CFD modeling of experiment for power electronics

Daat Research Corp. white paper[1]

Plate fin heat sinks cooling encapsulated power transistors is one of the most common configurations used for thermal management of electronics. One of the difficulties associated with modeling such configurations is flow regime. Typically power electronics requires fans and the flow inside most of the enclosure is turbulent. However, inside heat sinks it is often not. Heat sinks present a considerable resistance to the flow and with unshrouded heat sinks a lot of the air bypasses them resulting in relatively low flow rate through the sink. The bypass phenomenon in addition to narrow spacings between plate fins dampens turbulent fluctuations and forces the flow to relaminarize.

Modeling mixed flows, which involve turbulent, transitional, and laminar areas is a formidable challenge. If one is to assume flow as laminar to accurately model the flow between plate fins, besides the impossibility of making such a set up to converge due to oscillations associated with turbulence outside of the heat sink, one would incorrectly model the rest of enclosure. So, one is required to use turbulence models that can correctly describe the flow environment by transitioning back and forth between laminar and turbulent regimes as flow conditions change.

In this study we used Coolit with its specially tuned turbulence models to predict flow in a wind tunnel with a flush-mounted heat sink on top of an encapsulated power transistor. The computed results were compared to experiment by Ventola et al (2016). The schematic of the experimental setup is shown in Figure 1.

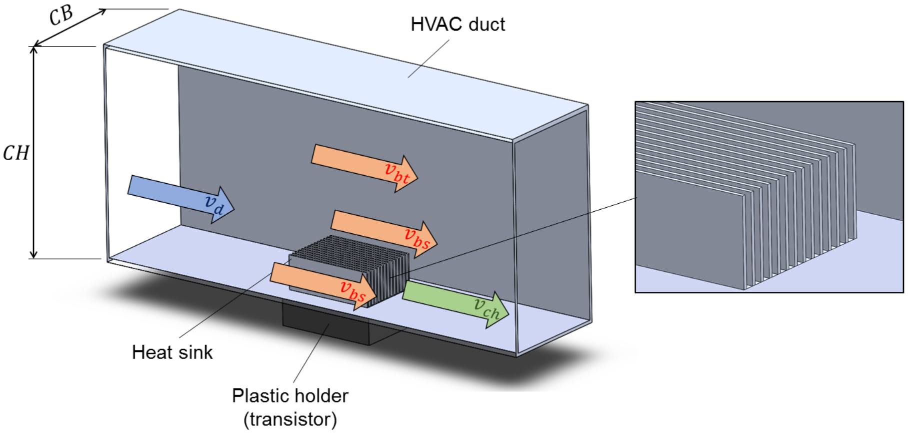

Figure 1: Schematic of the experiment by Ventola et al (2016) modeled in this work. The heat sink is flush-mounted in the wind tunnel with the heat source (power transistor) underneath.

For detailed description of the setup refer to [1]. The authors of the paper wanted to ensure that the airflow is simple enough to be described reasonably accurately using approximate analytical models, which could then be used in heat sink optimization studies. Therefore the heat sink was flush-mounted to prevent complex 3D flow patterns such as the ones shown in Figure 2 where the heat sink is mounted on top of the wind tunnel floor.

