

NEWISYS SERVER PROCESSOR COOLING AUGMENTATION USING SYNTHETIC JET EJECTORS

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ABSTRACT

This paper focuses on an implementation of synthetic jet ejectors for enhancing existing fan performance by controlling the bypass flow and imparting additional momentum to the flow. Synthetic or “zero-mass-flux” jets, unlike conventional jets, require no mass addition to the system, and thus provide means of efficiently directing airflow across a heated surface. Because these jets are zero net mass flux in nature and are comprised entirely of the ambient fluid, they can be conveniently integrated with the surfaces that require cooling without the need for complex plumbing. Wind tunnel tests are used to characterize the performance of an array of localized synthetic jets cooling two high density heat sinks in the presence of varying mean flows. The increased flow rate and heat dissipation due to the jets is measured. Results show that the percentage improvement in heat transfer due to the SynJets depends strongly on the relative flow rates of the SynJet and the mean flow. A NEWISYS server chassis was retrofitted with a synthetic jet module such that no changes to the mechanicals of the chassis were necessary. Two AMD processors in the server were stressed for high heat dissipation. It is shown that operating a synthetic jet in conjunction with a fan enables higher heat dissipation due to localized cooling by the synthetic jets without impeding the flow of the fan. The high momentum SynJets enable the entrainment of significantly higher flows and heat dissipation through the heat sink than the fan alone. It is also shown the adding the SynJets enables a reduction in fan RPM for equivalent thermal performance, thus resulting in significant reduction in the sound pressure levels.

KEY WORDS: synthetic jets, jet ejector, augmentation cooling, turbulent mixing, thermal management

I. INTRODUCTION

The rise in power dissipation levels of microprocessors accompanied by a shrinking thermal budget has resulted in the need for advanced cooling technologies. The steep cooling requirements have prompted development of two-phase and pumped liquid cooling techniques and it is perceived that even consumer systems will eventually need to use fluids other than air for cooling. However, while two-phase and liquid cooling has potential for very high heat-removal requirements,

commercial, consumer-oriented systems continue to focus on air-cooling due to its simplicity [1]. Even two-phase cooling concepts need an air-side heat exchanger to dump heat into the ambient. The most common method of improving air-side heat transfer has been to use larger and more efficient fans driving higher flow rates. Since the power dissipation requirements have necessitated placing fans closer to the heat sink, the associated noise levels due to the flow-structure interaction have become an issue. Also, while fans are capable of supplying ample volume flow rate, they may be hindered by long-term reliability.

Fan based cooling systems are relatively inefficient in terms of the heat removed at a given volume flow rate. Air-jets typically have higher heat transfer coefficients and thermal effectiveness [2], but conventional air-jets are not very useful for consumer products, due to requirements of pressure supplies and conduits for directing the jets to the heat sink.

Synthetic or “zero-mass-flux” jets, unlike conventional jets, require no mass addition to the system, and thus provide means of efficiently directing airflow across a heated surface. Because these jets are zero net mass flux in nature and are comprised entirely of the ambient fluid, they can be conveniently integrated with the surfaces that require cooling without the need for complex plumbing. Synthetic jets are formed by periodic suction and ejection of fluid out of an orifice bounding a cavity by the time periodic motion of a diaphragm that is built into one of the walls of the cavity. The evolution of a two-dimensional synthetic jet has been studied in detail at Georgia Tech [3]. Although synthetic jets are formed by a train of periodic vortical structures, their far field characteristics (e.g. rate of lateral spreading and streamwise decay of centerline velocity) are similar to conventional turbulent jets.

The concept of using synthetic jets for heat transfer is relatively new. It was demonstrated that integrated cooling of single- and multi-chip modules can be achieved using synthetic jet technology [4]. They tested the effectiveness of a single 1.6 mm round jet for direct normal impingement cooling of a horizontal, 49-element MOSFET multi-chip module. At a die temperature of 100°C, a 250% increase in power dissipation was observed over natural convection. It was also shown that enhanced heat transfer from a Single

Level Integrated Module could be achieved by the coupling of local side-blowing synthetic jet cooling and a global fan-driven flow [5]. Russell used a single 2-D synthetic jet to show that a power density of 17 W/cm^2 could be achieved when the jet is coupled with a heat sink and that an order of magnitude higher flow rate would be needed to achieve comparable cooling with a global flow created by a fan.

