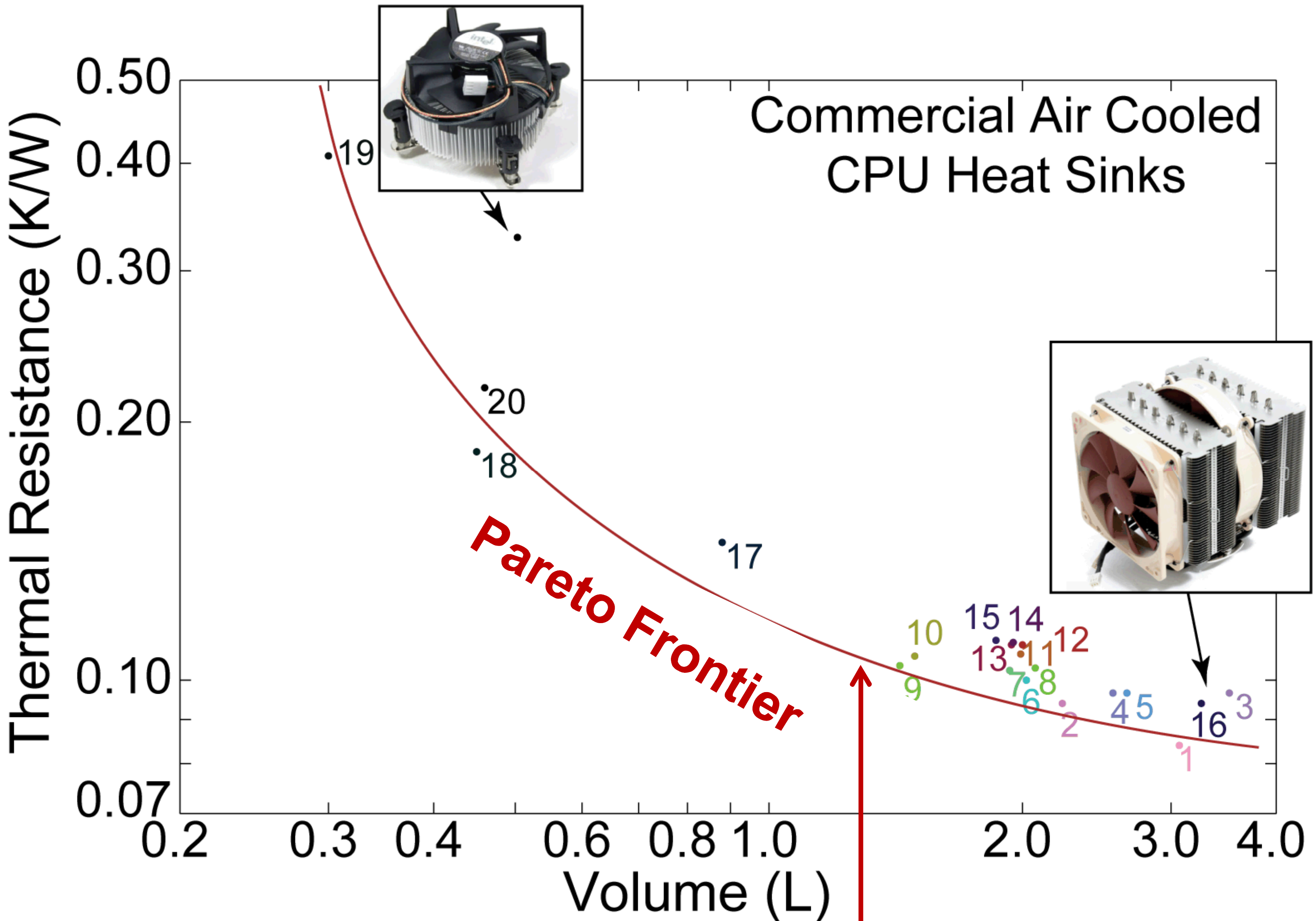





- The fundamental design of air cooled heat exchangers has not evolved
  - Fan + high surface area heat sink
  - Heat transfer limited by boundary layer of air next to heat sink surface
  - Air flow rates limited by fan power and noise
  - Surface area limited by available volume and pressure drop



Pareto Frontier curve for CPU cooler technology



Heat exchanger technology has been stuck on this trade-off curve

The Sandia Cooler is a breakthrough in air-cooled heat exchangers

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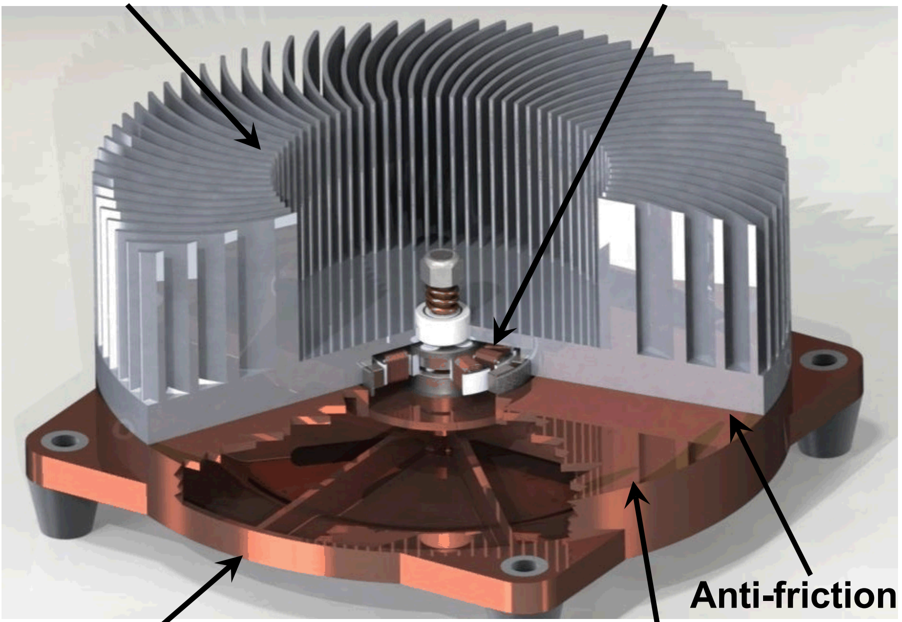
How it works:

