

The Sandia Cooler

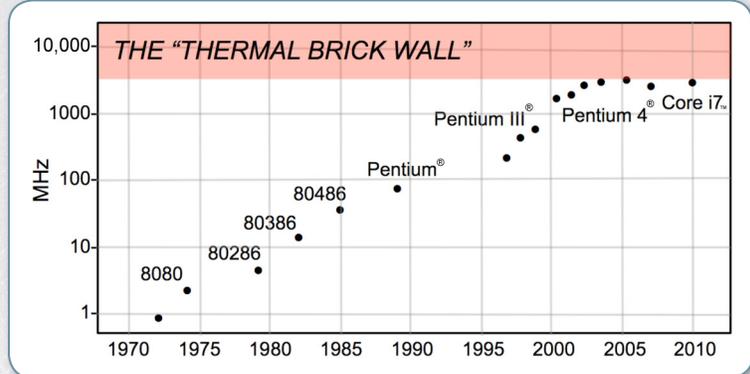
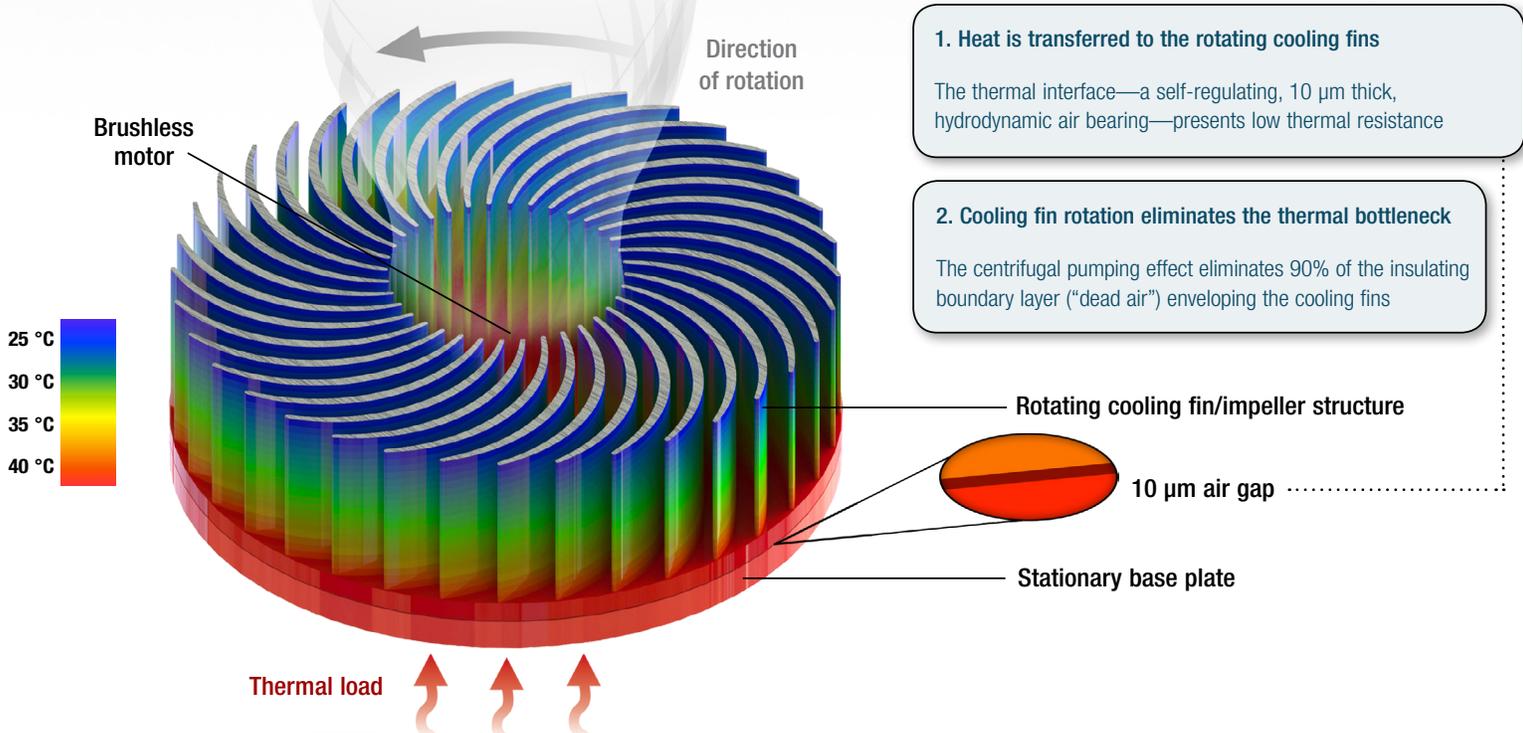
A fundamental breakthrough in heat transfer technology