More recently, the focus of thermal management using synthetic jets has been based on the principle of jet ejectors. The concept of conventional jet ejectors or jet pumps [6,7] has been known for several decades now. A jet ejector consists of a primary high momentum synthetic jet driving a secondary airflow through a channel as shown in Figure 1. The low pressure created by a primary jet discharging into the channel results in entrainment of quiescent ambient flow, thus creating an increase in overall flow rate at the channel exit. In conventional jet ejectors the primary jet is created using a pressure source ducted into the entry of a channel. The use of synthetic jets as the primary jet is an attractive option since the only input to the primary jet is electrical, requiring no plumbing and pressure supplies. Also, synthetic jets are attractive due to the ease of incorporating a jet module in low-profile compact geometries. During the blowing stroke of the primary synthetic jet, the jet ejector phenomenon is similar to steady jet ejectors, wherein a primary high momentum jet creates a low pressure in a channel resulting in the entrainment of fluid from the secondary quiescent medium. During the suction stroke, the low pressure in the jet cavity results in additional secondary flow entrainment, which is forced out during subsequent blowing stroke.

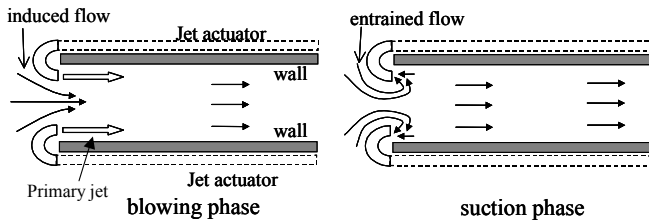


Figure 1. Basic principle of operation of a synthetic jet ejector

It has been recently shown that synthetic jet ejectors can be used effectively in a channel for driving a mean flow with high heat transfer coefficients and thermal effectiveness [8]. The same concept was also used to develop an active heat sink integrated with synthetic jets that could dissipate nearly 80W at 80°C case temperature [9].

In thermal management of servers, flow bypass of global air flow over and around heat sinks results in a significant reduction in the amount of flow entering a heat sink due to pressure drop in the heat sink. Additionally presence of other blockages upstream of the heat sink might impede the flow of cool air to the heat sink. Increasing fan speeds to enable a large flow rate in the heat sink is an ineffective means of

improving performance since flow bypass typically increases with the fan speed.

Synthetic jets have been shown to be very effective in control of mean flows in aerodynamic flow control applications [10]. A similar principle can be applied to flow bypass control as shown in Figure 2, which describes the use of synthetic jets for controlling a fan induced flow passing over an extruded heat sink. The dotted lines in the figure show the streamlines that were observed using smoke visualization. In the top figure, a fully un-ducted heat sink is subject to a fan flow that is pulling air through the heat sink. As can be seen from the streamlines a significant portion of the incoming flow tends to flow over the heat sink. Adding an array of synthetic jets upstream of the inlet to the heat sink enables controlled re-entrainment of the inlet flow to reduce flow bypass while simultaneously breaking up the local boundary layers on the walls of the heat sink.

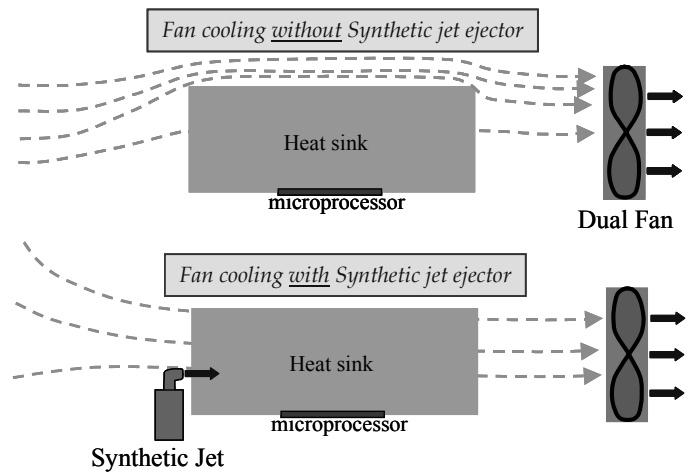


Figure 2. Visualization of flow bypass control with synthetic jets

In an uncontrolled preliminary test, the augmentation in thermal performance due to the synthetic jets for the setup described in Figure 2 is measured using a thermal die measuring 25.4mm on the side. The temperature of the die was measured using a thermocouple embedded in the case. Two test cases were compared. The control test case was with the fans cooling the heat sink and the jets removed. The comparison case was with the jets in place and operating at a fixed voltage and frequency. Figure 3 shows that the synthetic jets control inlet flow to reduce flow bypass with a resultant 24% reduction in thermal resistance. Conversely, for the same heat dissipation, fans could be operated at 5V instead of 12 V, resulting in lower fan noise and higher fan reliability.

