SynJet Augmented Cooling for Cloud Computing

Raghav Mahalingam

The Evolution of Computing

Cloud computers

Client computers

- Computing systems are moving in two opposing directions
  - Cloud computing that handles the heavy computing workload, data handling and processing
    - This requires high efficiency, high heat dissipation cooling of microprocessors, TCO is important
  - Portable “clients” that handle input/output and display media, such as tablets and smartphones
    - This requires low form factor, “zero” power consumption cooling to cool RF devices, video chips etc.

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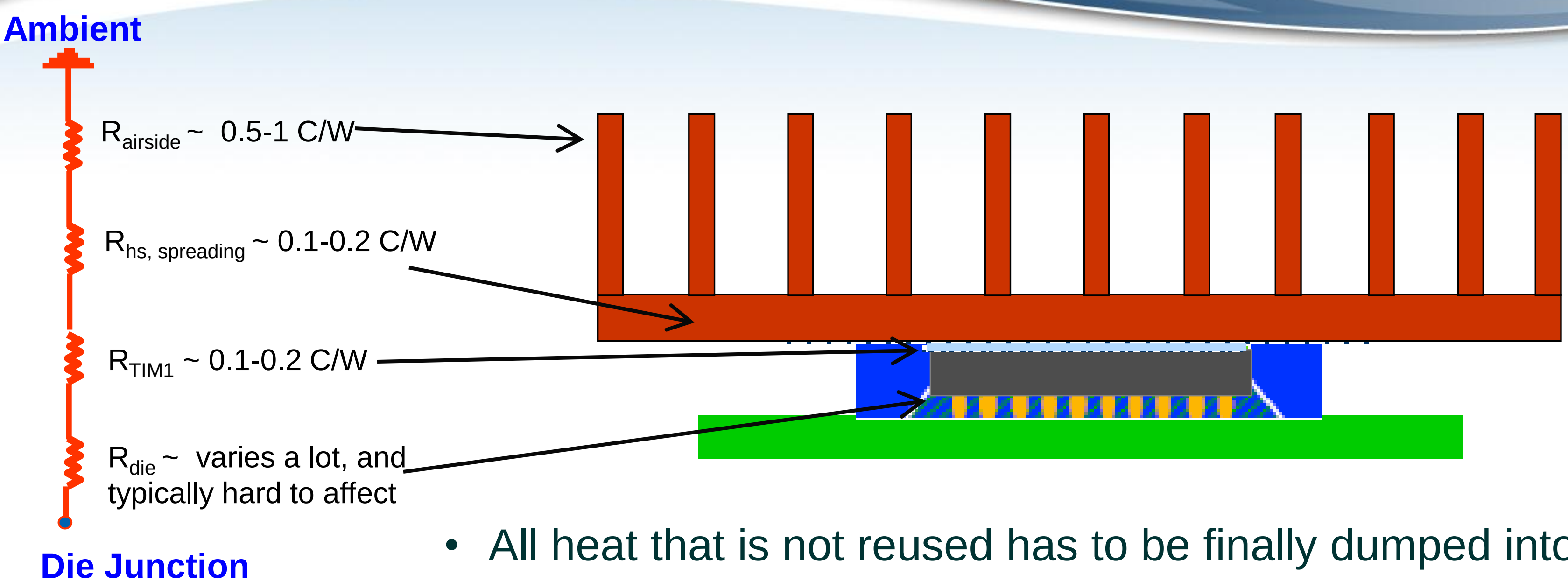
Nuventix SynJets : Next Generation Cooling

- Low flow rate, high turbulence airflow – Efficient
- Cooling systems that are whisper quiet – Quiet
- Products that are immune to contaminants – Rugged
- Lifetimes in excess of 30 years at 60 C ambient – Long Lifetime
- Low power consumption – Green

Overview

- SynJet Technology
  - Motivation for SynJets
  - SynJet principles
  - Heat transfer with SynJets
  - Standalone Chip cooling
- SynJets for Augmentation of Fans
  - Principle of localized augmentation
  - Wind tunnel experiments
  - Case study of a fan cooled server augmented with Synjets

The “bottleneck” is airside heat transfer



- All heat that is not reused has to be finally dumped into air, water or the ground
- Cooling volume ~ 100 cc
- Die size ~ 10mm x 10mm
- TIM ~ 10-20 mm^2 C/W ~ 0.1- 0.2 C/W
- Air side ~ 0.5 - 1 C/W

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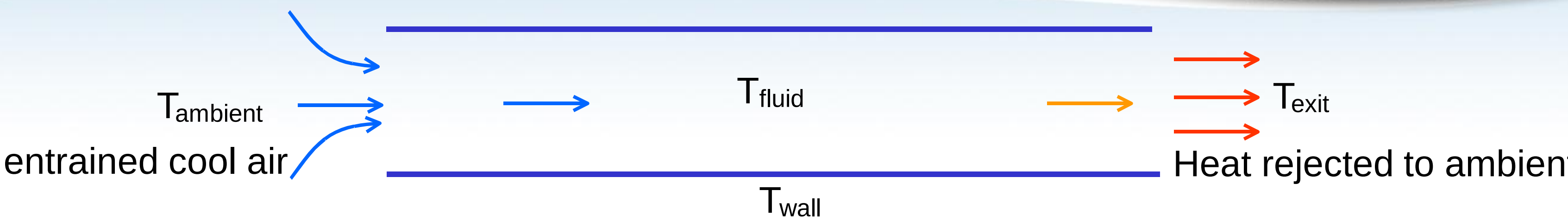
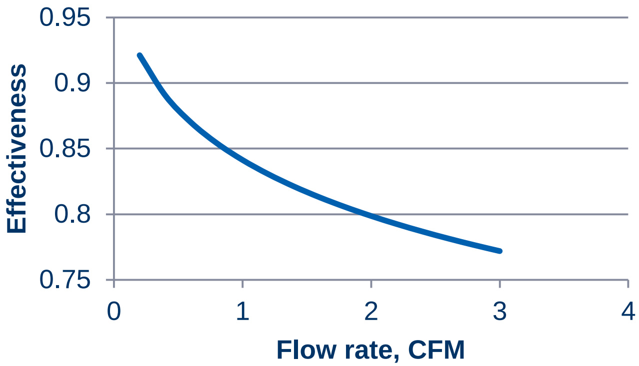
Diminishing returns on airflow



