Application of

Air Jet Impingement in a 1-U System

As their speeds increase, the heat dissipation from high performance processors requires more innovative cooling techniques for heat removal. One such technique, jet impingement, provides one of the highest heat transfer coefficients among cooling methods. This property of jet impingement has been put to use by Advanced Thermal Solutions (ATS) in a 1-U server application. Jet impingement has also been applied to ATCA chassis.

A Ujet-1000™ 1-U chassis made by ATS was assessed in the company's thermal test lab. Four identical heat sinks were tested under conventional parallel flow and ATS' proprietary Therm-Jet™ impingement flow. The results showed a 20 to 40 percent improvement in the thermal performance of the heat sinks.

The Ujet-1000 is a 1 to 2 KW 1-U chassis system (depending on component case and ambient temperature) designed for the most demanding, telecom and server applications. Lab tests demonstrated that four heat sinks on four simulated chips located on a PCB achieved 0.16 to 0.18°C/W thermal resistance. The power dissipation of each simulated component was maintained at 200 W. On the other hand, the thermal resistance of the same heat sinks with parallel flow, using the same fans, was almost 20 to 40% worse.

The new ATS Therm-Jet technology uses a specially made duct with an impingement plate beneath it to create jet impingement on top of the components and heat sinks. The tremendous increase in heat transfer coefficient leads to significant reduction of thermal resistance compared to the other conventional 1-U systems. A Therm-Jet system can be built for any specific configuration. The impingement duct is less than 5 mm thick and is located in the chassis on top of the motherboard. In addition to high heat transfer coefficient, fresh air is distributed between all heat sinks at inlet temperature. In contrast, in conventional cooling systems, the upstream heat sinks and components receive air at inlet temperatures which are cold and gradually warm up as the air moves downstream. The increase of air temperature effectively reduces the cooling effect of the air downstream. The other advantage of Therm-Jet is that there is no need to make a special duct for each heat sink, thus freeing the motherboard for other components. Even by adding ducts, other components such as memory cards, resistors and capacitors located upstream of the heat sinks on the PWB would deprive the heat sink of the flow at its most critical point, which is close to the base.

Figure 1 shows a CAD drawing of the real system under test. The cooling is provided by eight 40 mm high capacity double fans located in the midsection of the 1-U chassis. The power to the heat sinks was provided by four heaters attached below and dissipating 200 W each. The heat dissipation of the power supply was simulated by attaching a rectangular heater strip under the power supply which dissipates about 100 W. A "U" shape frame made of aluminum was located under the hard drives. The power of four hard drives was simulated by placing a rectangular heater under the "U" shape frame which dissipates about 80 W. Four thermocouples were placed in holes at the center of the base of the heat sink downstream.

The holes were filled with thermal grease to minimize the interfacial resistance. Three thermocouples were attached to the aluminum "U" frame, and their average temperature was recorded as an approximate temperature of a real hard drive. One thermocouple was also attached to the base of the power supply to measure its approximate temperature. All temperature measurements were taken using J type thermocouples.

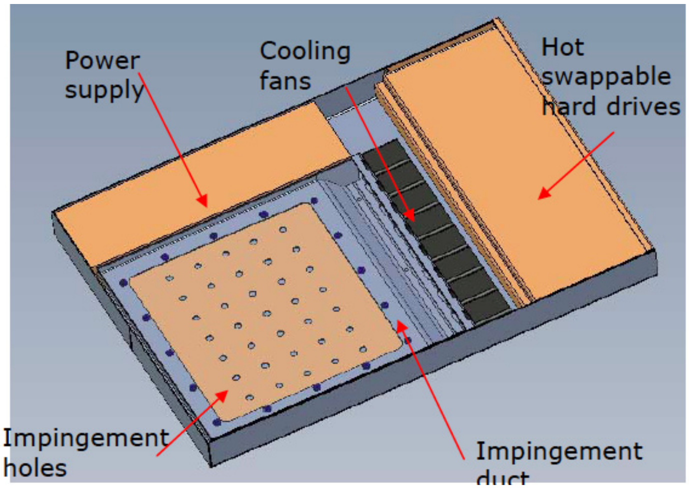

Figure 1. Schematic of the Ujet-1000™ and the Therm-Jet Cooling Duct.