EXECUTIVE SUMMARY

In a conventional CPU cooler, the heat transfer bottleneck is the boundary layer of stagnant air that clings to the cooling fins. This insulating layer is largely unaffected by the impinging airflow generated by the fan. The radically different approach described below overcomes this thermal bottleneck, generating a several-fold improvement in cooling performance in a device that is smaller, quieter, and resistant to clogging by dust.

In this new device architecture, heat is efficiently transferred from a stationary base plate to a rotating structure that combines the functionality of cooling fins with a centrifugal impeller. Dead air enveloping the cooling fins is subjected to a powerful centrifugal pumping effect, providing a 10x reduction in boundary layer thickness at a speed of a few thousand rpm. Additionally, high-speed rotation greatly reduces the problem of heat exchanger fouling. The heat-sink-impeller fin geometry is designed to cleanly separate and rejoin the flow field passing between adjacent fins. This translates to extremely quiet operation. The above benefits have been quantified on a proof-of-concept prototype.

PRINCIPLES OF OPERATION



Timeline of CPU clock speeds

BENEFITS

- Dramatic increase in cooling performance without resorting to exotic methods
- 10x smaller than current state-of-the-art CPU coolers
- Exceptionally quiet operation
- Resistant to dust fouling
- Simple, rugged, and cost-competitive design

FREQUENTLY ASKED QUESTIONS

Principles of Operation**Q: Is the thermal resistance of the air gap region large enough to be a problem?**

A: In our current 10-cm-diameter device, the dominant contribution to thermal resistance is heat transfer between the fins of the heat-sink-impeller and the surrounding air. Because the air gap area is very large (80 cm²) and the air gap distance is very small (5 to 10 μm) the thermal resistance of the air gap region is low (0.02 to 0.05 C/W depending on device settings). We are currently investigating techniques for increasing convective transport in the air gap region, and we are designing a larger-volume device intended to provide 0.05 C/W CPU cooling.

Q: How does a hydrodynamic air bearing work?

A: A video of a very rudimentary hydrodynamic air bearing is available at <http://youtu.be/ed3uWxV2tXg>

Q: Does the stationary base plate simply consist of a solid piece of thermally conductive material?

A: As in a conventional forced-convection heat sink, the base plate acts as a heat spreader, and may comprise a solid piece of thermally conductive material or a vapor chamber heat pipe.

Q: Is the radial-air-flow architecture depicted here the only possible device geometry?

A: No—a wide variety of device geometries are possible, including axial-flow configurations, and devices in which more than one rotating cooling fin/impeller operate in parallel to further lower thermal resistance.

Q: Is the heat-sink-impeller shown on the previous page your current-generation design?

A: No. We are now using more advanced designs based on detailed CFD modeling and laboratory measurements that provide much better performance.

Real-World Practicality**Q: Can the device be mounted in any orientation?**

A: Yes. In the radial direction the heat-sink-impeller is directly supported by a long life roller bearing assembly. In the axial direction a spring-loaded mechanism is used for retention of the heat-sink-impeller and preloading of the hydrodynamic air bearing.

Q: In your current version of the Sandia Cooler, what is the volumetric flow rate of air?