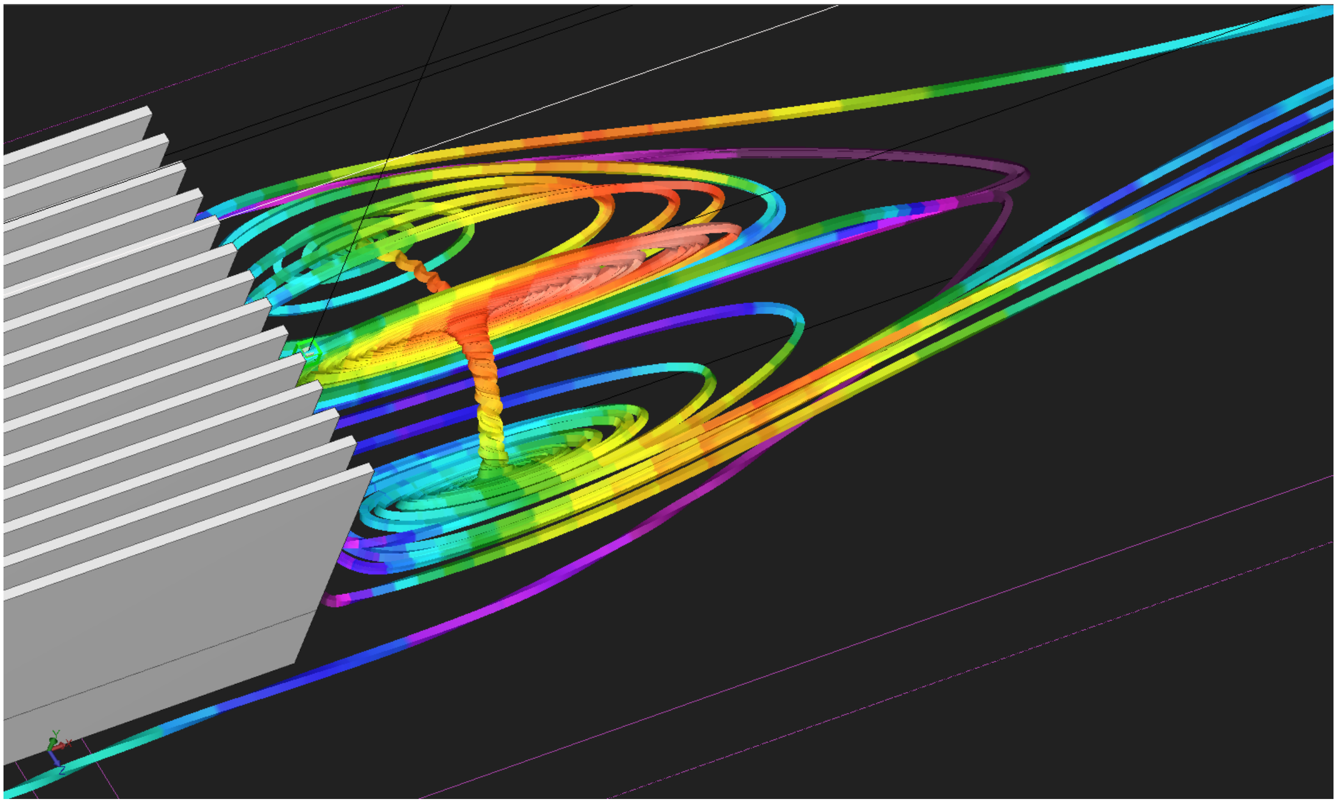

Figure 2. Vortical structure aft the heat sink calculated by Coolit. It is visualized using flow rods painted in turbulence eddy viscosity ratio. The heat sink's base in this model is on top of the wind tunnel floor.

Seven flow configurations were considered with inlet flow velocity ranging from 5.6 to 13.9 m/s and the power transistor dissipating from 56.64 W to 87.32 W. The cases presented excellent setup for this study with turbulent flow in most of the wind tunnel and with largely laminar flow between plate fins.

Figure 3 shows a cross section painted with the turbulence eddy viscosity ratio. The section includes the area between plate fins. While the free flow turbulence in this case reaches the robust 200 eddy viscosity ratio, the flow between fins is laminar with the turbulence eddy viscosity ratio close to zero.