$$R_{th} = \frac{1}{\dot{m}c_p\left(1 - e^{\left(-\frac{hA_{eff}}{\dot{m}c_p}\right)}\right)}$$



- The heat exchanger model includes an effectiveness, $(1 - e^{\frac{-hA}{mCp}})$
- As mass flow increases, heat transfer coefficient doesn't increase as fast as mass flow (i.e., its less than linear)
- Thus, as mass flow increases, effectiveness decreases
- The way to increase effectiveness is to increase h at a given mass flow rate

Moffat, R., "Modeling Air-Cooled Heat Sinks as Heat Exchangers," Proc. of the 23rd IEEE Semi-Therm Conference, 2007.

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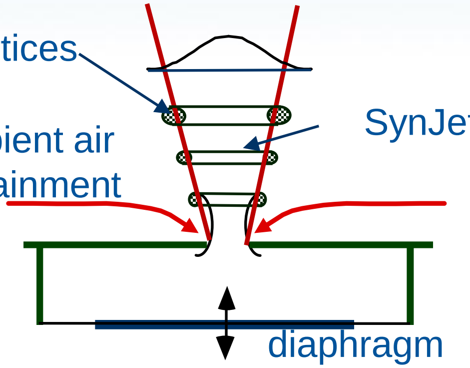
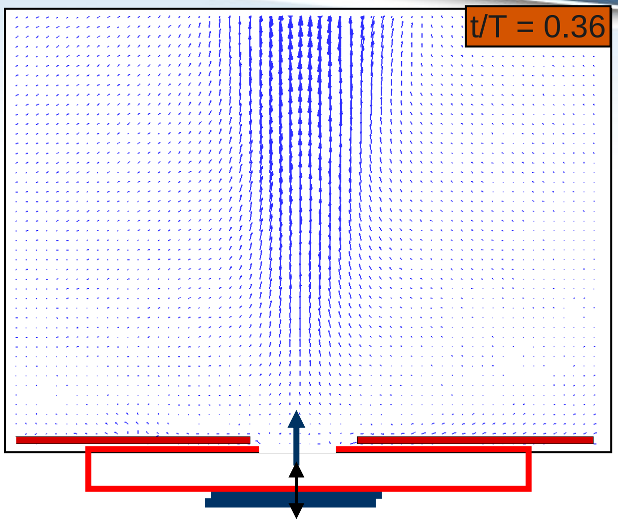
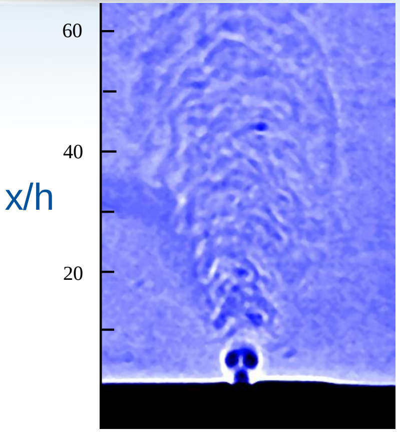
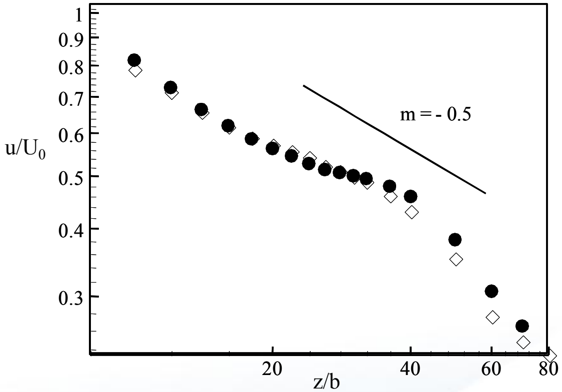
SynJet Principles







- Unsteady turbulent jet
- Operates without net mass injection
- Synthesized from surrounding fluid
- Net momentum transfer to the flow



time averaged axial velocity decay

Glezer, A., and Amitay, M., "Synthetic Jets", Annual Review of Fluid Mechanics, 2002

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Evolution of a SynJet: Velocity