A: Under typical operating conditions, our current device has a free-delivery volumetric flow rate of 1700 L/min (60 CFM) and a maximum pressure rise of 100 Pa (0.4 in-H₂O). The impeller design and rotational speed can be altered to achieve higher or lower flow rates and pressure rises if desired.

Q: Is an air bearing suspension mechanically stiff and rugged?

A: Yes—because the rate of change of the pressure lifting force with respect to gap distance is extremely large. A spring constant of order 1 N/μm is typical.

Q: What other types of equipment use air bearings?

A: Devices range from hard disk read-write heads to large CNC milling machine spindles.

Q: What if small (less than 10 μm) particulates are somehow introduced into the air gap region?

A: Such particulates would be entrained in the rotating flow field of the air gap region and centrifuged out of the air gap region because they are much denser than air.

Q: How do you prevent contact between the air bearing surfaces at low rpm?

A: During startup and shutdown there is a brief period of time (of order 1 second) during which the heat-sink-impeller and base plate are in sliding contact. We use a low-cost ceramic anti-friction coating with an extremely low wear rate to protect the air bearing surfaces.

Q: I watched the video of the older version (v4) of the Sandia Cooler at <http://youtu.be/JWQZNXEkaU> that Sandia prepared for the 2012 R&D 100 award competition. Have you now implemented the silent brushless motor to address the noise problem?

A: Yes. In version 5 the brushless motor noise is negligible and the rotor cavity is completely sealed.

Q: When are you going to show data for CPU overclocking performance?

A: Soon. We are putting together a test bed with 3 identical Core i7 processors, one equipped with the stock Intel CPU cooler, one with a Noctua NH-D14 cooler, and one with our version 5 Sandia Cooler.

Q: Have you made measurements of acoustic noise yet?

A: Because the device is very quiet this hasn't been our top priority. But we are planning to make detailed acoustic measurements in an anechoic chamber in the coming months.

Q: Some people have speculated that the rotating heat-sink-impeller, which is made of aluminum and looks kind of like a circular saw blade, might be dangerous (e.g. to fingers). Is this true?

A: Because of the backward-swept and rounded-edge geometry of the fins, placing your finger in contact with the rotating blades at 2500 rpm feels like running your finger along a picket fence. And in an actual production device a metal grill would be included to prevent anything from coming into contact with the rotating heat-sink-impeller.

Manufacturability**Q: Does the 10 μm air gap require that the entire mechanical assembly have tight manufacturing tolerances?**

A: No—the hydrodynamic air bearing gap distance is passively self-regulating.

Q: Is the surface quality/flatness spec of a conventional heat sink mating surface adequate?

A: Yes. We fabricate our heat-sink-impellers the same way that many other companies fabricate conventional heat sinks: cold forging (to ensure very low fabrication cost) followed by CNC machining of the bottom surface.

Performance**Q: I read several news articles online that claimed that the Sandia Cooler was “30x more efficient” than conventional CPU coolers. Are they referring to the fact that the Sandia Cooler transmits ~30 times more heat per unit fin surface area than a typical CPU cooler?**

A: That is correct. This 30x figure tells you that the device architecture of the Sandia Cooler is very effective at reducing the thermal resistance of the heat sink boundary layer.

Q: Based on laboratory testing of early prototype devices, what level of performance is expected for a CPU cooler based on Sandia's air bearing heatexchanger principle?

A: Current generation devices based on a heat-sink-impeller diameter of 10 cm and a total package height of 5 cm will likely be spec'ed at 0.10 C/W and a power consumption of 5 W. Our aim was to provide cooling performance comparable to a Noctua NH-D14 CPU cooler in package volume 1/10 the size. We then plan to develop somewhat larger-sized devices spec'ed at 0.05 C/W. Because low-thermal-resistance CPU coolers are particularly susceptible to performance degradation due to cooling-fin fouling (a thin layer of dust can easily increase thermal resistance by a factor of 2), the added benefit of resistance to fouling is also a crucial performance specification. Further reductions in thermal resistance would likely involve engineering trade-offs against device size and dBA rating.

For more information contact:
ip@sandia.gov or (505) 284-2001



Sandia National Laboratories

