Evaluation of Forced Physics Joule-Force SP5 Cooler

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Preamble

This brief report is written in my capacity as a Technical Consultant for Forced Physics. I was asked to evaluate the cooling performance of a Forced Physics Cooler used to cool an AMD SP5 socket by repeating some of the experimental measurements that were made by the Forced Physics team to evaluate repeatability and secondly by critically examining experimental data reported by Forced Physics in its development of the SP5 prototype. I was given access to a prototype for testing, and sufficient information about the design and construction of the device so as to understand its basic physics.

Summary

The SP5 cooler that I evaluated is shown in Fig. 1 which shows the device mounted onto an electrical heater block. In principle, the cooler is a suction device that sucks air through a microchannel fin array. The fin array is thermally connected to a vapor chamber which conducts heat from the heat source at the base of the device. The unique design of the device combines flow suction (rather than blowing) of cooling air, a highly dense engineered fin array, and a method for efficiently transporting the heat from the heat source to the fin array. The device demonstrates thermal performance that significantly exceeds the performance of advanced air-cooled heat sinks of conventional design, as is demonstrated by laboratory data.

The base of the cooler is a metallic base which conducts heat into a vapor chamber. The vapor chamber transports heat upwards on the long sides to a vertical member which forms the base for an array of microchannel fins. In Fig. 1, the microchannel fin array is located beneath the gray cap. The vertical member conducts heat to the base of the microchannel fins. The gray cap on the top of the fin array is an open chamber that is sealed against the fin array. The top of the chamber is connected to a tubular pipe that is connected to a suction hose. Air suction on this open chamber "pulls" air through the fin array. The air enters through a channel at the base of the fin array which is open on both sides of the device.

Two physical mechanisms are apparent in the device which contribute to its superior performance: (1.) extremely high surface area for heat rejection to the air, and (2.) a cooling of the air as it enters the device due to the well-known Joule-Thompson effect due to the drop in pressure from ambient to the sub-ambient pressure within the device due to the suction. A third innovation is the engineered vapor chamber that transports heat to the fin array from the heat source. Other physical mechanisms in the gas at the micro-channel and molecular scale may contribute additional benefits, but these are not evaluated in this preliminary examination of the device.

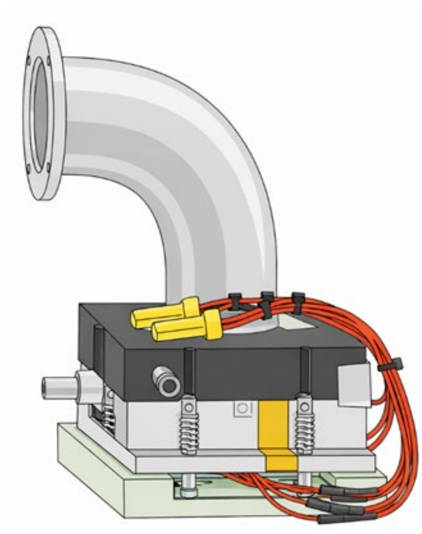


Figure 1. Illustration of Forced Physics cooler

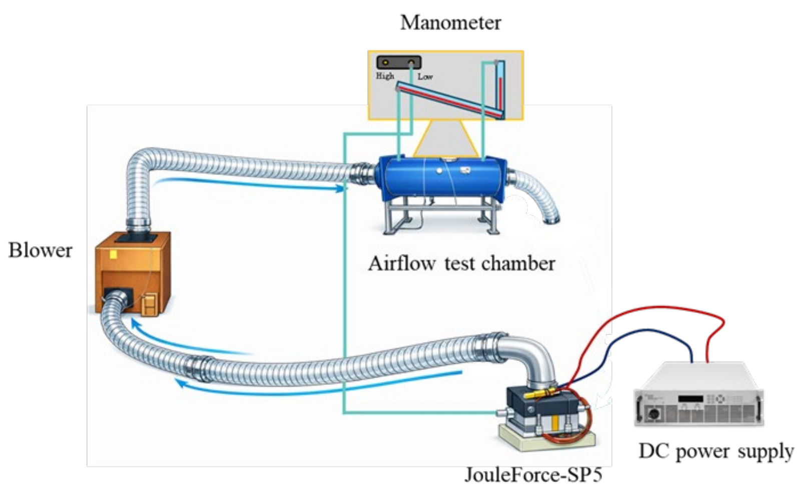


Figure 2. Schematic of test assembly at the Villanova Laboratory for Advanced Thermal and Fluid Systems (LATFS)