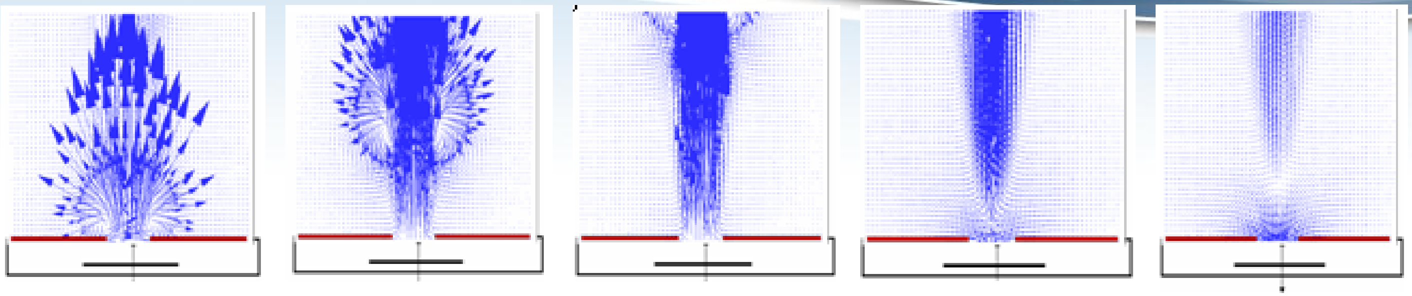

Figure 1a Figure 1b Figure 1c Figure 1d Figure 1e

- Figure 1a: The emerging pulse of air
- Figure 1b: The pulse has moved away from the nozzle
  - Note the large velocity vectors associated with the vortices accompanying the SynJet pulse formation
- Figure 1c: Pulse has moved further away down the heatsink
  - Entrained air can be seen behind it in the form of the large velocity vectors all pointing in the direction of the pulse
- Figure 1d: Tail of the pulse is seen
- Figure 1e: Pulse has almost fully left the frame
  - air can be seen recharging the nozzle in preparation for the next pulse

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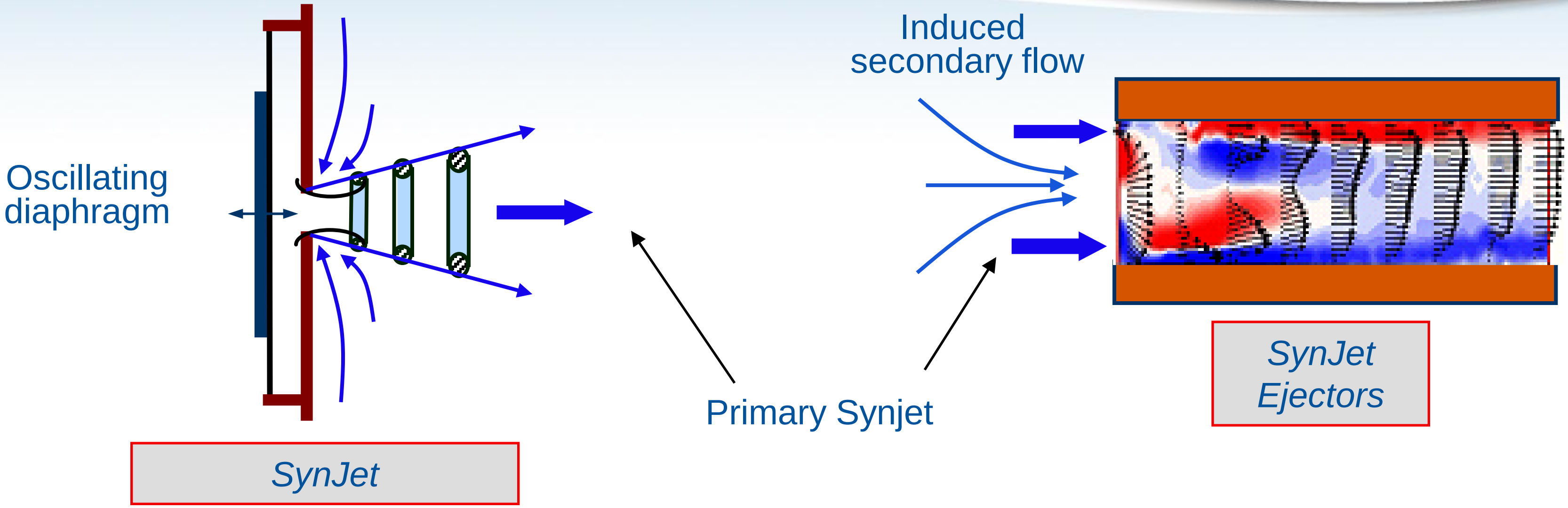
SynJet Ejectors



- High momentum primary jet “drags” along ambient air
- Significant flow entrainment by jet ejector effect
- Entrained flow up to an order of magnitude higher than jet flow
- Net momentum transfer to the flow
- Significant flow mixing

Secondary Flow Entrainment

- Smoke visualization shows entrainment effect

- The SynJet module expels high momentum pulses of air

- A low pressure area is created behind the pulse

- Nearby ambient air is pulled or **entrained** into the low pressure area and travels along with the turbulent pulse

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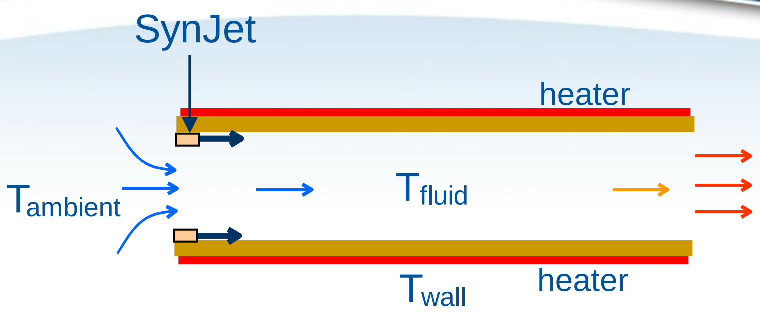
Thermal Management Metrics

