Forced-convection air cooling of an electronics cabinet

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Introduction

A case study has been conducted in PHOENICS of the cooling of an electronics cabinet through forced convection. The cabinet is a typical server unit, inside of which is a PCB board, on which rest a number of heat-emitting chips such as would usually be found in a computer, plus a finned heatsink. A constant stream of air is forced into the cabinet through two inlets to cool the components, before exiting through an array of outlet slots on the opposite side of the cabinet.

A simple CFD simulation was run in PHOENICS to study the air flow and heat distribution inside the cabinet, with especial interest on the temperatures of the components. A number of simplifying assumptions were made for this case study.

The PHOENICS CFD model

Modelling Assumptions and Strategy

The energy equation was solved for temperature without radiation, as the effects of radiation were deemed to be small enough to neglect for an initial study. The flow is turbulent, and the Chen-Kim two-equation k-ε turbulence model is used in the simulations. However, an estimation of the Reynolds number between the fins of the heatsink suggests laminar flow, and so the Chen-Kim model is not strictly valid. For this simulation, this complication was ignored for simplicity, and further work would be needed to model the flow more accurately between the fins.

The flow is assumed steady, and the cabinet casing is assumed adiabatic, such that all heat must leave the cabinet through the outlet slots. Buoyancy effects, which may be present locally in some regions, are ignored in the present simulations.

Physical Properties

The air inside the cabinet and at the inlets is at an ambient temperature of 20^{o}C. The case of the cabinet and heatsink are aluminium, and the chips and PCB board properties were specified as new materials through the PHOENICS PROPS file. Their properties can be seen in Table 1.

Table 1 - Component Properties

Name	**Aluminium (Case/heat sink)**	**PCB Board**	**Chips**
Density (kg/m^3)	2719	1000	1000
Specific Heat Capacity (J/kgK)	871	150	100
Thermal Conductivity (W/mK)	202.4	30	15

Geometry and Solution Domain

The electronics cabinet case has 2 round inlets on the front and a series of slotted outlets on the rear. Inside the case, various heat-emitting chips, ranging from 1W to 20W, are spread across the PCB board. The heatsink consists of a base and a number of vertical fins with small channels between them, and these are placed directly on top of the 20W chip. The set-up in PHOENICS is shown in Figure 1. Aside from the ends of the cabinet, which were imported from CAD objects, the geometry was built from the basic geometry shapes available in PHOENICS. For simplicity, a single INLET object was placed at the end of the domain outside the case to simulate the forced

flow into the case. An individual OUTLET object was placed behind each slot of the case to allow the average temperature at each slot to be recorded.
The size of the cabinet is approximately 20 cm x 11 cm x 4 cm.

Boundary Conditions
The inlets were defined to have a fixed, uniform velocity of 2m/s, with a turbulence intensity of 5%. The air entering the domain at the inlets is at an ambient temperature of 20^{o}C.

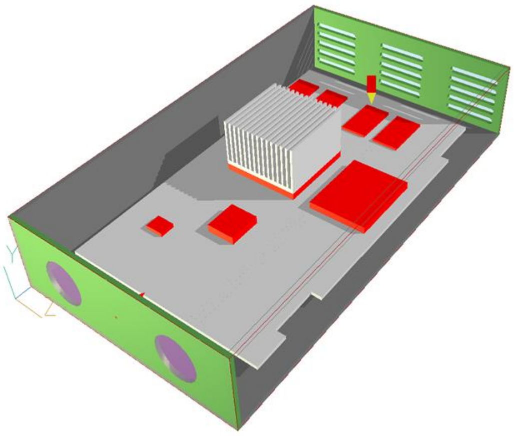

Figure 1 - Geometry set-up in PHOENICS

Mesh
A Cartesian immersed-boundary (SPARSOL) mesh of 140x40x140 cells was used. This mesh is somewhat coarse for the problem; and further grid refinement was not performed for this study. In order to have a sufficient number of cells in the thin channels between the fins, at least 2 cells per fin (width-wise), and three cells inside the channels are required. Otherwise, the solution between the fins is entirely dependent on the wall functions and will not be realistic.