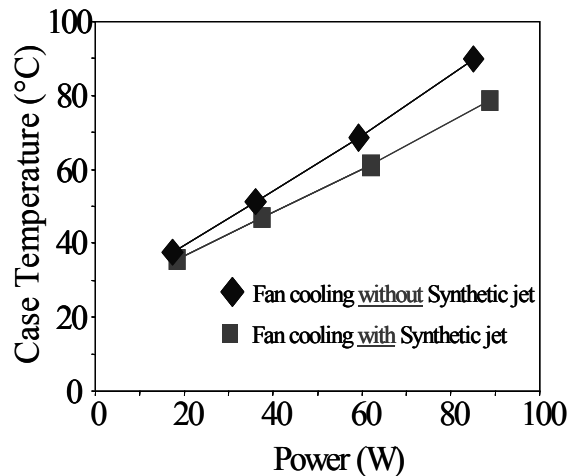


Figure 3. Effect of synthetic jet flow bypass control for a mean unducted flow

Section II discusses wind tunnel tests that characterize the augmentation in cooling due to synthetic jets in the presence of mean flows. Section III presents data from a NEWISYS server chassis retrofitted with synthetic jets. Section IV summarizes the paper.

II. WIND TUNNEL TESTS

The augmentation performance of an array of synthetic jets was characterized in a 20 cm x 20 cm low speed wind tunnel. The test section of the wind tunnel was modified to mimic the geometry of the NEWISYS server for which the jets were designed. Two AMD processors were simulated using heaters and production heat sinks from a NEWISYS server were used for the tests. The thin-film heaters were attached to the base of the heat sinks using a thermally conductive adhesive. The bases of the heat sinks were instrumented with thermocouples. The mean inlet flow to the heat sinks was measured with a hot wire velocity probe. Temperature data was recorded using data loggers. Two cases were looked at: (i) Mean flow only, (ii) jet augmentation over mean flow. Figure 4 shows the wind tunnel setup. In the figure, the flow is from left to right such that the fans are pulling air through the heat sink. For the test cases of the mean flow only, the synthetic jet is removed from the test section.

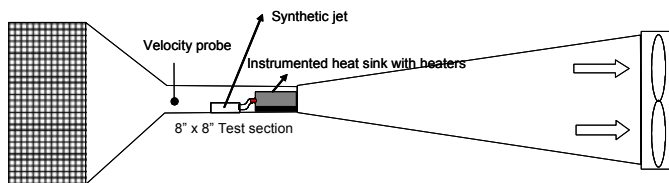


Figure 4. Wind tunnel setup

Figure 5 shows the increase the mean flow induced by the jets. As explained in the introduction section, the synthetic jets results in a jet ejector action where the slower moving mean flow is accelerated by the higher momentum of the synthetic jets. The ratio of the induced flow to the baseline mean flow

varies with baseline flowrate, going from about 1.25 (i.e., 25% more airflow) at about 300LFM to 1.08 (about 8% more airflow) at 700 LFM. The data for this plot is obtained using a jet module operating at a fixed frequency and power level. It is anticipated that there would be similar curves at other SynJet operating conditions.

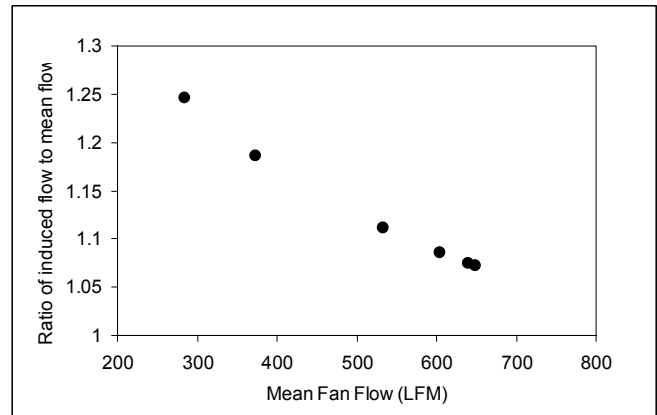


Figure 5. Increase in flow due to jets

Figure 6 shows the drop in thermal resistance on one of the CPU's being cooled due to the effect of the synthetic jets. The solid circles show the thermal resistance for the fan only case while the open circles show the thermal resistance for the jet augmentation case. Again, the magnitude of the drop in thermal resistance is a function of the baseline fan flow LFM with larger improvements at the lower baseline velocities.