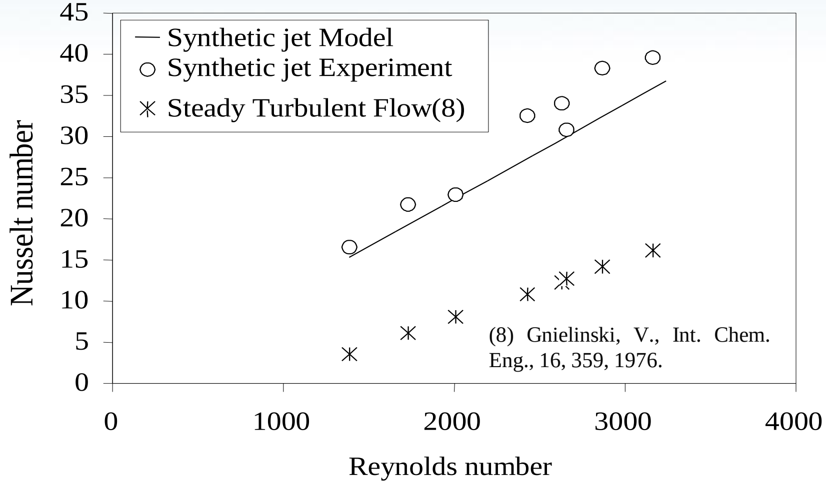
Any thermal management technology has to address multiple trade-offs

- **Thermal resistance: total heat dissipation, flux density**
- **Acoustics: loudness, psychoacoustics**
- **Power consumption: COP, controllability**
- **Reliability: MTTF, harsh environments**
- Cooling volume and weight: Smaller is always better
- Form factor flexibility
- Manufacturability

Thermal Efficiency



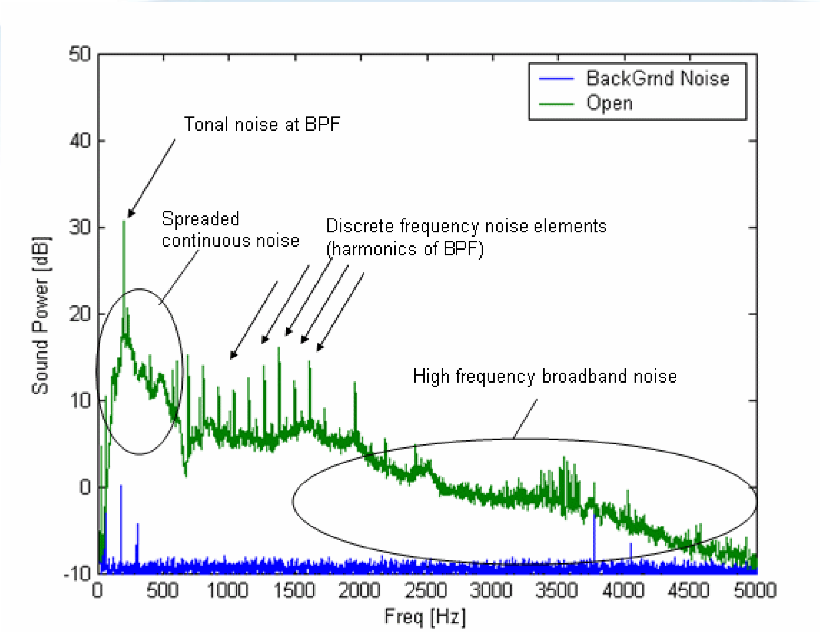
Nusselt number correlations



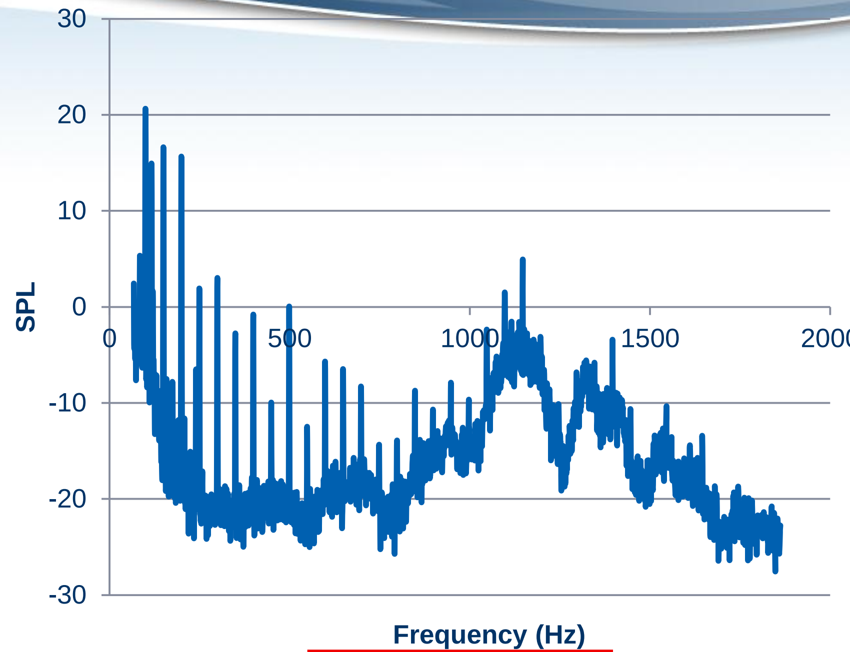
Nusselt Number, Nu = h . D / k
Reynolds Number, Re = U . D /n