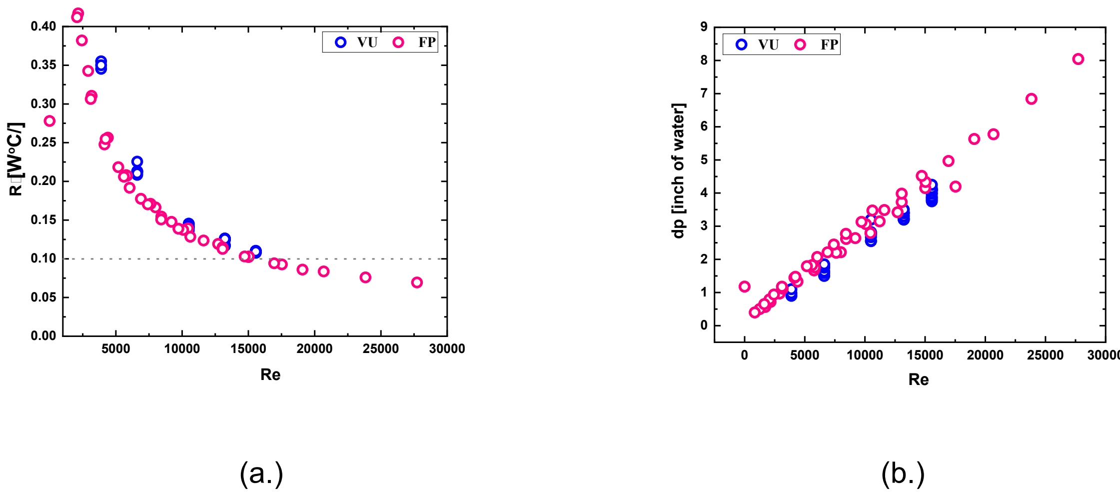


Figure 3. Comparison of Villanova laboratory data compared to Forced Physics laboratory data; (a.) Thermal resistance; (b.) Inlet to exit pressure drop across cooler

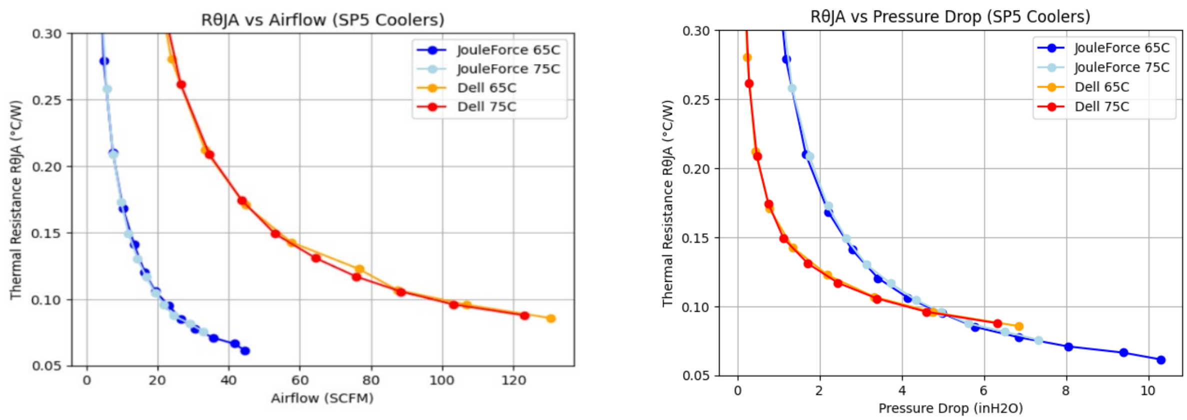
Findings

In order to independently confirm repeatability of the Forced Physics data, the prototype SP5 cooler was tested at the Villanova LATFS using the apparatus shown in Fig. 2. The SP5 was mounted on the same heater block used at the Forced Physics laboratory. A thermal interface material (TIM) Heat was supplied to the heater block by a precision DC power supply which digitally displayed the output power in Watts. The device was attached to the suction end of a centrifugal blower by a suction hose. The volumetric flow rate on the blower discharge was measured with an array of ASME nozzles located in the blue tube shown in the figure. The air temperature and the heater temperature were measured with thermocouples through a calibrated data acquisition unit. The pressure drop across the ASME nozzle and across the Forced Physics cooler were measured with a slant-tube manometer.