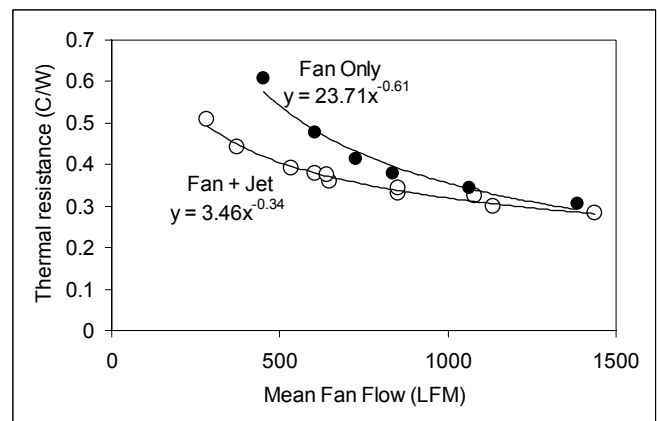


Figure 6. Improvement in thermal resistance due to jet augmentation

Figure 7 shows the percentage improvement in heat dissipated due to SynJet augmentation case when compared with the fan only case. When plotted as a function of the ratio between the jet and the baseline LFM, it can be seen that in the range of velocities tested, for every doubling of the jet speed there is about an added 20% improvement in performance. The percentage improvement in performance tapers off slowly and is expected to asymptote eventually, indicating that there exists a jet to fan velocity ratio beyond which there is no significant improvement in performance augmentation.

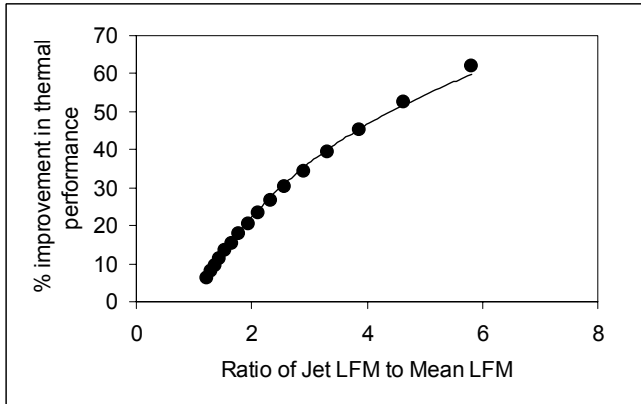


Figure 7. Percentage improvement in heat dissipation as a function of jet/fan LFM ratio.

III. NEWISYS SERVER CHASSIS TESTS

A synthetic jet assembly was inserted into a Newisys 4300 model server currently commercially available. This is a quad-socket, 3U, AMD Opteron rack-mounted server. Due to the space constraints and PCB layout within the server, two of the processors had reduced-height heat sinks which conformed to a 1U form factor, and two of the processors had full-height 3U heat sinks. The SynJet was located directly in front of these shorter heat sinks without modifying the existing server chassis architecture. Figure 8 shows the flow measured in the Newisys server chassis as a function of fan speed. The velocities are measured at the inlet to the heat sink. A fan speed of 9000 RPM represents a high thermal load case, while 5500 RPM represents an idling scenario. The inlet velocities vary approximately linearly in the range of 550 to 750 LFM over the range of fan speeds.

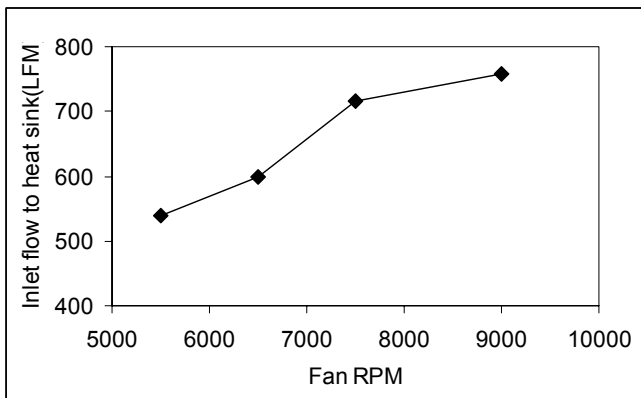


Figure 8. Mean fan flow in chassis as a function of fan RPM

Figure 9 shows the case to ambient thermal resistance of one of the CPU's with and without the jet augmentation at different fan speeds. At each speed a clear performance improvement is observed. At the idling speed of 5500 RPM the thermal resistance drops from about 0.43 C/W to about 0.35 C/W (taking the processor from 70W to 85W for a case temperature of 65C), while at the full speed of 9000 RPM, the

performance goes from 0.325 to 0.302 C/W (taking the processor from 92W to 100W for a case temperature of 65C).