- Nusselt numbers (i.e., heat transfer coefficient) for SynJet cooling in a channel much higher than fully developed, dynamically similar (i.e., same Re) steady duct flow

SynJet Acoustics



Typical 120mm fan



Typical Synjet

- Amount of air flow needed to cool the same heat load is significantly reduced
- Lower flow rates translate directly to lower acoustic emissions
- Synthetic jets have very low sharpness (high frequency noise)
- Most of Synjet tonality occurs at low frequencies, where the human ear is less sensitive

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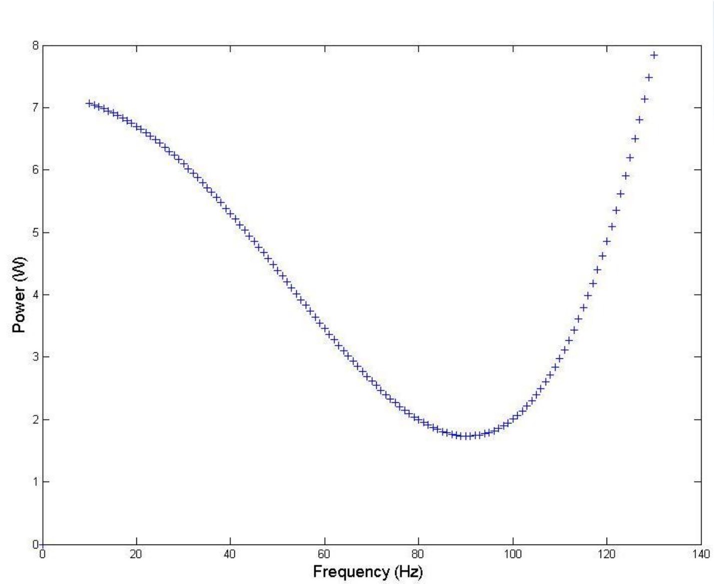
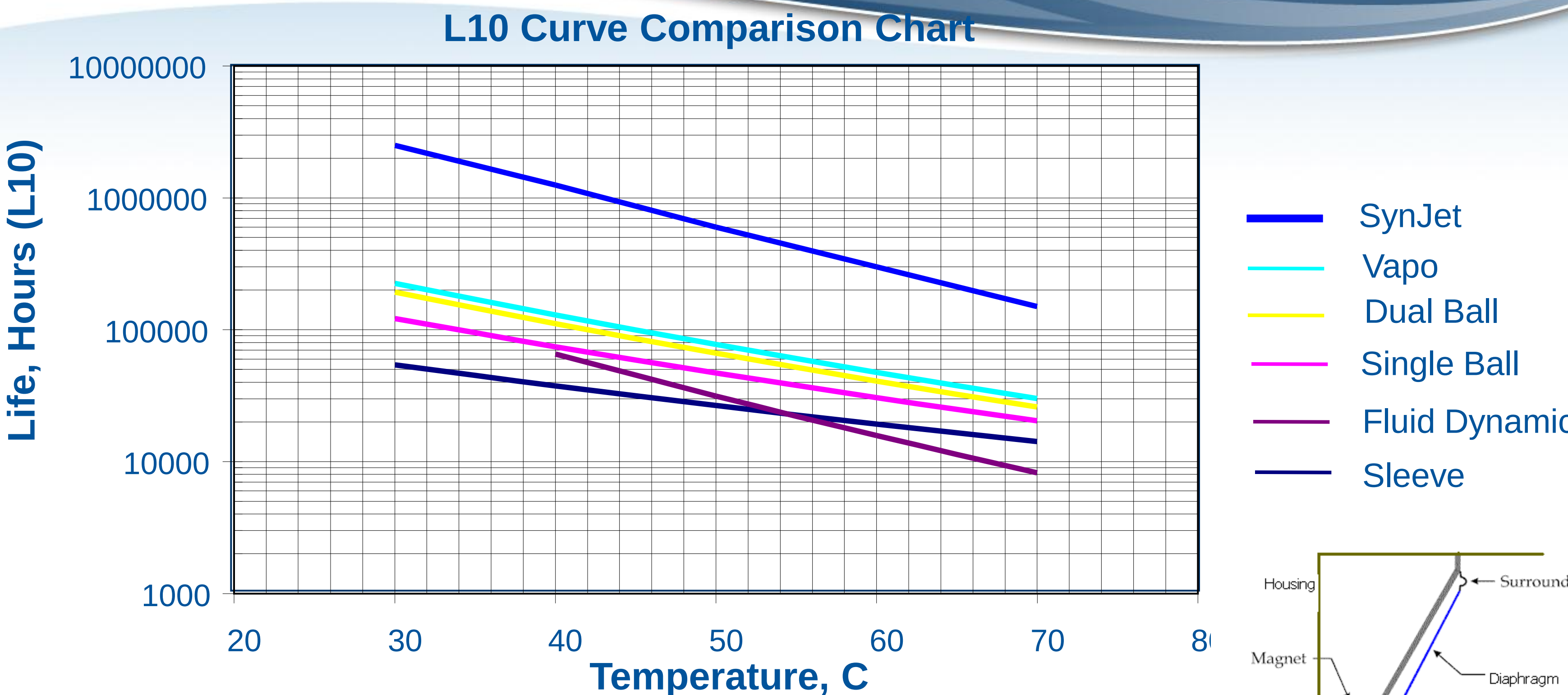
SynJet Power Characteristics