The experimental data taken at the Villanova laboratory matched both the thermal resistance and the device pressure drop to +/- 5% as seen in Fig. 3. The thermal resistance, which is the most common performance metric used to rate the thermal performance of a heat sink, is defined as:

$$\theta_{ja} = \frac{T_{heater} - T_{air,in}}{Q} \tag{1}$$

where Q is the heat input to the heat sink. The *Re* is a non-dimensional form of the volumetric flow rate. The thermal resistance monotonically and non-linearly decreases with flow rate as cooling capacity increases, which is the commonly observed behavior of finned heat sinks. The pressure drop increases monotonically with flow rate as is also commonly observed in flow through finned heat sinks. Figure 4 shows experimental data taken at the Forced Physics laboratory showing the cooler thermal resistance plotted against air volumetric flow rate 4(a.) and against pressure drop 4(b.) Data from a 1U Dell air heat sink of conventional design is also plotted for comparison. Figure 4(a.) shows that the Joule Force cooler achieves a remarkably low thermal resistance approaching 0.04 C/W at about 40 SCFM (standard cubic feet per minute). By comparison, the Dell heat sink asymptotes to a thermal resistance of 0.08 C/W, at greater than 120 SCFM, that is 3X the flow rate. The Joule Force cooler achieves a thermal resistance which is 50% lower with 1/3 the flow rate. Figure 4(b.) shows that the Joule Force cooler achieves comparable performance as the conventional heat sink at the same pressure drop but achieves better performance without a significant pressure drop penalty.



(a.) (b.)

Figure 4. Thermal resistance of Joule Force cooler compared to Dell heat sink plotted against (a.) air flow rate, and (b.) device pressure drop.

For reference, data are included for a high performance fine-pitch copper base-copper fin air-cooled heat sink that was thoroughly evaluated using similar methods in Dr. Ortega's laboratory at The University of Arizona, Fig. 5. The data are included as an example of the performance of a well-designed conventional heat sink without the assistance of heat pipes for example. The heat sink is similar in size to the Joule Force cooler, but the flow is forced flow from one side of the tall copper fins. A photograph and drawing are shown in Fig. 5. For this heat sink, the volumetric flow rate at the approach velocity of 10 m/s was 75 SCFM. Two sets of data are shown in Fig .6: (i.) data for a small 1 inch x 1 inch heat source that includes heat spreading in the larger heat sink base, and (ii.) data for a heat source the same size as the base, hence with no heat spreading. It can be seen that at 75 SCFM, the thermal resistance of this heat sink without heat spreading is higher than that achieved by the Joule Force cooler at 40 SCFM. However a heat sink of this type is not intended to operate on a heat source that is the same size as the heat sink base. Heat sinks are designed with a base that is larger than the heat source in order to take advantage of a larger available surface area. The data in Fig. 6 for a 1 inch x 1 inch heat source shows that the additional heat spreading resistance increases the overall resistance to 0.16 C/W at 75 SCFM, greater than the resistance achieved by the Joule Force cooler. While this comparison is not entirely rigorous since the heat source and heat sink sizes are different, nevertheless this result would be similar if they were equivalent between the two devices.