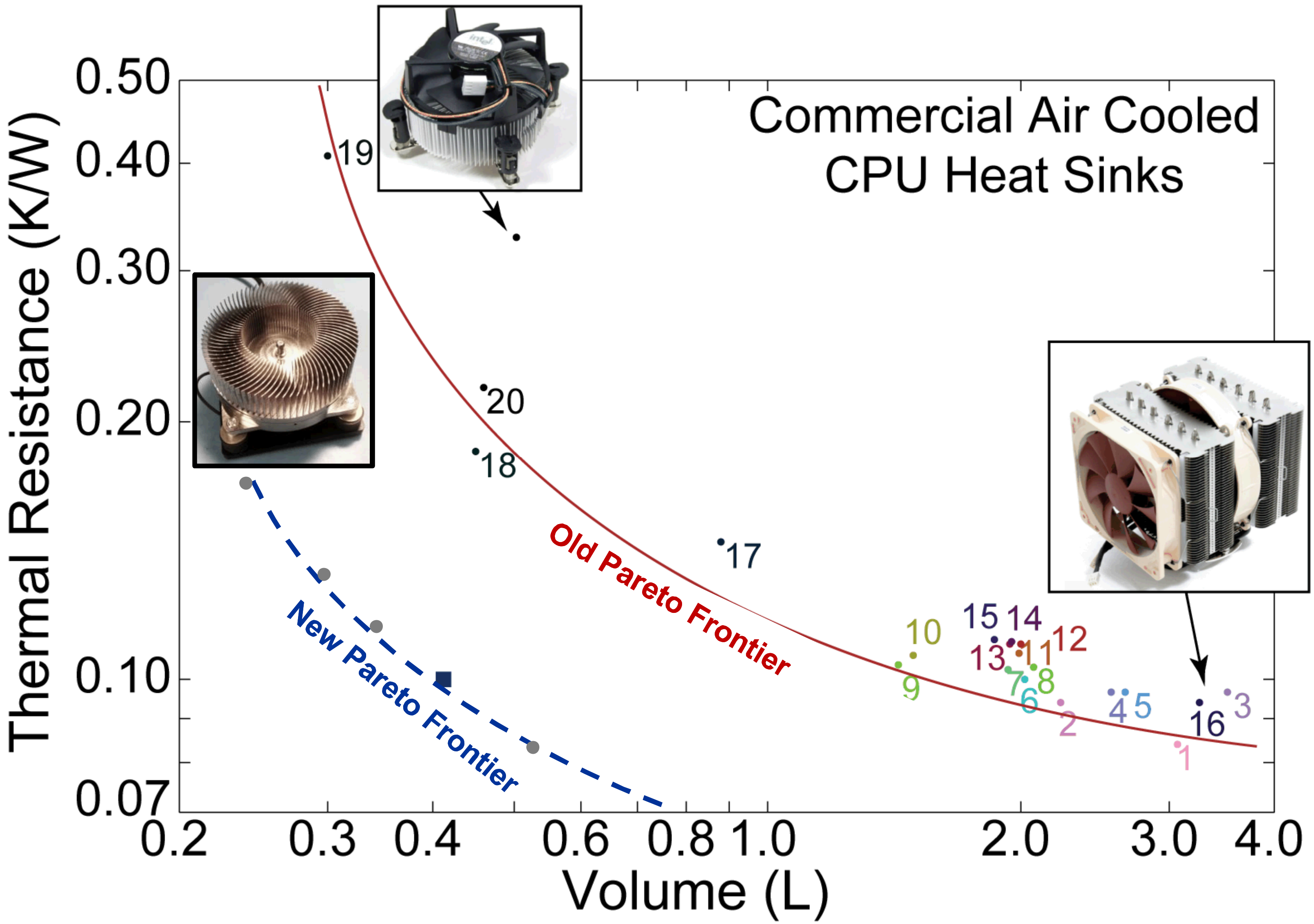
- Stationary baseplate spreads the heat from the thermal load
- Heat is conducted across the thin, self-sustaining, air bearing between the baseplate and the impeller
- Impeller transfers heat to surrounding air
- Brushless motor spins the impeller at several thousand rpm
- Anti-friction coating enables startup



Impeller is the key to the technology

- The impeller is a fan and finned heat sink all in one
- Centrifugal acceleration of air past heat sink fins greatly enhances heat transfer
- Rotating heat sink eliminates fouling from dust or frost
- Very low noise and low power consumption can be achieved

Crossing over to a new Pareto Frontier curve



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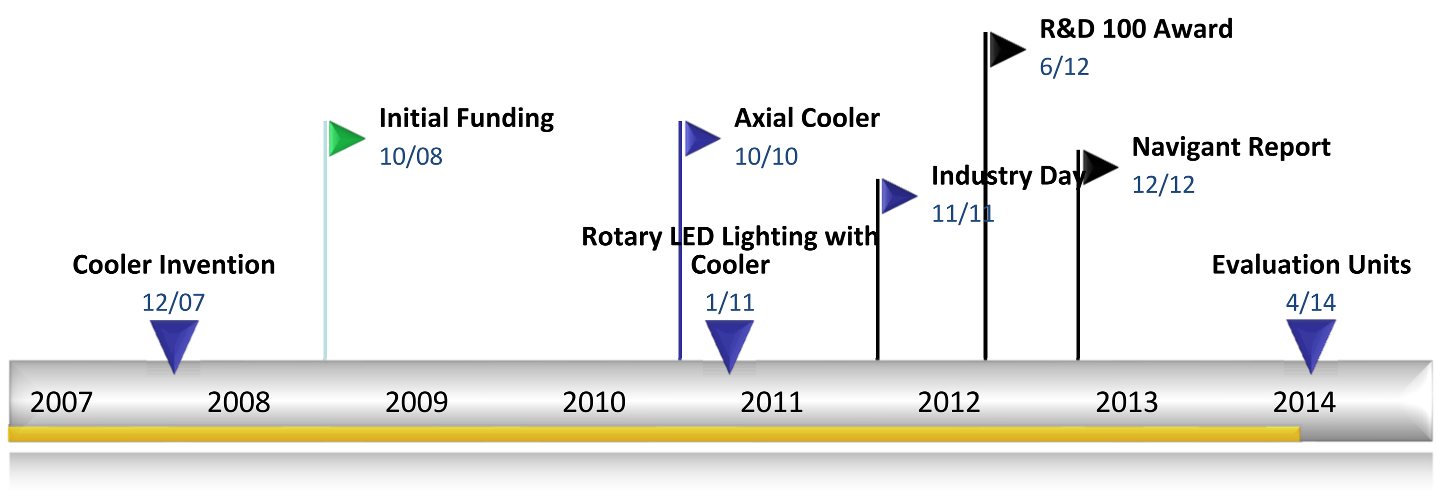


Invention

- TRL 1-2
- Lab bench system
- Follow-on Inventions
- Patent Protection
  - US + World

Proof of Concept

- TRL 3
- Industry Day
  - Lots of outreach
- Wide Press Coverage
- Interest ~ 20 companies

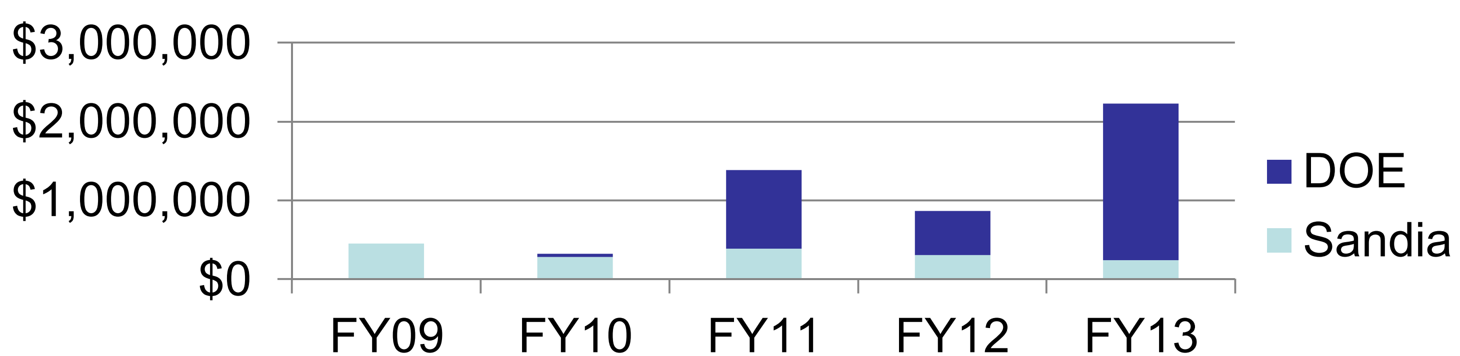
Development

- TRL 4-5
- Licenses to 2 Startups
  - 3 License Options
- Industry Waits for Prototypes
- Interest > 50 companies