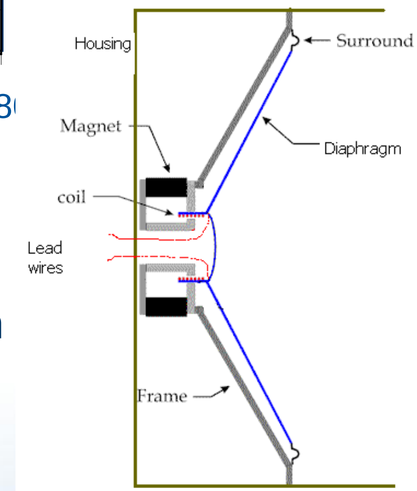


Typical Synjet Power Distribution

- SynJets are resonant systems, so the cooler can be designed to operate at resonance.
- Operating at resonance significantly reduces the power consumption of Synjets.
- For example, for a CPU type 100W heat sink, fans typically have a COP of ~ 15-20. Synjets can be designed to have COPs ~ 30-40.

SynJet Reliability





- L10 data obtained from accelerated lifetime tests.
- Achieved 300,000 hrs L10 @ 60C (34 years of 24x7 operation @60C)
- High reliability due to the fact that Synjets have no moving parts in friction

Schwickert, M., “Nuventix Reliability Report”, nuventix.com

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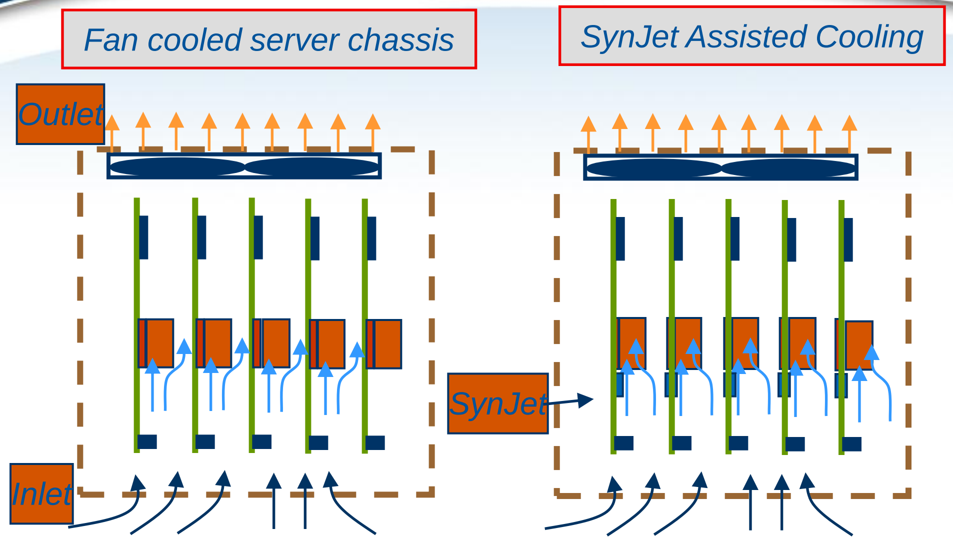
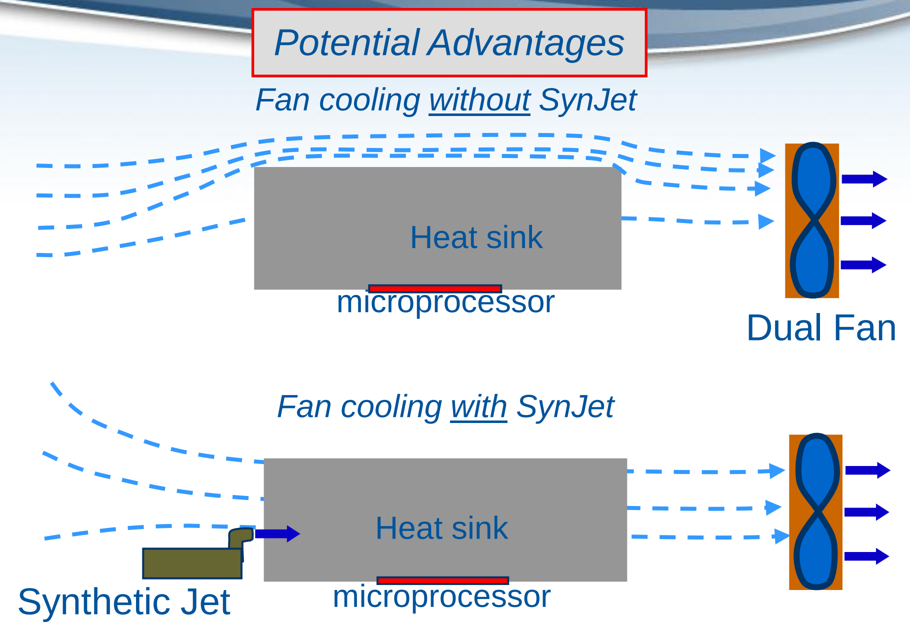
Synjet Cooled Heat Sinks