Results and Discussion

The average predicted temperature within the cabinet is 49.8^{o}C, with a peak temperature of 99.5^{o} achieved within the domain. This high point is at the chip with 20W heating power, which is the hottest component showing an average temperature of 96.3^{o}C. The average exit temperature at the outlets is 41.5^{o}C, from an initial ambient temperature of 20^{o}C.
Two streams of fast air flow directly from the two inlets where cool air is forced into the cabinet. Areas outside of the direct line of airflow from these inlets have low velocities, and thus show significant heating compared to the continually refreshed inlet streams.
Due to the nature of the outlet configuration, with multiple thin slots, some of the air is unable to leave the cabinet and recirculates back into the main flow (Figure 3).
The heatsink shows an average temperature of 95.2^{o}C, slightly below that of the 20W chip that it rests on (Figure 4). On the side with stronger airflow (that in direct line from the leftmost inlet) we see lower temperatures of 40-75^{o}C, with the opposite side (which is out of the direct line of flow from an inlet, with velocity close to zero) showing the higher temperature of nearly 100^{o}C. This is as would be expected because the cooler side has a constant flow of cooler air passing alongside the fins.
The PCB board has, as would be expected, its maximum temperature 99.4^{o}C where the hottest chip sits. However, the average temperature across the board is significantly lower, at 77.8^{o}C. This is due to the front end of the board being cooled by the constant air flowing from the inlets.
Pressure is largely constant within the flow field, with a region of stagnation pressure appearing where the flow impacts the heatsink, and a second near the outlets.

Conclusion

The PHOENICS solution for this study of forced-convection air cooling of an electronics cabinet shows an overall flow pattern largely as expected. Two main streams of air flow through the cabinet, and are interrupted by contact with the heatsink, showing some recirculation near the outlets (due to the small area of the outlet slots) and in the wake of the heatsink. The hottest parts of the domain are at the chip with the highest heating power, and at the aluminium heatsink placed above it. This shows that the heatsink is working as designed, drawing heat away from the chip on which it is placed. To extend this case study, a radiation model such as IMMERSOL could be activated so to investigate the effects of radiation on the cooling. Alternative turbulence models could be investigated to improve the solution between the fins, such as the LVEL model which models the flow better in small channels by accounting for transition to turbulence in the wall boundary layers. Finally, a finer mesh would allow better resolution between the fins, as well as improving the accuracy of the heat transfer predictions and the pressure drop across the heatsink.

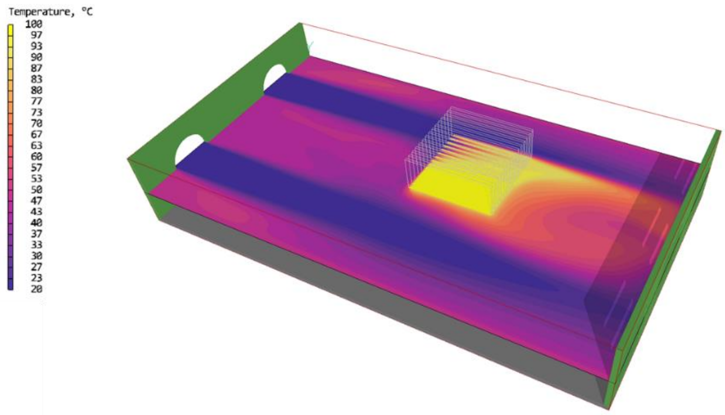

Figure 2 - Temperature contours.

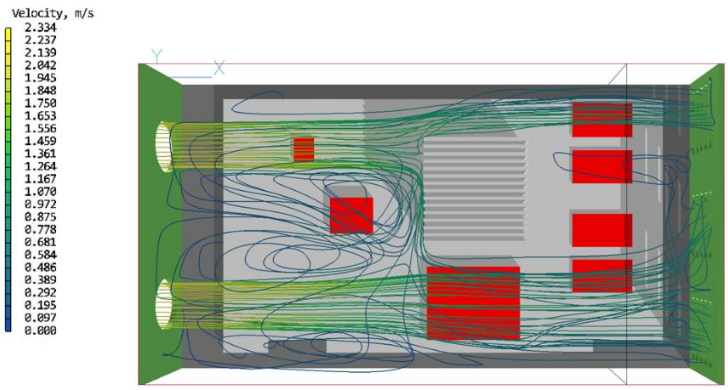

Figure 3 - Velocity streamlines.

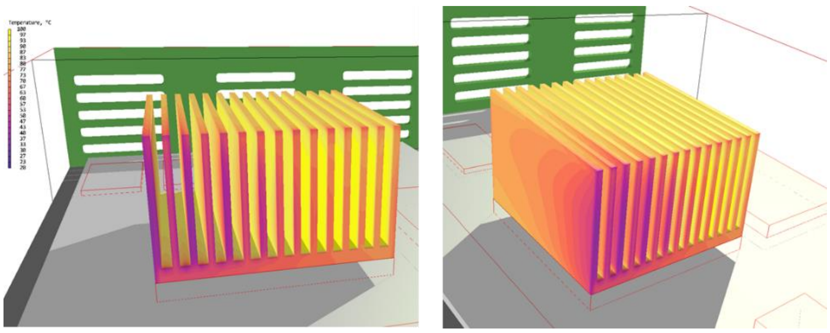

Figure 4 - Heatsink surface temperature contours.