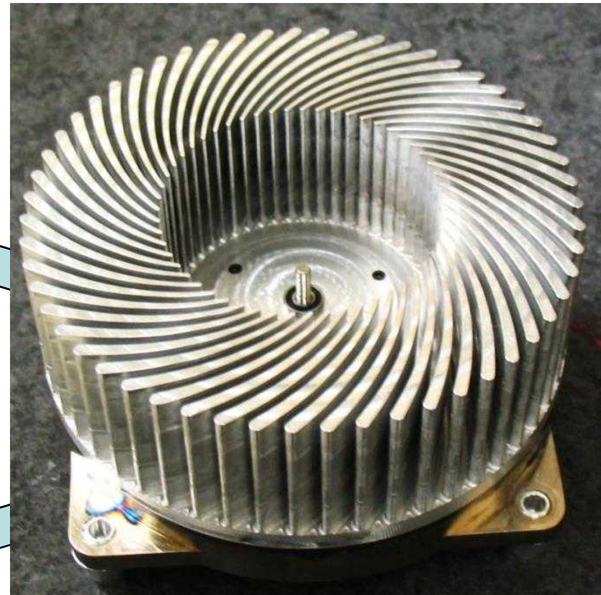
Deployment

- Evaluation Units
- Partnerships
- Application Specific R&D
  - Refrigerators
  - HVAC
  - LED Lighting

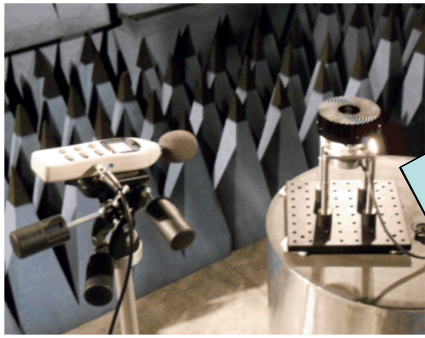
Funding



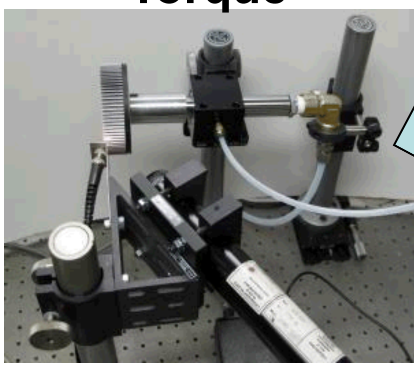
Test stands were developed to evaluate all aspects of the Sandia Cooler



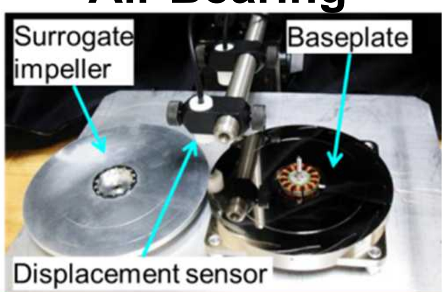
Acoustic



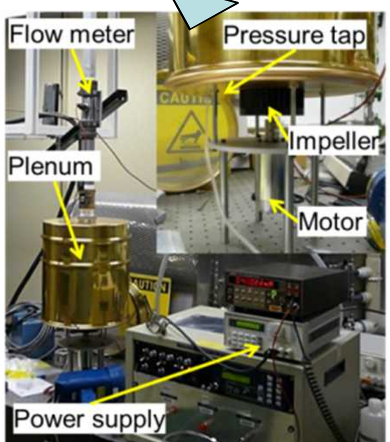
Torque



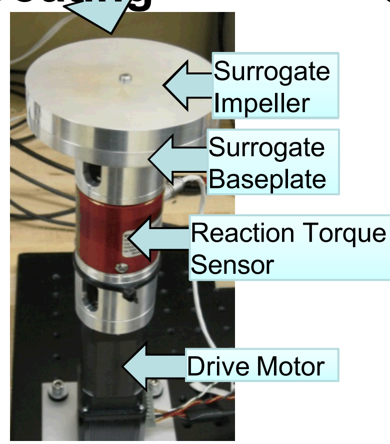
Air Bearing



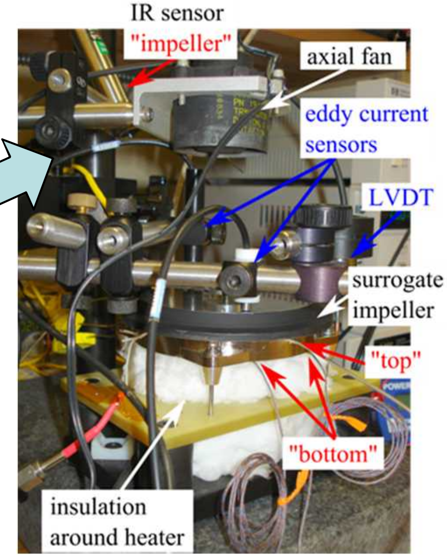
Pressure-Flow

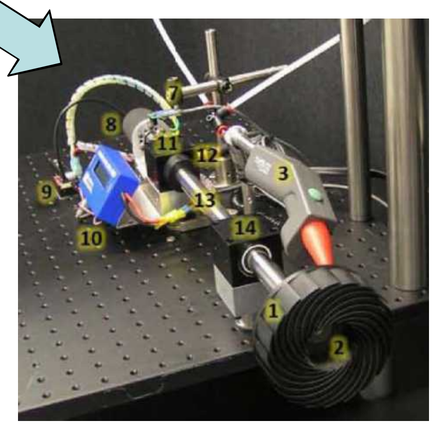


Anti-friction Coating



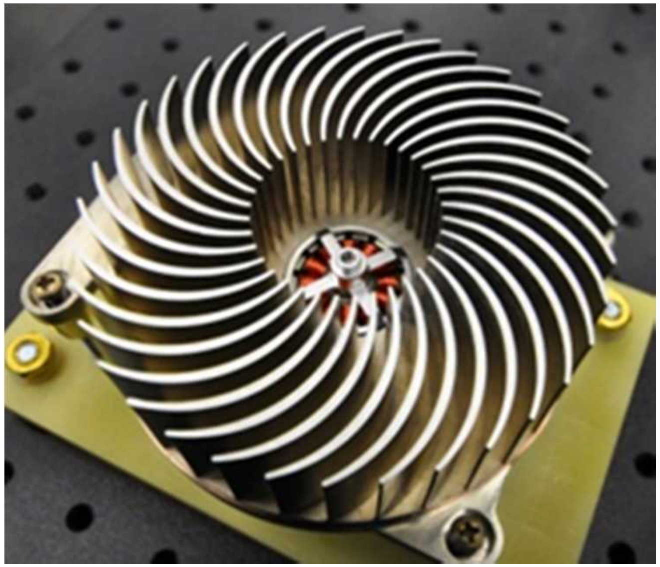
Thermal Resistance





Three different impeller geometries were extensively characterized

V4



OD	4.0”
ID	1.5”
Fin Height	1.0”
# Fins	36
Shape	Intersecting arcs

V5

OD	4.0”
ID	2.0”
Fin Height	0.95”
# Fins	80
Shape	Arcs

V6

OD	4”
ID	2.0”
Fin Height	1.18”
# Fins	55
Shape	Log spiral

Air bearing design was improved through experiment and analysis on two new baseplates