SynJet Augmented Fan Cooling

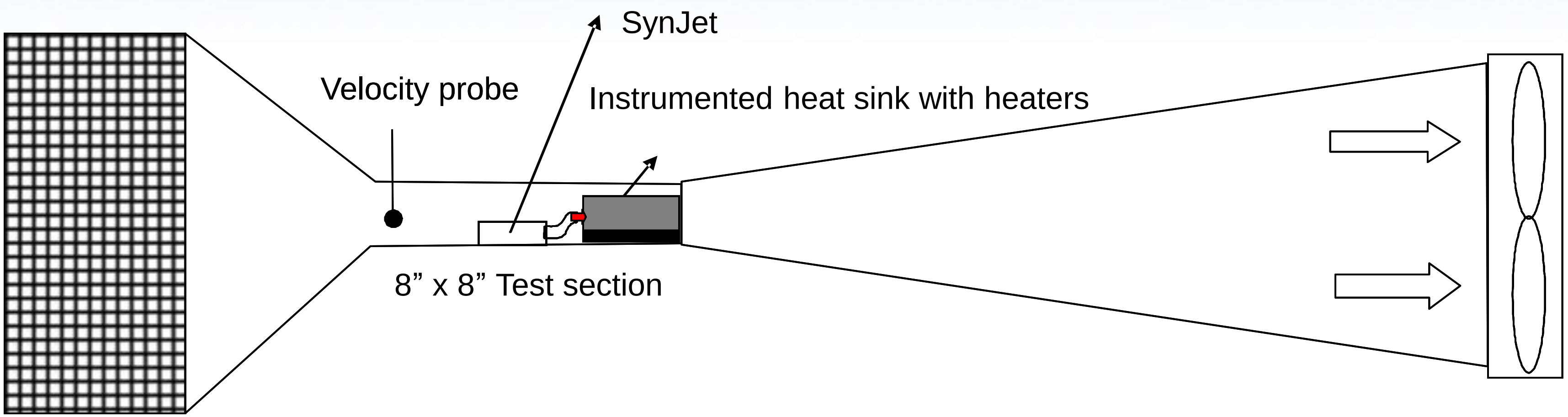
Fan Augmentation





- Smaller, lower speed fan (enables low noise, cost, better reliability)
- Increased heat transfer coefficient and flow rate through heat sink (enables higher power processor)

Experimental Setup for augmentation tests



- Wind tunnel test cross section could be varied to achieve different bypass ratios
- SynJet placed upstream of heat sink, directing airflow into the heat sink.
- Flow velocities and heat sink thermals measured

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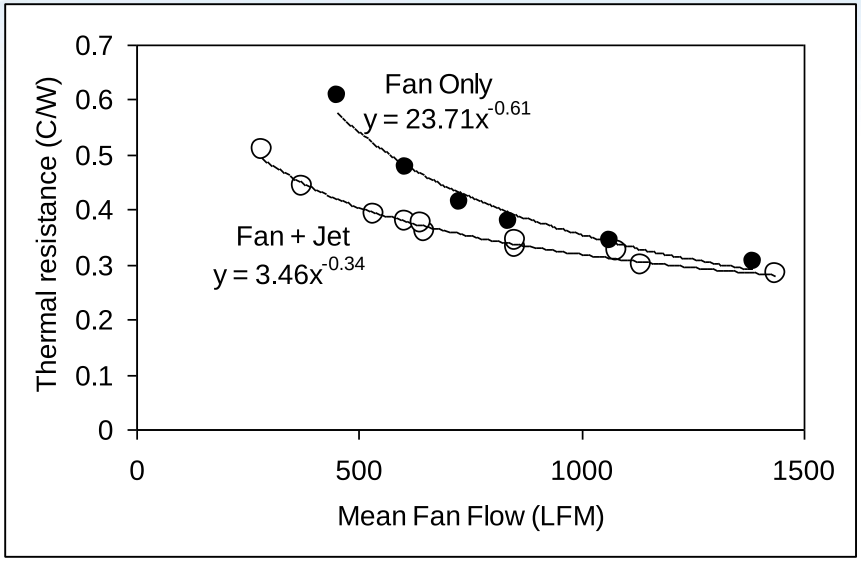
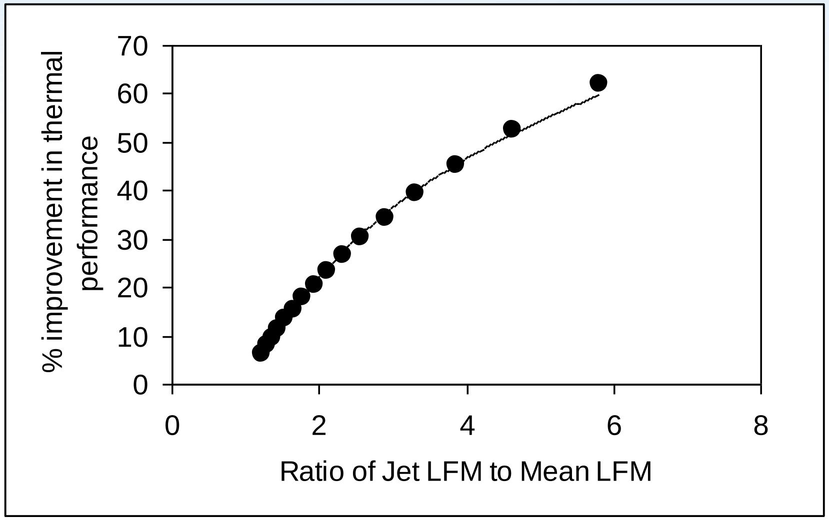
Heat transfer enhancement with SynJets