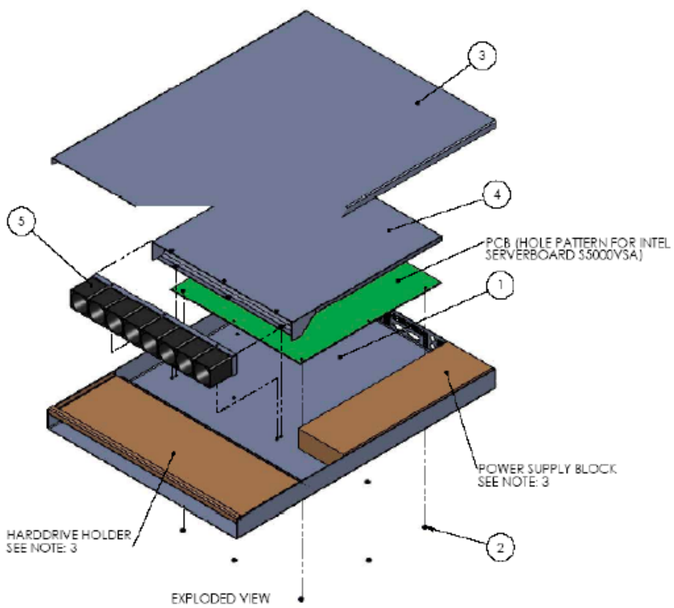

Figure 2. Exploded View of the Ujet-1000™ and the Therm-Jet Cooling Duct.

Figure 2 shows the exploded view of the Ujet-1000 chassis.

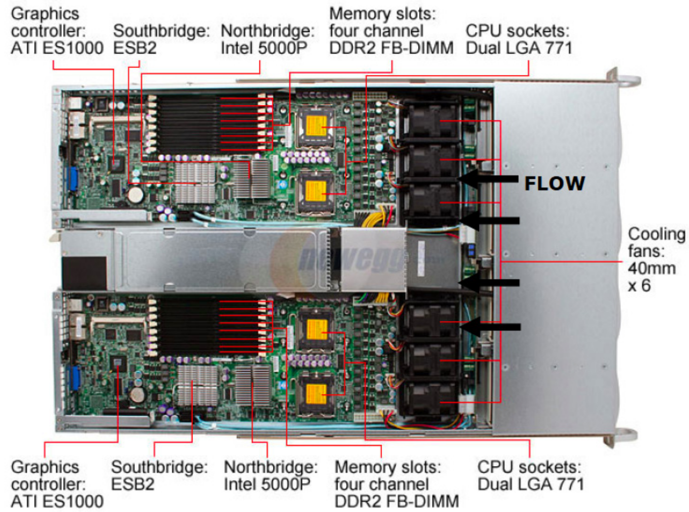

Figure 3. Conventional Cooling System in a 1-U Application.

Figure 3 shows a conventional cooling system for a 1-U system. In this system, the air flow from the fans is parallel to the heat sinks.

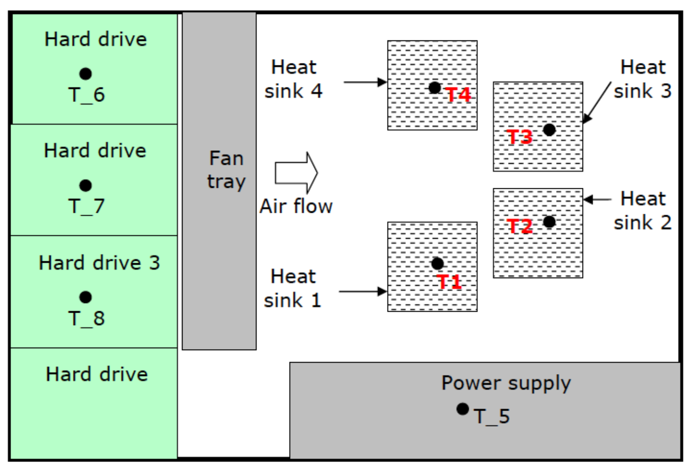

Figure 4. Configuration of Conventional Layout in a 1-U System for Temperature Measurement.

