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ANALYSIS OF CABLING EFFECTS IN THE TEMPERATURE DISTRIBUTION IN ELECTRONIC DEVICES RACK

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Abstract. *The target of this work is to evaluate the effect of the cables in the temperature distribution inside electronic equipment of aircraft racks using CFD (Computational Fluid Dynamic) tool. The cables (wiring) are modeled as a porous media and the continuity, momentum, energy equations are numerically solved in conjunction with the standard k-ε turbulence model. The finite volume method with a segretated formulation is employed to solve the mathematical model. Four different cases are simulated: the standard case without wiring and with air ventilation shows the baseline airflow and temperature distributions; the second case without ventilation and without wiring indicates that the effect of the natural convection is important; in the third case with constant velocity input, the effect of the porous media is verified through the calculation with several source terms showing that the pressure increase does not affect the temperature distribution; in the last case (constant pressure boundary condition with wiring) several source terms are used and are verified that the velocity magnitude increase in the entry affects significantly the temperature distribution of the components. Each imposed equipment heat flux is evaluated from the experimental temperature results. Numerical average equipment temperature results exhibit an asymptotic behavior as a function of the input airflow velocity.*

Keywords*: CFD, temperature distribution, electronic devices, wiring, cabling.*

1. Introduction.

Commercial transport aircraft have become increasingly dependent on electronics for navigation, guidance, communication, and other aircraft subsystem control functions. The heat dissipation from these items of electrical and electronic equipment is a problem requiring coordinated effort by both the avionic supplier and the airframe manufacturer. The environment in which equipment is installed; the average and local temperature within the equipment case, and the cooling method employed have a distinct bearing on the avionics design and reliability, SAE (1992). Avionics temperature control in current commercial aircraft employs direct contact cooling aiflow. The equipment is located in a rack and ambient cooling air is drawn through its component parts. Thermal environment strongly influences performance, life and reliability of electronic equipment, SAE (1976). The rise of the rate of failure is strongly dependent on temperature and humidity values exceeding recommnended levels.

Typical aircraft avionic equipment units are compact assemblies (racks). Many require forced-air cooling while in opration, particularly in military combar aircraft. The weight and space economics which influence the avionics designer also press the cooling system to employ the lowest possible air temperature for cooling purposes in order to minimize the penalties of system weight and operating weight due to airflow quantity, SAE (1997).

The installation of electronic devices in aircrafts is limited not only to weight and power consumption constraints, but also to the development of dedicated cooling systems. Besides the economic aspects, directly related to fuel consumption and maintenance costs, the electronic devices should be kept under manufacturer's specifications to reduce failure rates. There are also safety issues since, in extreme conditions, the equipment performance may be affected, generating spurious outputs that can be misinterpreted by both crew and other onboard aircraft systems software.

In this context, the analysis and the modeling of rack-mounted electronic devices becomes a necessity to keep the electronics operating under nominal conditions. That should be achieved minimizing the energy consumption, weight and cost of the cooling system. One important aspect this kind of modeling is the evaluation of the relation between the pressure loss in the airflow rate throught the rack and the temperature distribution on each electronic device.

According to Guyer (1989), the electronic devices dissipation is usually higher than what can be removed by natural convection, which makes forced convecton a necessity. Krauss & Bar-Cohen (1995) present an extensive study of both natural and forced convection applied to the design and optimization of cooling electronic devices.

When the operational temperature limit of equipment is reached, the performance, the life and the reliability are significantly reduced. Tipically, for each 10 ºC reduced in the temperature of the device, the operational life doubles. According to Wang and Muller (2000), the supply of ventilation should take into account:

- Positioning the electronic devices in order to get higher cooling velocities;
- Use of airflow with high turbulence;
- Minimization of the loss of cooling air not directed to the electronic devices;
- Searching and neutralizing hotspots in the compartment.

Besides, some additional gains in terms of cost and power should be pursued by trying to reduce the number and the power of fans, a lower acoustic noise, more compact and efficient fins and better equipment qualification.