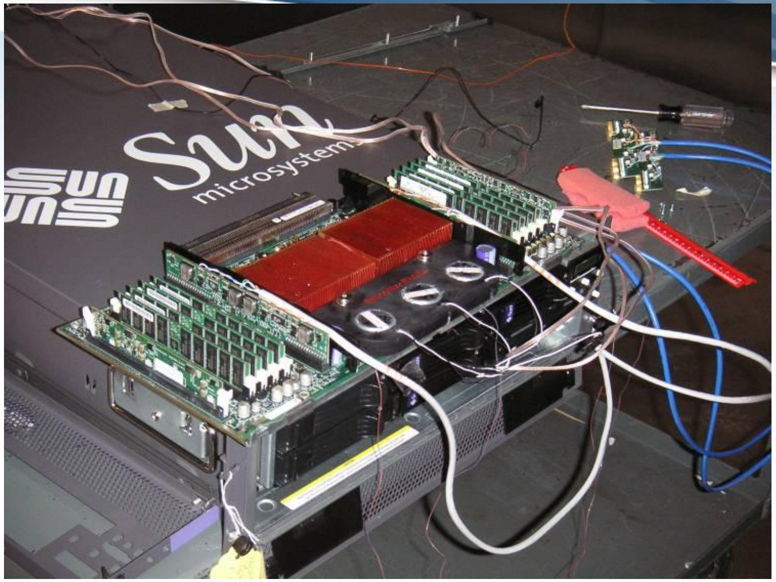
Improvement in thermal resistance due to jet augmentation



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

- Jet augmentation significantly decreases thermal resistance of heat sink
- The key metric for determining performance improvement due to jet augmentation is the ratio of the jet velocity to freestream flow velocity

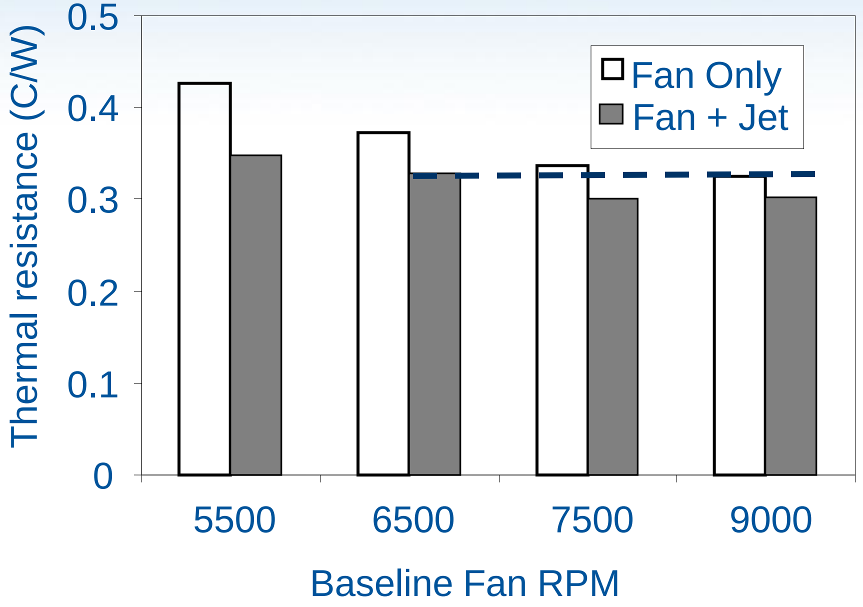
Augmentation Case Study



- 800W Newisys 4300 quad-socket, 3U, AMD Opteron rack-mounted model server
- Inlet speed varied from 560(5500RPM) to 800 LFM(9000RPM)

Performance Augmentation in Mean Flows

Improvement in Thermal Performance



Cooling System Power Consumption and Acoustics

Fan RPM	Cooling System power consumed (including Synjets)	System Acoustics (including Synjets)
9000	108W	75dBA
6500	62W	65dBA

Equivalent thermal performance

Using the synthetic jets helped reduce the speed of the system fans from 9000 to 6500RPM resulting in a

- **drop in cooling system power consumption from 108 to 62W**
- **drop in system acoustics from 75 to 65 dBA**
- **Reduction in Total Cost of Operation, due to lower power consumption**

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Effect on Cooling System Reliability

Fan Cooling Only

- Fan at 9000 rpm — λ = 58 ppm
- → Chip at 80 °C — λ = 34 ppm
- → λ_{System} = 92 ppm
- L10 = 25,000 hr

Fan Assisted Augmentation

- Fan at 6000 rpm — λ = 39 ppm
- → Fan at 6000 rpm — λ = 39 ppm
- → Chip at 80 °C — λ = 34 ppm
- → λ_{System} = 112 ppm
- L10 = 20,000 hr

SynJet Assisted Augmentation

- Fan at 6000 rpm — λ = 39 ppm
- → SynJet — λ = 10 ppm
- → Chip at 80 °C — λ = 34 ppm
- → λ_{System} = 83 ppm
- L10 = 28,000 hr

- Assumptions
  - Fan reliability ~ 40000 hours L10 or 58ppm
  - SynJet reliability ~250000 hours L10 or 10ppm
  - One main fan
  - Augmentation done with either 1 Synjet or 1 Additional Fan

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Summary

- SynJets are turbulent, unsteady jets created by an oscillating diaphragm
- SynJets provide high local heat transfer coefficients
- Localized SynJets enable increased heat dissipation from fan cooled systems
- The increased heat dissipation can be translated into lower fan speeds
- Lower fan speeds result in overall improvement in cooling system acoustics, power and reliability and potentially, TCO.

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