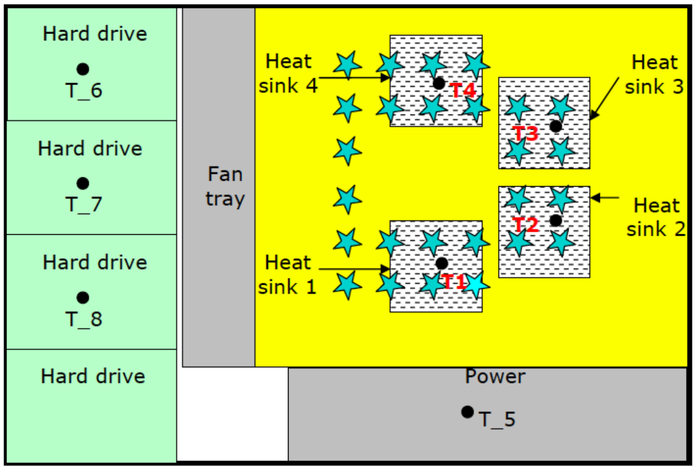

Figure 5. Configuration of an ATS Therm-Jet Application in a 1-U System for Temperature Measurement.

Layout	Fan Voltage	R_{S-1} (°C/W)	R_{S-2} (°C/W)	R_{S-3} (°C/W)	R_{S-4} (°C/W)	R_{HD} (°C/W)	R_{PS} (°C/W)	Noise (db)- 0 m	Noise- (db)- 1 m
Conventional	12	0.25	0.26	0.25	0.22	0.13	0.17	88	79
Therm-Jet	12	0.17	0.15	0.17	0.17	0.16	0.15	79	79
Therm-Jet Improvement % Over Conventional		40%	40%	33%	21%	-20%	10%		

Table 1. Experimental Test Results Comparing Conventional and Therm-Jet Results with Twelve Volts to the Fans

Layout	Fan Voltage	R_{S-1} (°C/W)	R_{S-2} (°C/W)	R_{S-3} (°C/W)	R_{S-4} (°C/W)	R_{HD} (°C/W)	R_{PS} (°C/W)	Noise (db)- 0 m	Noise- (db)- 1 m
Conventional	6	0.37	0.38	0.36	0.30	0.17	0.17	80	68
Therm-Jet	6	0.23	0.22	0.23	0.24	0.22	0.16	80	68
Therm-Jet Improvement % Over Conventional		37%	42%	35%	20%	-26%	9%		

Table 2. Experimental Test Results Comparing Conventional and Therm-Jet Results with Six Volts to the Fans.

Results

Figure 4 shows the schematic set up of the conventional cooling system. In this configuration, eight (8) blowers move the air in parallel to the heat sink fins.

Figure 5 shows the implementation of an ATS Therm-Jet, which provides jet impingement on the same four heat sinks, and the location of impingent holes with respect to the heat sinks.

Tables 1 and 2 show the experimental values obtained within a 1-U chassis made by ATS. The two sets of tests were done for both 12 and 6 volts to the fans. The thermal resistance data of all four heat sinks, hard drives and the power supply were obtained for both conventional cooling and jet impingement cases. The acoustic noise for each case was also recorded for comparison. The data shows an improvement of thermal resistance of 22% to 42% for the heat sinks from jet impingement as compared to conventional cooling. The power supply shows a 10% improvement in the thermal resistance.

The hard drive, though, shows a 20% degradation. This is due to the fact that, with jet impingement, the pressure drop on the fans increases, consequently decreasing the flow through the system. However in an actual system the percentage will be smaller. That's because the heat generated will be more volumetric compared to the current setup where heat is generated on the surface of the "U" shape aluminum piece located at the bottom of hard drives. In that case, the decrease of flow through the system will have less impact. Additionally, the increase in hard drive temperature is less than 2°C in this experiment, which is generally not large enough to be a concern.

Flow Type	Fan Voltage	HS #1 (°C)	HS #2 (°C)	HS #3 (°C)	HS #4 (°C)	Hard Drive (°C)	Power Supply (°C)
Impingement with 23.5 mm Heat Sink	12	59.8	55.6	58.4	59.2	36.8	39.7
23.5 mm Heat Sink-Parallel Flow	12	75	77	75.8	68.8	34.7	41.4
Ducted with 28.5 mm Heat Sink	12	71.9	73.8	72.6	66.1	34.7	41.4
Impingement with 23.5 mm Heat Sink	6	70.8	68	70.6	73.4	41.9	40.2
23.5 mm Heat Sink-Parallel Flow	6	99	100.2	96.4	85.6	38.1	41.8
Ducted with 28.5 mm Heat Sink	6	95.6	96.7	93.1	82.8	38.1	41.8

Table 3. Comparison of Temperatures for Jet Impingement and Parallel Flow with 23.5 mm Heat Sinks and Ducted Flow with 28.5 mm Tall Heat Sinks.