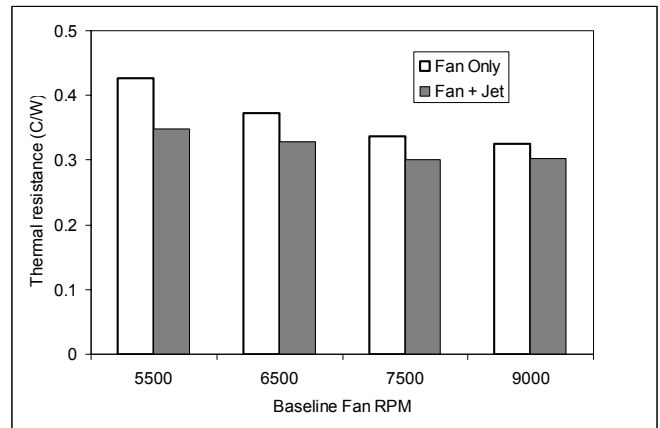


Figure 9. Decrease in thermal resistance due to the SynJet augmentation

Figure 10 shows the improvement in the noise levels to the jet augmentation. The SPL was measured in an acoustic chamber. The data shows the sound pressure level for the fan only and the jet augmentation case at the same heat dissipation level. Thus, by operating the fans at lower speed and using the jets to augment the performance of the fans, the SPL of the system was effectively dropped by about 9 dBA.

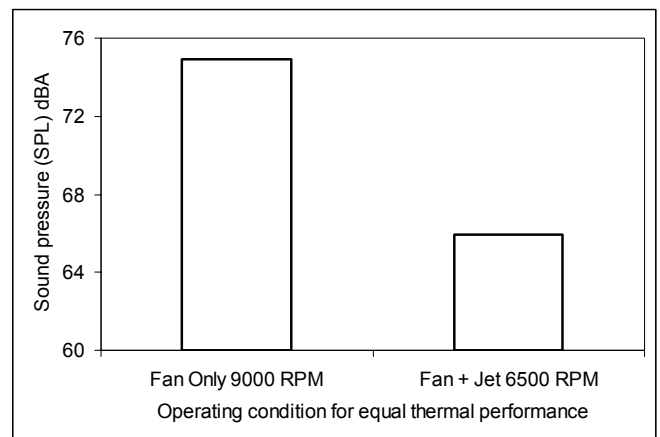


Figure 10. Sound Pressure Level Improvements due to Synthetic Jets.

In addition to improving the acoustic emissions, the addition of SynJets has the potential to improve the system reliability by enabling reduced fan speeds. Reducing the system fan speed will greatly affect the system reliability by reducing wear of mechanical fan components, by reducing the rate at which airborne contaminants foul the system and the fan, and by reducing vibrations on the system imposed by the fan.

The predominant failure mode during normal fan operation is accumulated damage to the bearing surfaces resulting in loss

of axial and rotational bearing control over time, leading to loss of performance and increase in noise until the fan stops working. Assuming constant load, the life time of a fan reduces exponentially with the rotational speed [11a]. By extrapolating the specific parameters provided in the NIDEC reference [11b] as an example, one can estimate that a fan with a given life time, L , at 9,000 rpm may extend its life time at 6,500 rpm over 3 times, using the data of models E3439X ($X=2,3,4,5,6,7,8,9$):

$$\text{Log}(L) = f(T) - \text{const} * \text{speed}$$

where $f(T=50\text{ }^{\circ}\text{C}) = 5.31$ and $\text{const} = 2.15 \times 10^{-4}$

IV. CONCLUSIONS

This paper discusses the concept and practical implementation of the use of synthetic jets to augment a fan cooled heat sink in a server environment. It is shown the synthetic jets can augment the cooling provided by a global fan flow by reducing flow bypass. Results in a controlled wind tunnel test showed the using jets to augment fan flows resulted in a 10 to 25% increase in induced flow and 10 to 50% increase in heat dissipated. The heat dissipation is related to the increased flow as well as the pulsations induced by the unsteady jets. It is also shown that in the range of velocities tested, for every doubling of the jet speed there is about an added 20% improvement in performance. Jets retrofitted to a Newisys server chassis without altering existing mechanicals, showed a 22% improvement in heat dissipation at idle and about 8% at full speed of 9000RPM. For an equivalent thermal performance, the jets enable a 9dBA reduction in the sound pressure level and a significantly higher system lifetime estimate by allowing the fans to operate at 6500 RPM instead of 9000 RPM.

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