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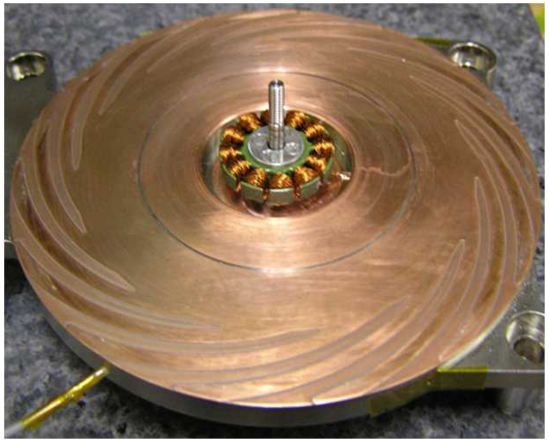
Original Design

Greater lift than needed
Significant pre-load for 10 μm gap
Groove area and depth larger than required



Parameters	
Ø_Impeller	101.6 mm
Groove Depth	81 μm
λ, r_Inner/r_Outer	0.75
α, Groove Angle	15°
k, # of Grooves	15
g, ridge width/groove width	1.0

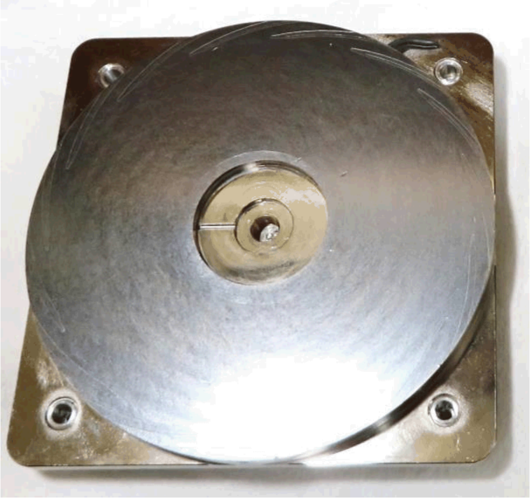
V5 Design

Good stiffness with less thermal resistance
Less sensitivity to impeller speed
Groove area still larger than required

Parameters	
Ø_Impeller	101.6 mm
Groove Depth	25 μm
λ, r_Inner/r_Outer	0.9
α, Groove Angle	15°
k, # of Grooves	15
g, ridge width/groove width	1.0

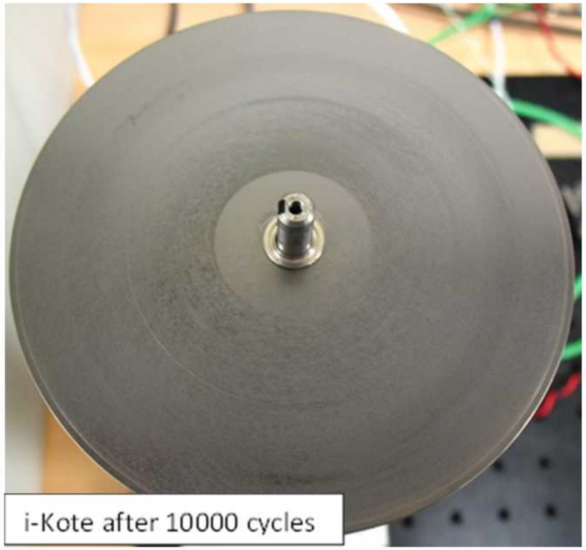
Final Design

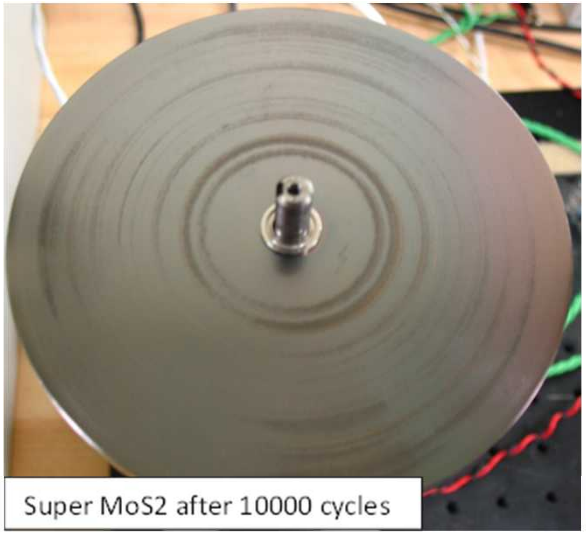
Maximum stiffness at a 10 μm gap
Minimal pre-load
Minimum thermal resistance