The question might be raised as to whether the performance of the heat sinks could be improved if we removed the impingement duct, increased the heat sink height by the height of impingement duct and ducted the flow. We analyzed this situation and found that the improvement would be at most 5%, if we assume that the heat sink is ducted and the pressure drop is the same in both short and tall versions. To study this problem in detail one must consider the fan curves instead of using a fixed volumetric flow rate. Interested readers will find an article in a previous issue of the ATS Qpedia eMagazine [1] with more information about this topic.

Flow Type	Fan Voltage	Heat Sink #1 (°C)	Heat Sink #2 (°C)	Heat Sink #3 (°C)	Heat Sink #4 (°C)
Jet Impingement Improvement Compared to 23.5 mm Heat Sink with Parallel Flow	12	15.2	21.4	17.4	9.6
Jet Impingement Improvement Compared to 28.5 mm Ducted Heat Sink	12	12.1	18.2	14.2	6.9
Jet Impingement Improvement Compared to 23.5 mm Heat Sink with Parallel Flow	6	28.2	32.2	25.8	12.2
Jet Impingement Improvement Compared to 28.5 mm Ducted Heat Sink	6	24.8	28.7	22.5	9.4

Table 4. Comparison of Temperature Improvement for Jet Impingement and Parallel Flow with 23.5 mm Heat Sinks and Ducted Flow for 28.5 mm Tall Heat Sinks.

Table 3 shows the temperatures of the four heat sinks, the hard drive and the power supply. As we mentioned earlier, the heat sinks were mounted on 200 W devices, the power supply was dissipating 100 W and the hard drives were dissipating 80 W. The results are shown for jet impingement and conventional parallel air flow over 23.5 mm tall heat sinks, and ducted flow over heat sinks with 28.5 mm tall heat sinks. It can be seen that heat sink temperatures are significantly lower for jet impingement even compared with a taller heat sink with ducted flow.

Figure 6 is a graphical representation of Table 4. The figure shows the significant temperature increases in the case of parallel flow and ducted flow for the heat sinks compared to jet impingement technology. Components (heat sinks) 2 and 3 are hotter than components 1 and 2 because they are downstream and the approach air temperature is higher for a ducted flow.

In the jet impingement mode, the impingement flow is at upstream temperature and therefore much cooler than the air received in ducted flow. In impingement mode, there is another flow coming axially toward the components, called cross flow. It is the interaction of cross flow and impingement that causes the cooling of the component (heat sink).

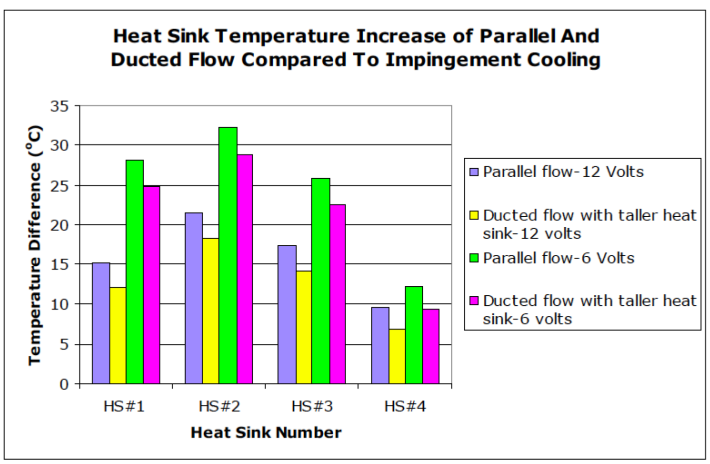

Figure 6. Heat Sink Temperature Increase of Parallel And Ducted Flow Compared to Jet Impingement Cooling.

It should be noted that the above experiment was done for a heat source that is the same size as the heat sink base; hence, the spreading resistance is zero because it is almost independent of the heat transfer coefficient. The spreading resistance can be added to the above numbers for other sizes of heat sources.

The same concept of jet impingement has been applied to simulated components in ATCA chassis. The results will be published in subsequent Qpedia articles. The data improvement is promising. Even though conventional air cooling technology is fast approaching its thermodynamic limit, there are still numerous potentials for air cooling which will enable this technology to be used in the years to come.

Reference:

1. Heat Sink Thermal Resistance as a Function of Height-Ducted Flow with Fan Curve, Qpedia eMagazine, Advanced Thermal Solutions, Inc., January 2009.