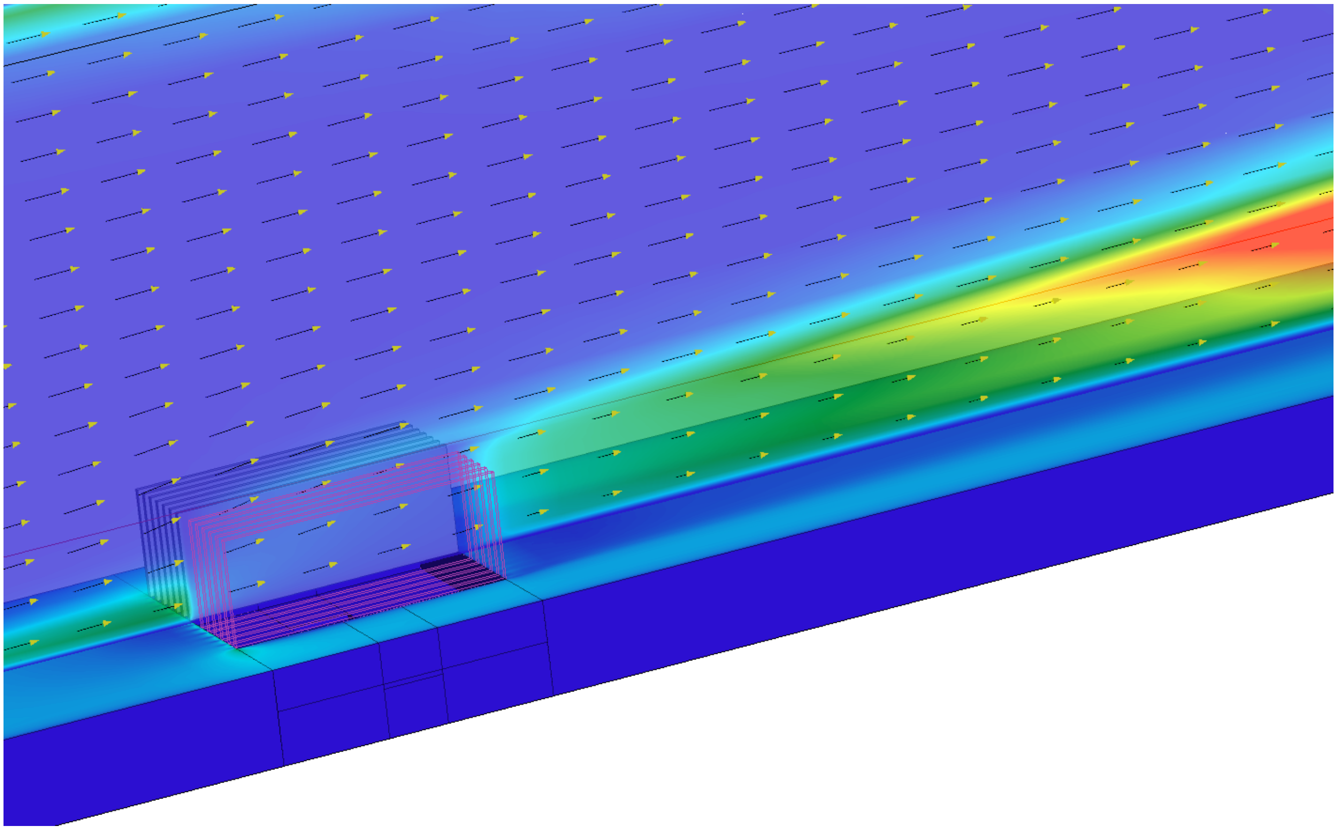

Figure 3. Section through the middle of the heat sink channel painted in the turbulence eddy viscosity ratio. Black arrows show velocity vectors. By hiding several plate fins, one can see that flow inside the sink is laminar. The turbulence ratio in the wake reaches over 200.

The case was run with several different grids to ensure grid independence of computed results. The computed and experimental results for the junction-to-air resistance, $R_{ja}=\frac{T_{junction}-T_{ambient}}{Power}$, plotted as a function of the inlet velocity are shown in Figure 4.

The computed results show good agreement with experiment - well within the experiment's margin of error stated in the paper.