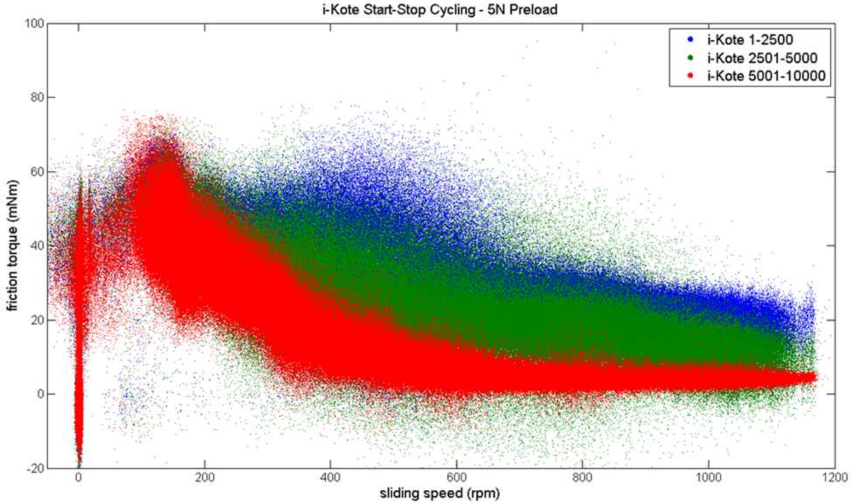


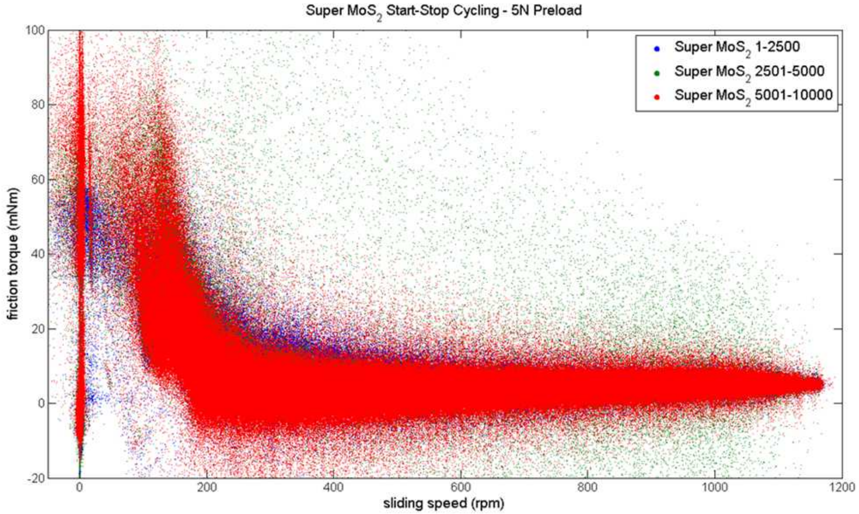
Parameters	
Ø_Impeller	101.6 mm
Groove Depth	35 μm
λ, r_Inner/r_Outer	0.9
α, Groove Angle	12°
k, # of Grooves	15
g, ridge width/groove width	1.4

Two anti-friction coatings perform well out to 15,000 start/stop cycles



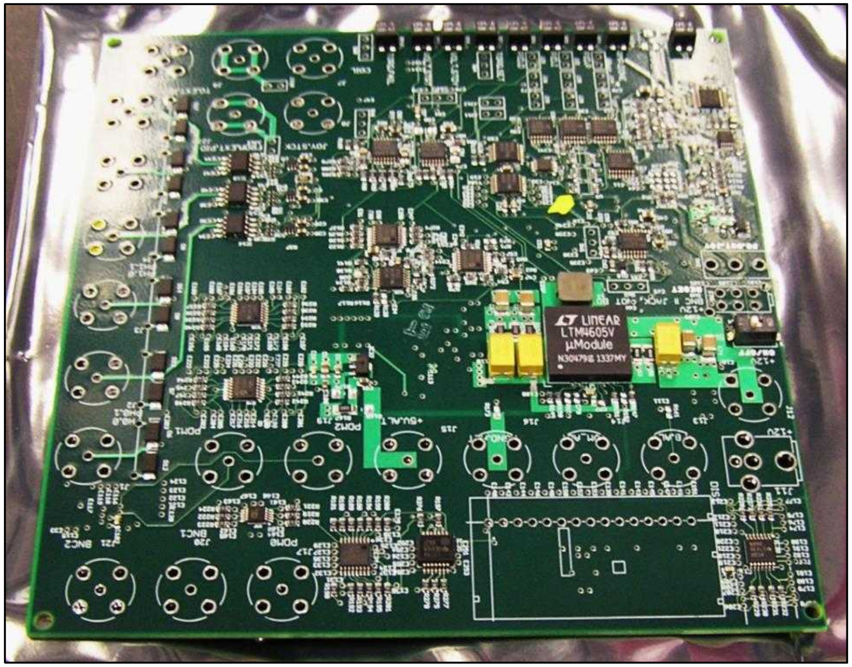


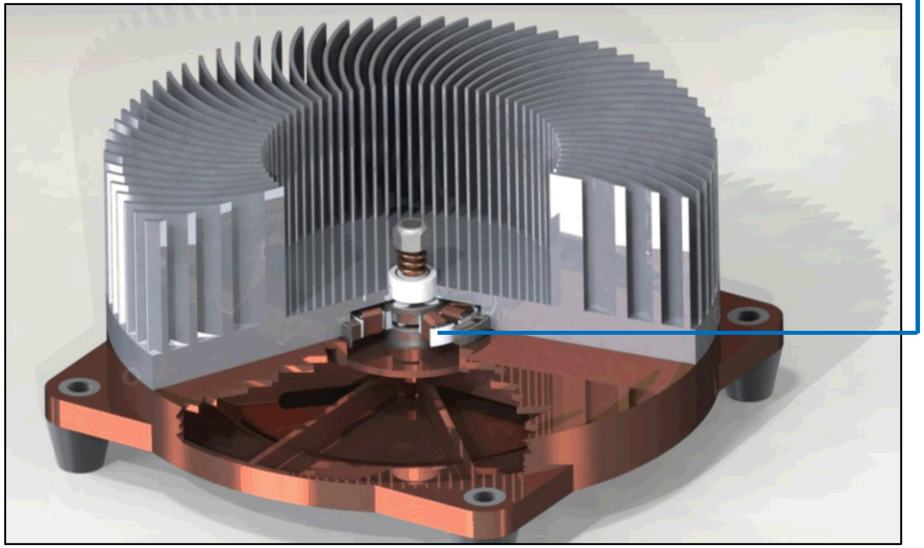




Custom motor controller in final stages of development

- Extremely high startup torque per unit volume (55 mN m in 2.5 cm^3 package)
- Ultralow-noise and cogging torque (vibration) via three-phase PDM drive waveform
- 70% efficiency (extremely high for such a small format brushless motor)
- No available space or manufacturing budget for Hall effect sensors
- 1000 to 5000 rpm operating range with rpm readout
- Built in PID controller
- Automated handling of fault conditions (locked rotor, loss of synchronism, thermal)
- Circuit design fully compatible for reduction into single ASIC chip





The beta version motor controller board at left will be converted to final controller board about the size of a business card for the 10 Sandia Cooler demo units

Computational fluid dynamics (CFD) models tell us a lot about the cooler performance

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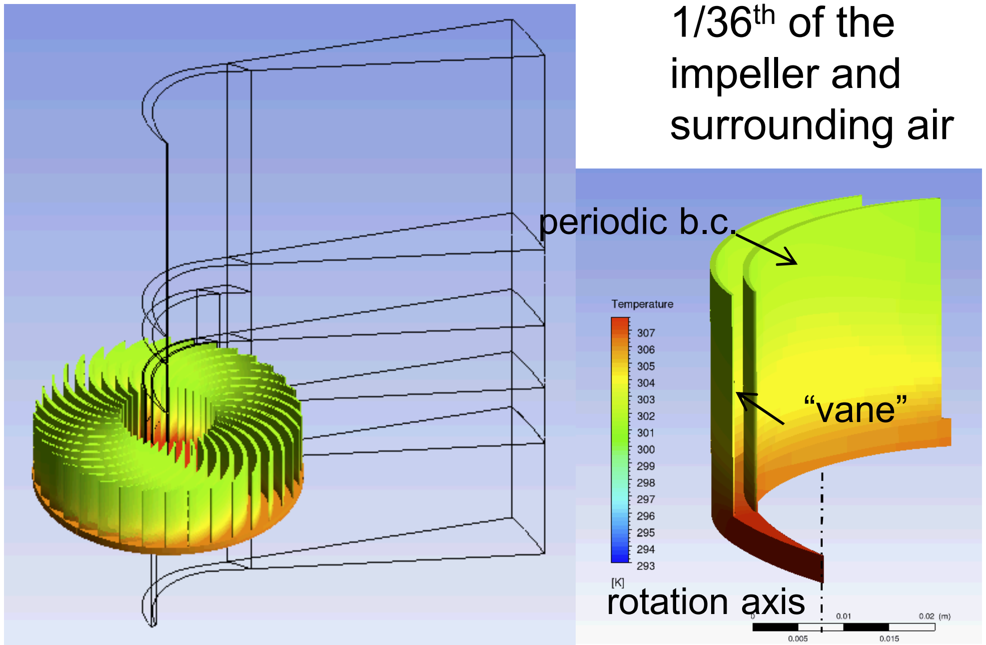
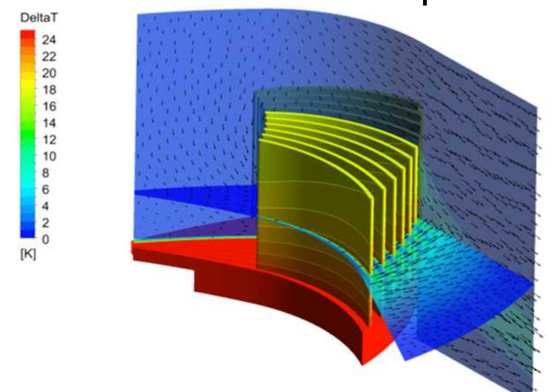
Example: V4 with 36 blades