The preliminary design of ventilation systems mostly takes into account average temperatures obtain by energy balances of the heat generated by the lectronic devices and the heat loss to the surrounding environment. When detailed design is necessary the actual geometry of the rack and positioning of each box has to be analyzed. An important tool for the analysis of different configurations is the use of CFD tools. There are customized specific tools with similar purposes for the electronic device packging itself, as ICEPAK, and for general cooling such as AIRPACK, but the general purpose CFD software FLUENT has all the necessary modeling capabilities to address the issue. The CFD analysis focuses in the following points:

- Obtain the temperature distribuition of the surrounding environment around each box to check the operational limit and identify hotspots;
- Through the visualization of the velocity field find stagnation regions and recirculation that can affect the heat transfer between the device and surround ing air;
- Compute and monitor the evolution of the temperature on the boxes surfaces, and candidate point for temperature sensors.

All those aspects are analyzed in order to accept or not a certain arrangement of the boxes.

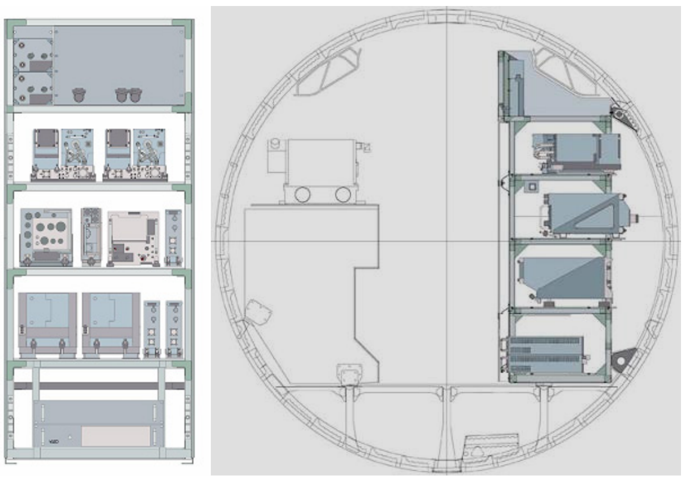

Figure 1. Rack with electronic devices (left) and its position inside the aircraft (right).

As clearly shows Figure 1, a considerable amount of cabling can be necessary to connect the boxes among themselves and to external equipment. Since the dimensions of the cables are extremely smaller than the boxes and there is high uncertainty on their actual position, the construction of an accurate geometrical model, and consequently a computational mesh, is prohibitive by today standards. Therefore, the main purpose of the present work is to investigate a methodology of including the effect of the presence of the cables in the obstruction of the flow and its impact on the electronic devices operating temperatures.

In order reach that goal a series of analyses is conducted taking as reference the installation shown in Fig. 1. This represents a typical electronic rack installed in an aircraft. This installation has been implemented in an actual aircraft and measurements were taken which can used to support the accuracy of the analysis.

2. Mathematical Model and Solution Strategy.

A Newtonian fluid with constant properties is considered. The equations for conservation of mass, momentum and energy are solved coupled the standard k- ε turbulence model. In order to model the influence of the obstruction caused by cabling, the interior air volume is treated as a porous media. The porous media is represented by a source term, actually a volumetric loss, of momentum which can be shown in momentum equation as:

$$\frac{\partial}{\partial t}(\rho \vec{u}) + div(\rho \vec{u}\vec{u}) = -grad\ p + div(\tau_{eff}) + \rho \vec{g} + \vec{F} + \vec{S}_i \tag{1}$$

The source term which represents the porous media obeys the relation:

$$\vec{S}_i = C_0 |\vec{u}|^{C_1} \tag{2}$$

where the constants C_0 and C_1 control the intensity of the obstruction which should be determined by the proposed numerical experiment. For the pressure interpolation scheme, the first-order default is used. The SIMPLE Pressure-Velocity coupling method is used. The first-order upwind discretization is used for all the others equations. In addition, the following hypotheses are adopted:

- Steady state conditions – since the critical cases are related to prolonged operation of the electronic devices during flight, this hypothesis represents the real case;
- The electronic devices generate heat according to manufactures dissipation rates which are implemented as volumetric sources. This energy release is uniform;
- The external temperature is specified as constant along the walls of the compartment containing the rack;
- The rack mounting itself is not represented in the mesh, the boxes are set as “floating” inside the compartment;
- Radiation effects are not considered;
- The air moisture is not taken account;
- The thermal effects of the cables (inertia and conduction) are not modeled only head loss is taken into account.