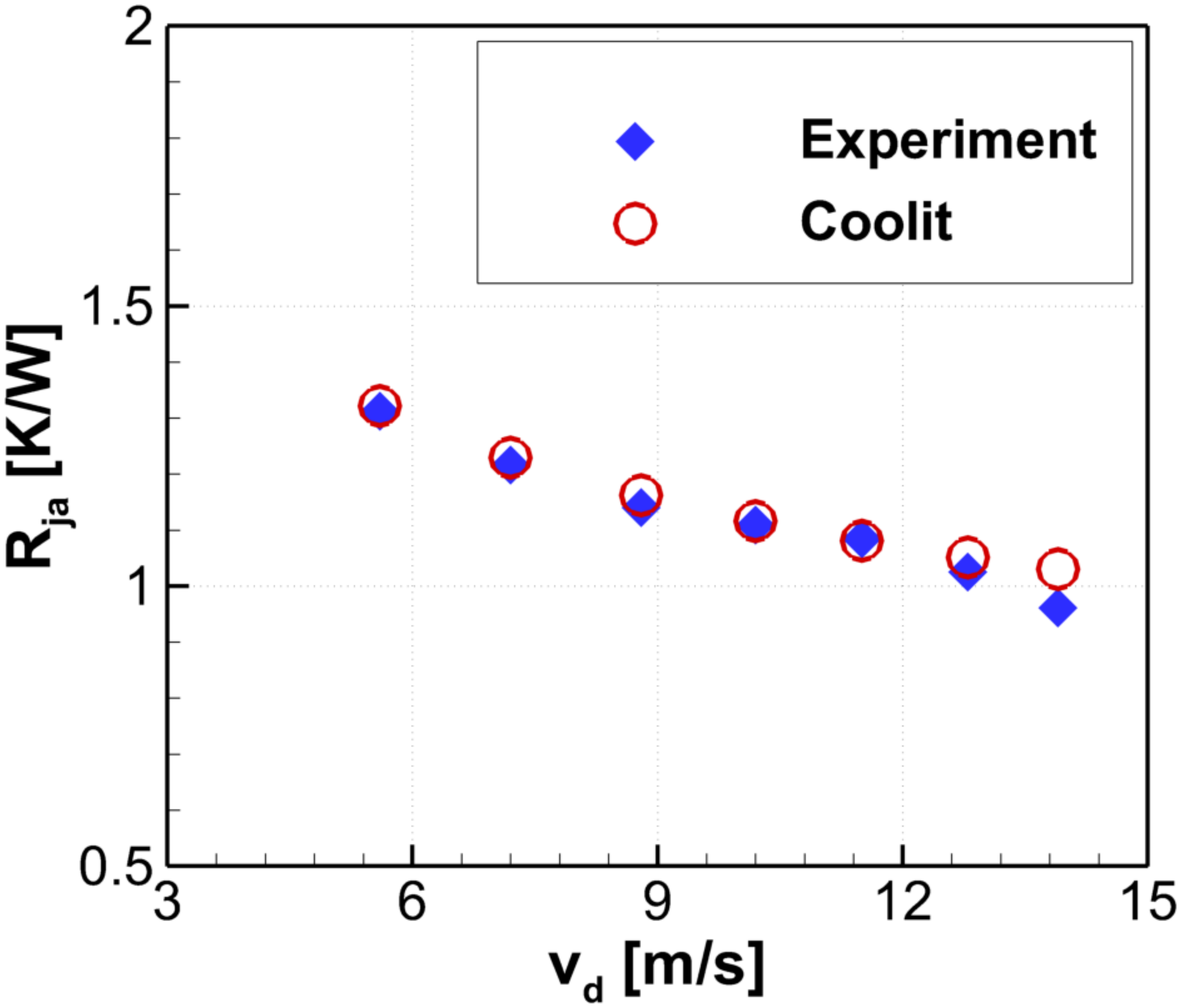

Figure 4. Experimental and computed junction-to-ambient thermal resistance as a function of inlet velocity. Experimental data are from [1].

References

1. Ventola, L., Curcuruto, G., Fasano, M., Fotia, S., Pugliese, V., Chiavazzo, E. and Asinari, P., Unshrouded Plate Fin Heat Sinks for Electronics Cooling: Validation of a Comprehensive Thermal Model and Cost Optimization in Semi-Active Configuration, Energies 8 (9), 2016.