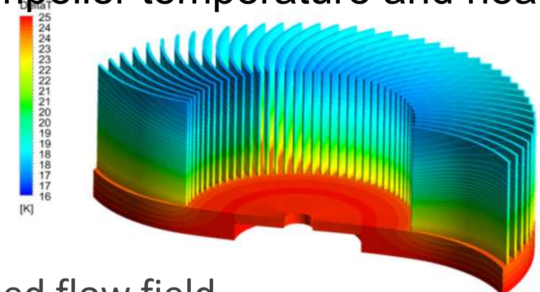


- ANSYS CFX V14.0
- Conjugate heat transfer (solid and fluid computation)
- Rotational reference frame for impeller
- Periodic boundary conditions take advantage of symmetry
- Reynolds-Averaged Navier Stokes (RANS) equations for flow field
  - Shear Stress Transport model

Flow field and air temperature

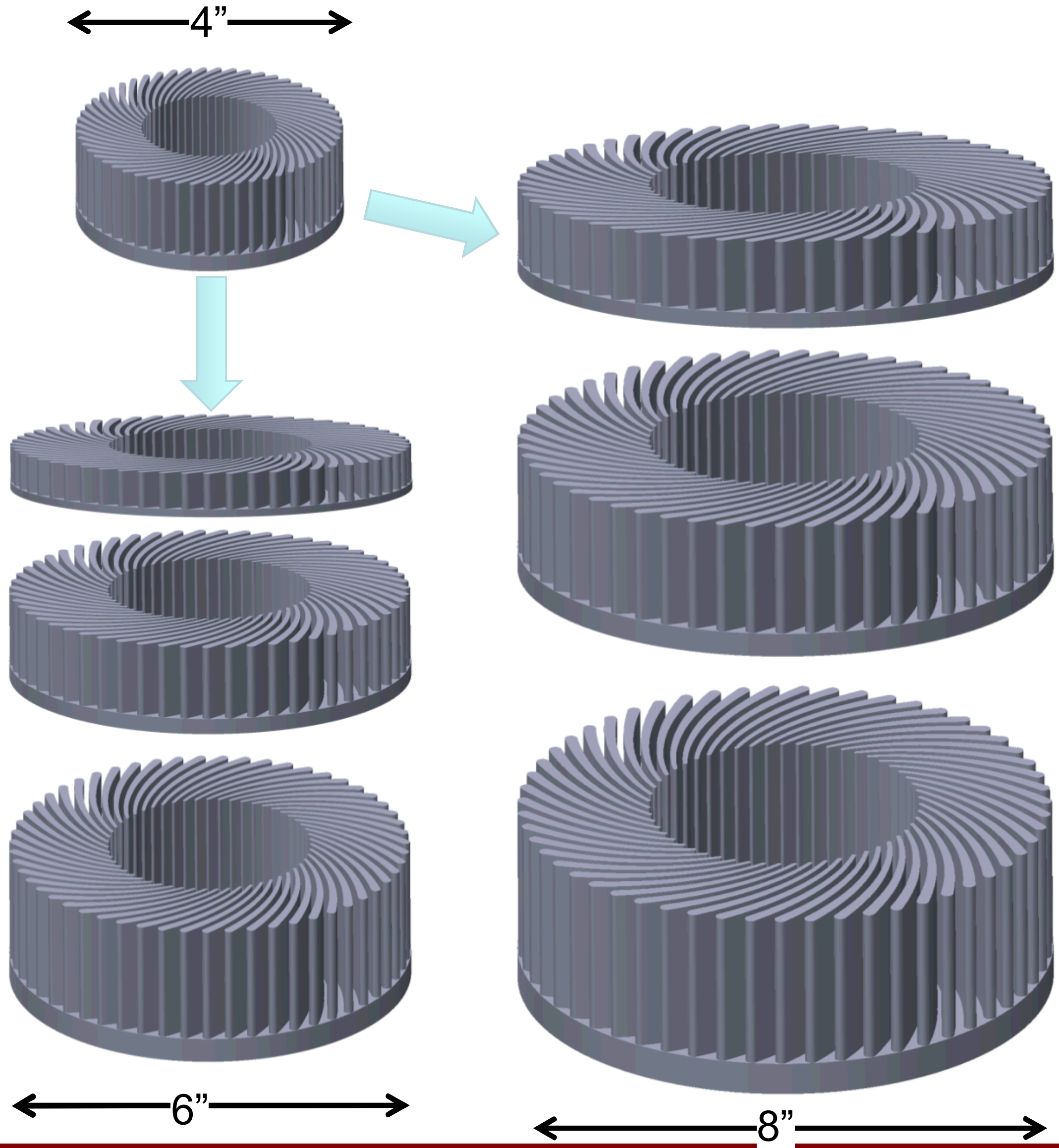


Impeller temperature and heat flux



- Detailed flow field
- Temperature distribution in air
- Torque and power consumption
- Heat transfer coefficient
- Temperature distribution within solid regions
- Fin efficiency
- Where solid material is efficiently being used

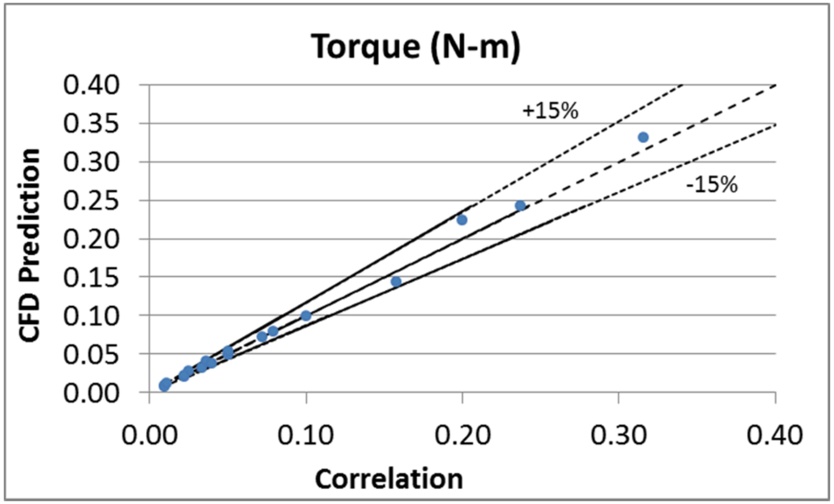
Scaling study to determine performance at different diameters and fin aspect ratios