As mentioned before, the computational model chosen a CFD model using the capabilities of the commercial code FLUENT. In order reach that goal a series of analyses is conducted taking as reference the installation shown in Figure 2. This represents a typical electronic rack installed in an aircraft. This installation has been implemented in an actual aircraft and measurements were taken which can used to support the accuracy of the analysis.

The computational mesh is illustrated in Fig. 2. It has 93,503 tetrahedral elements and each electronic device is represented by a box which is considered as solid, and therefore has internal elements. The surface of the boxes connects the internal solid mesh and the fluid mesh filling the rack air volume. All the boundary conditions are depicted in Fig. 3:

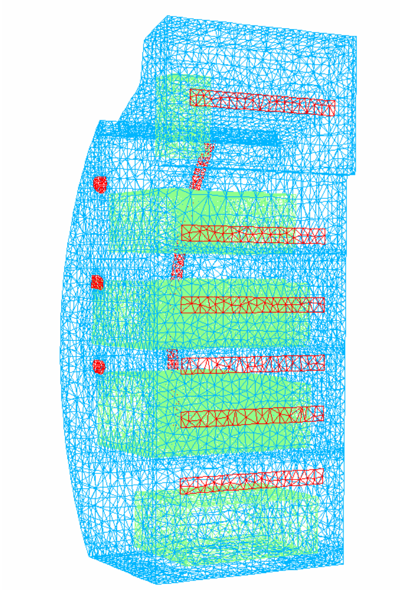

Figure 2. Mesh inside the rack with 93,503 tetrahedral elements.

- *Inflow*: Is represented by a velocity inlet boundary condition on the slot along the side of the compartment that fits the fuselage curvature (*slot*). The inflow velocity is set to 0.35 m/s, the inflow temperature to 283 K, the turbulent intensity to 10%, considering a hydraulic diameter of 0.01 m, to set the turbulence variables.
- *Outflow*: The model has nine potential outlets. Three of them are exhaust fans (*ext2*), in which the gauge pressure is set to approximately -0.48 Pa. The remaining are six grills with exit to the ambient (*grill*) set as pressure outlets at 0 Pa gauge.
- Walls: The walls are isothermal set to 298 K, except the families identified as *bin* e *hollow* which are set to 282 K.
- Heat sources: The electronic devices are modeled using volumetric heat release rates. The experimental values used and the heat fluxes considered are shown in Fig. 4. The equipment named "eq 0" has no heat volumetric generation.

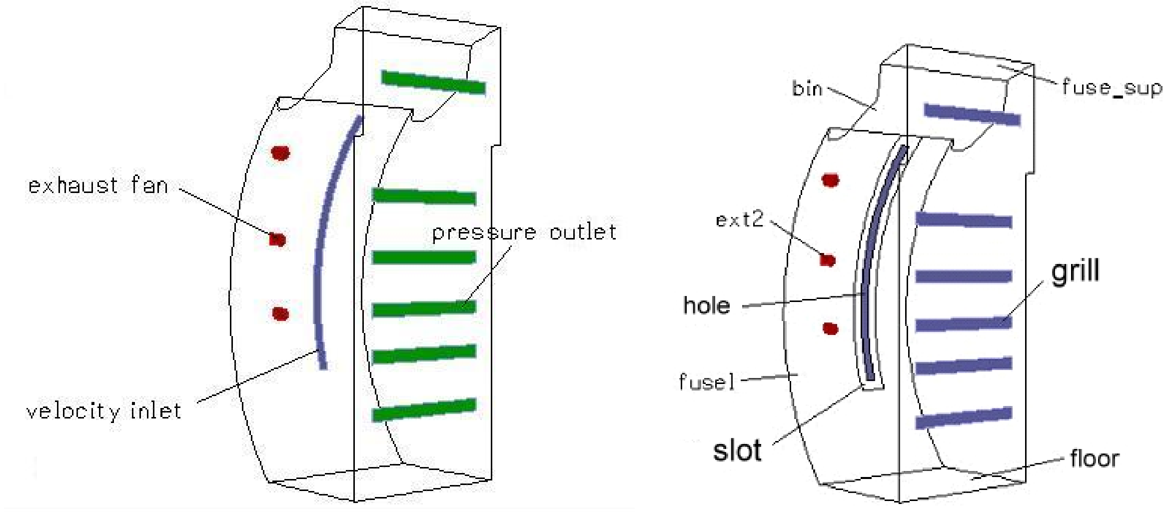

Figure 3. Representation of the rack boundary conditions.