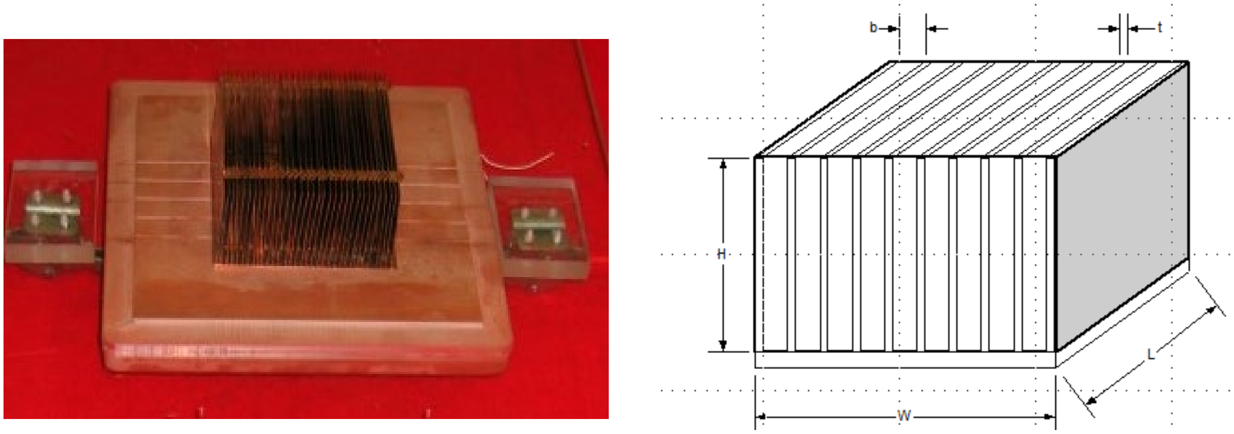


Figure 5. Photograph and drawing of high performance fine-pitch copper base-copper fin air-cooled heat sink. W=82 mm; L=90 mm; H=43 mm; b=1.5 mm; t=0.4 mm.

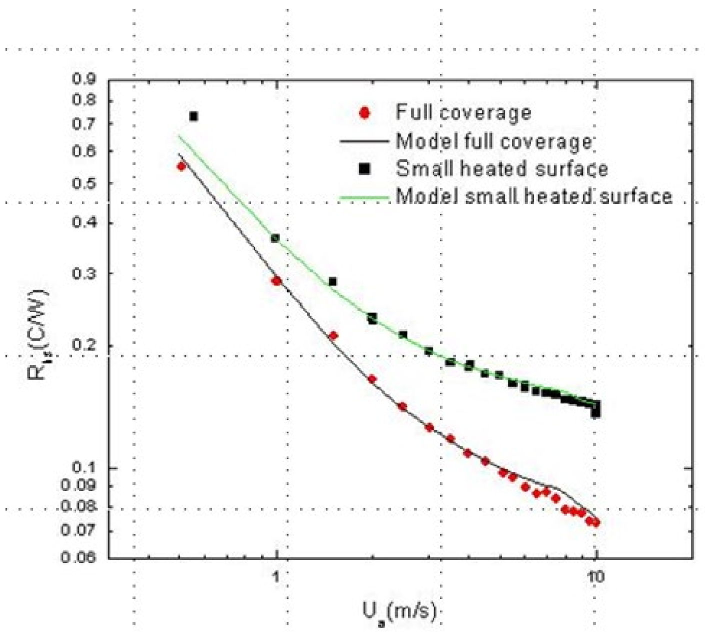


Figure 6. Thermal resistance versus approach velocity for high performance fine-pitch copper base-copper fin air-cooled heat sink. 10 m/s corresponds to 75 SCFM air flow rate

Conclusions:

1. The Forced Physics AMD SP5 Socket Test Data for thermal resistance and pressure drop was in good agreement (+/- 3-5%) with data collected at Villanova University.

2. The thermal resistance is the common metric used to demonstrate heat sink thermal performance. It indicates the amount of power that the heat sink can dissipate while maintaining the design heat source temperature at its target. The Joule Force cooler was able to achieve a thermal resistance of .**06 °C/W** at 700W, 65°C junction temperature at a volumetric flow rate of 45 SCFM, in laboratory testing at Forced Physics.

3. The findings summarized here show that the performance achieved by the Forced Physics cooler is superior to air-cooled heat sinks of conventional design, including heat sinks currently used for cooling the demonstrated AMD SP5 socket and heat sinks tested in the author's own laboratory.

4. The Forced Physics JouleForce heat sink achieves equivalent die temperatures using **significantly less airflow** than traditional air-cooled solutions. This translates to a **reduction in energy consumption**, representing a fundamental improvement in watts per SCFM.

5. The JouleForce heat sink achieves superior thermal performance at significantly lower flow rates but without a significant increase in pressure drop. This means that the superior performance is achieved with a reduction in pumping power to deliver the flow.

6. Conventional air-cooled solutions typically reach thermal constraints in the range of **350–400W**. In contrast, JouleForce continues to scale efficiently beyond this range while maintaining equivalent temperature targets. This effectively extends the practical limits and lifecycle of air-cooling technologies

Appendix:

Additional figures provided by Forced Physics