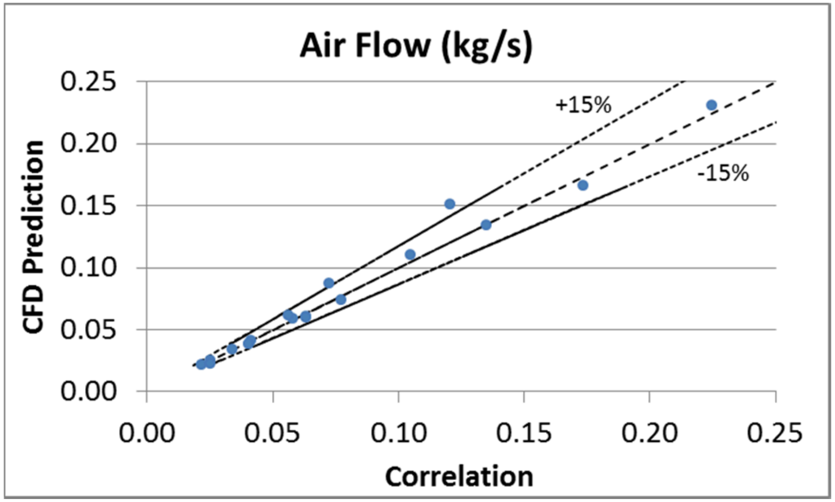
- V6 geometry: 55 fins, 45˚, 4” diameter, 1” inner radius, 1.175” height, 1.5 power law
- Uniform in-plane scaling; 1.5X and 2X
- Independent vertical scaling for some cases; 0.5X, 1X, 1.5X, and 2X
- Speed scaled inversely with diameter based on V6 @2500rpm for some cases

Correlations based on CFD studies predict impeller performance to within ±20%

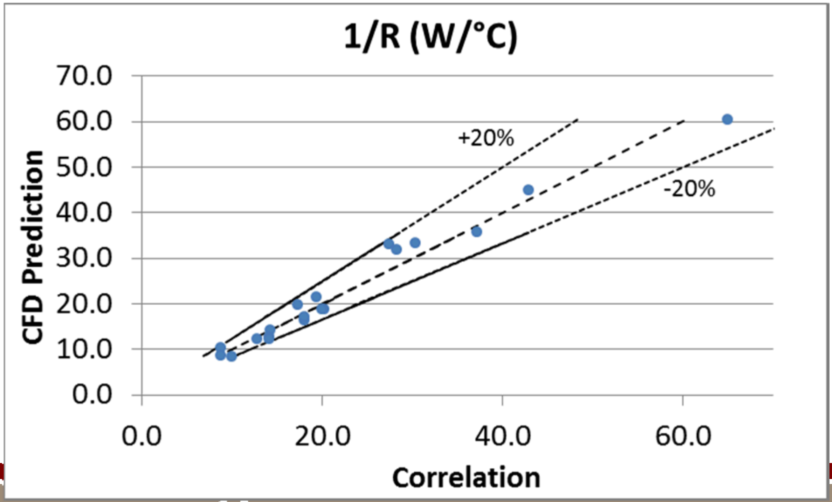
$$\tau = 4.8 \times 10^{-12} h \omega^2 d^4$$



$$Q = 1.16 \times 10^{-7} h^{0.9} \omega^{1.1} d^{2.25}$$



$$\frac{1}{R} = 2.82 \times 10^{-3} h^{0.5} \omega^{0.6} d^{1.8}$$

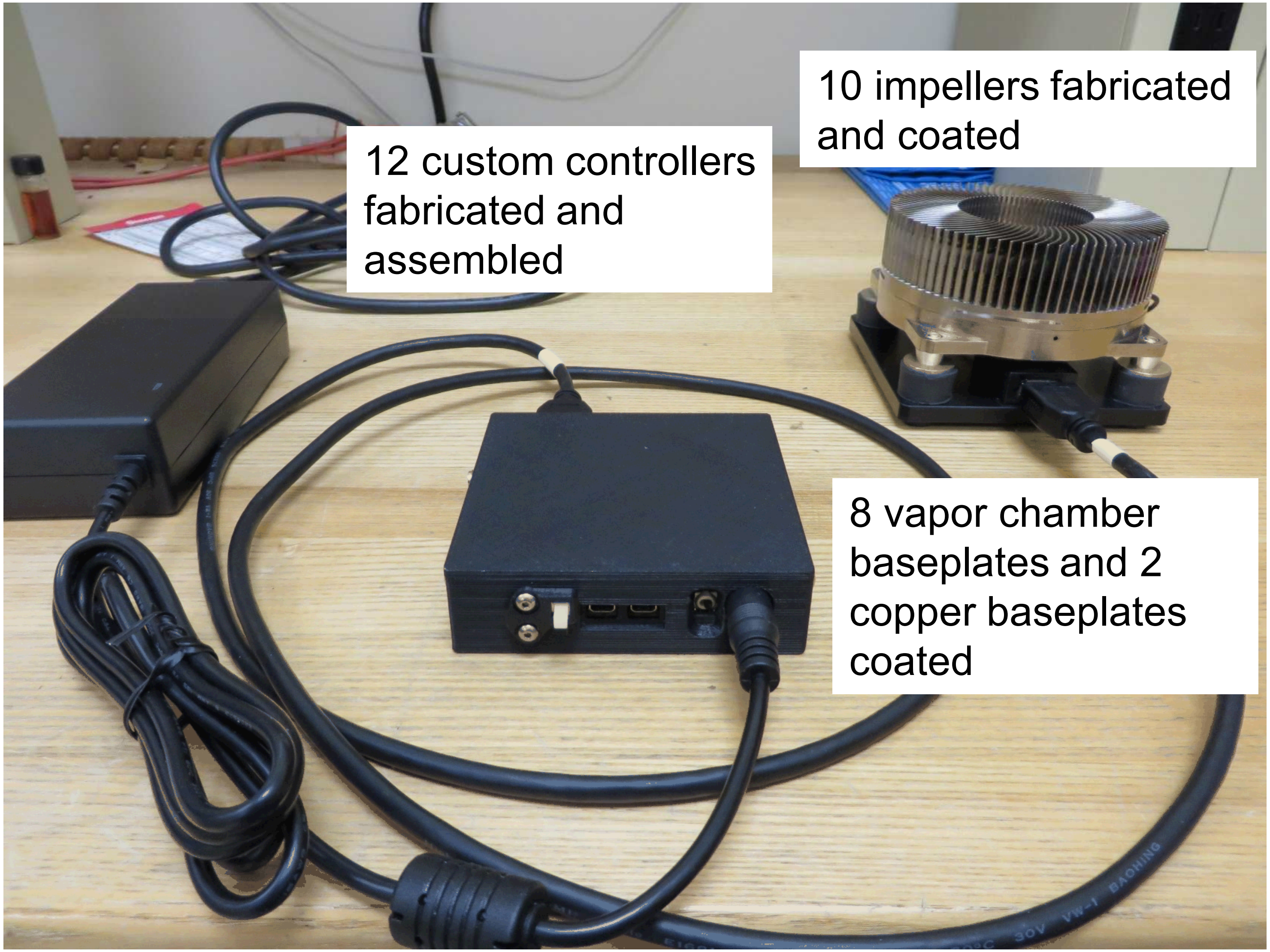


Note, since *Power* = τ x ω:

$$P = 4.8 \times 10^{-12} h \omega^3 d^4$$

ω in rad/s
h in cm
d in cm

Custom controllers completed; complete units will be assembled as-needed



V5 device compared to standard and after-market CPU coolers

	V5 (2500 rpm, 10 µm gap, Vap. Ch.)	V5 (3000 rpm, 5 µm gap, Vap. Ch.)	Intel i7 OEM cooler (Nidec F10T12MS1Z7)	Noctua NH-D14
Rth (C/W)	0.15	0.11	0.252	0.10
Impeller	0.084	0.073		
Air gap	0.052	0.027		
Baseplate	0.01	0.01		
Power consumption (W)	~5	~10	3.6	2.3
Dimensions (mm)	100X100X46	100X100X46	100X100X62	140X158X160
Volume (cc)	460	460	620	3540

Commercialization Status

- Over 50 companies are looking at Sandia Cooler
  - 1 Commercial License – Startup
  - 3 License Options – Niche markets + Startups
  - 1 Test and Evaluation License – Evaluation for Possible Project
  - 1 Terminated License – Startup – No funding
- Major Challenge
  - Lack of Data and Evaluation Units to allow companies to invest in Cooler

Companies that have expressed interest in the Sandia Cooler

Electronics Cooling

Listan, NVIDIA, Malico Inc, hp, LG Life's Good, lenovo, asetek, DYNATRON, CoolChip Technologies, NZXT, cooliance

Tesla

Solid-State Lighting

Innovative Technologies
StreamXY
LED Package Science
Leader International

L&L Luce&Light, Philips Lumileds

HVAC

Trane, United Technologies Research Center

Appliances

Electrolux, Whirlpool

Medical

GE Healthcare

Various

SEL Schweitzer Engineering Laboratories, Insitu, nbd nano, Elbit Systems, GBL Geothermal, Pacific Ozone, Spectrum Controls

Telecom

Juniper Networks, Huawei, Cisco

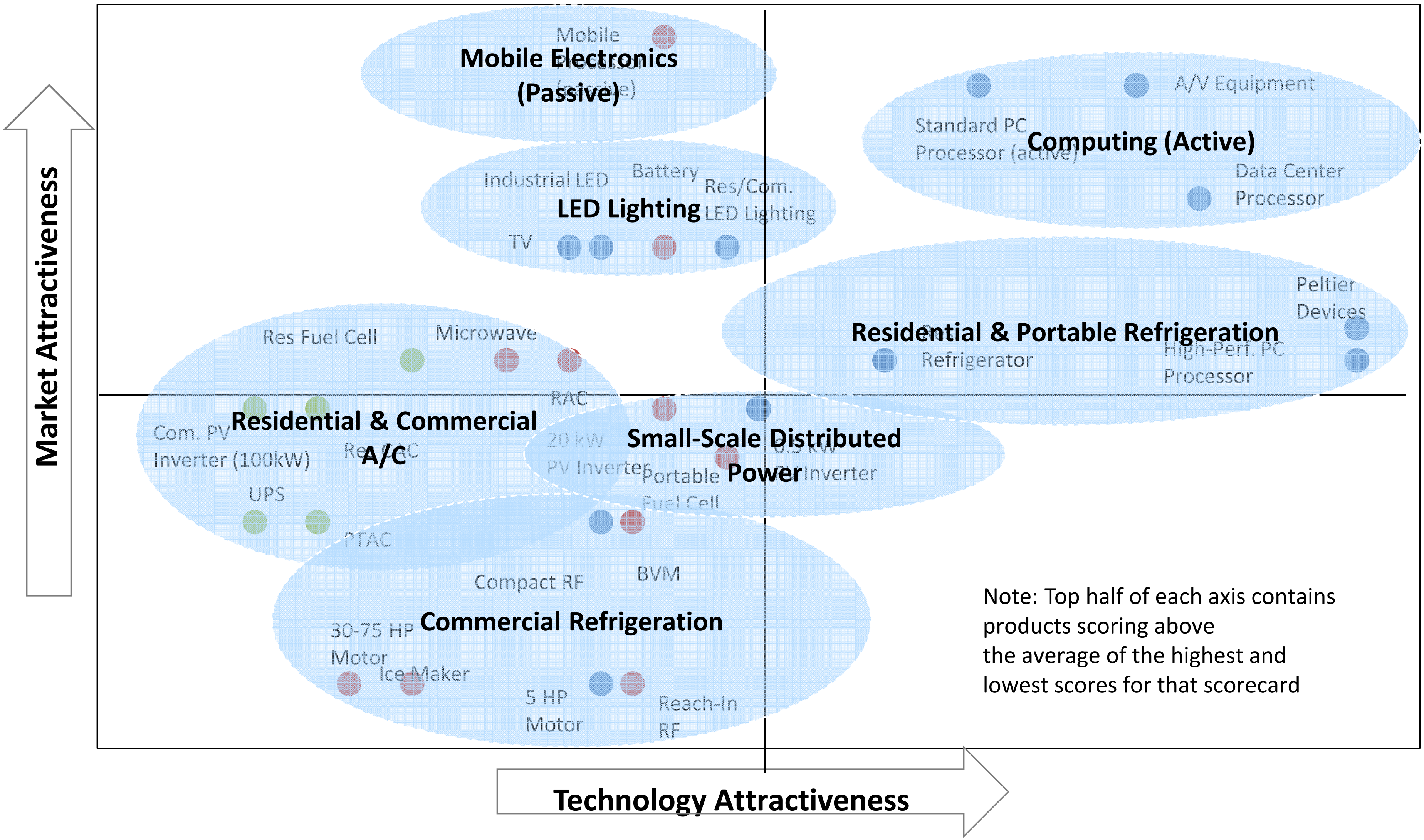
Optics

Ophir, Red Digital Cinema Professional

Sandia Cooler Prototype Evaluation Program

- Addresses major impediment to deployment
  - A dozen companies requested evaluation units in 2013 – none available
- Program details
  - One to two month evaluations
  - Test results shared with Sandia to advance development
- Timeline
  - March - Announce program to interested companies, outreach to small number at first
  - April – Process responses, prioritize, initial delivery to key companies
  - May - October – Evaluation units out to first couple of rounds of companies
  - November – Broader announcement of Evaluation Program

Navigant study identifies most promising commercial markets for the Sandia Cooler



● Single 5-20cm ● Multiple SC 5-20cm or Single SCs < 5cm or >20cm ● Multiple >20cm

We are now pursuing the most promising applications and partnering with experts in these fields

1. Condenser for Residential Refrigerator – **University of Maryland**
2. Thermoelectric Cooling Device – **University of Maryland/Optimized Thermal Systems**
3. Evaporator for Residential Refrigerator – **Oak Ridge National Lab and UMD**
4. Heat Exchanger for Residential Heat Pumps – **United Technology Research Center**
5. **LDRD** Solid state lighting
6. Sandia Heat Pump (axial flow technology) – **TRANE**