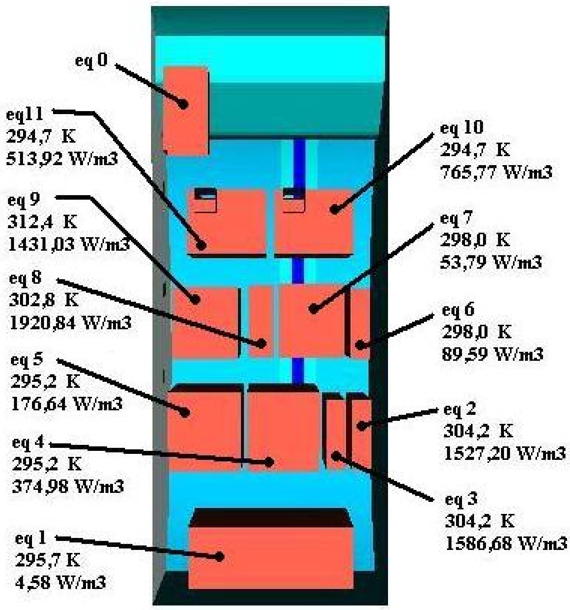

Figure 4. Experimental temperature values (K) and calculated heat generation (W/m^3) for each device.

3. Results for the baseline case (without cabling).

To estabilish a reference to compare the effect of the head loss in the compartment a baseline reference computation is performed. Given the experimental values of the surface temperature of the equipments the simulation is computed to obtain the equivalent heat release rate for each box, as presented on Fig.4. The temperature and flow field computed are considered for analysis effects as the nominal operating condition of the system for an ideal installation without cables.

The temperature profiles can be seen on Figure 5a and 5b for different views. It can be seen that the critical boxes are *eq. 1, 2, 3, 8* and *9* (compare with Fig. 4). From the transversal planes it can be seen that the lower part of the compartment remains at higher temperatures affecting mainly the box eq. 1. This trend can be confirmed by the flowfield patterns shown in Figs. 6a and 6b.

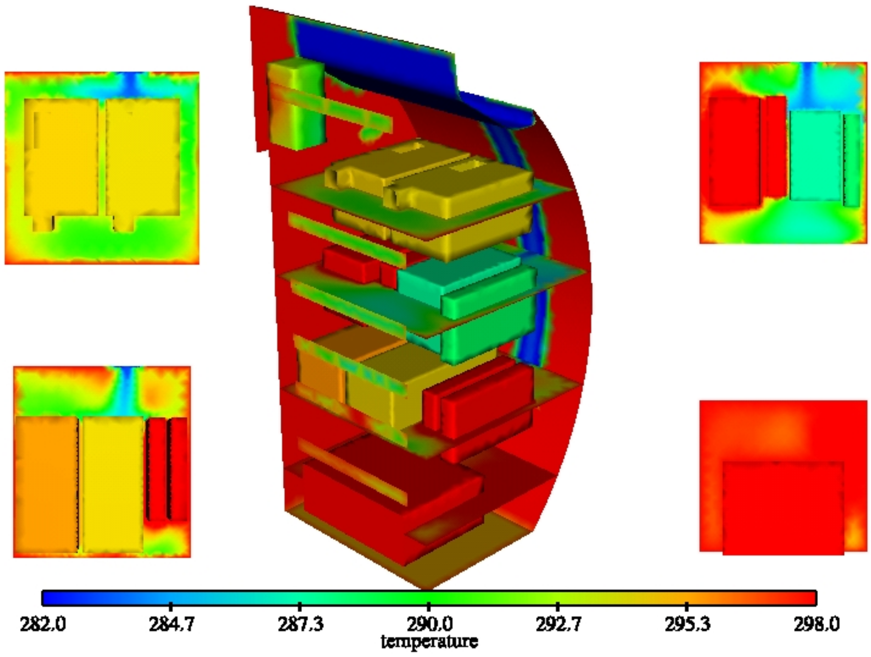

Figure 5a. Temperature distribution (K) results for the baseline case: transversal planes

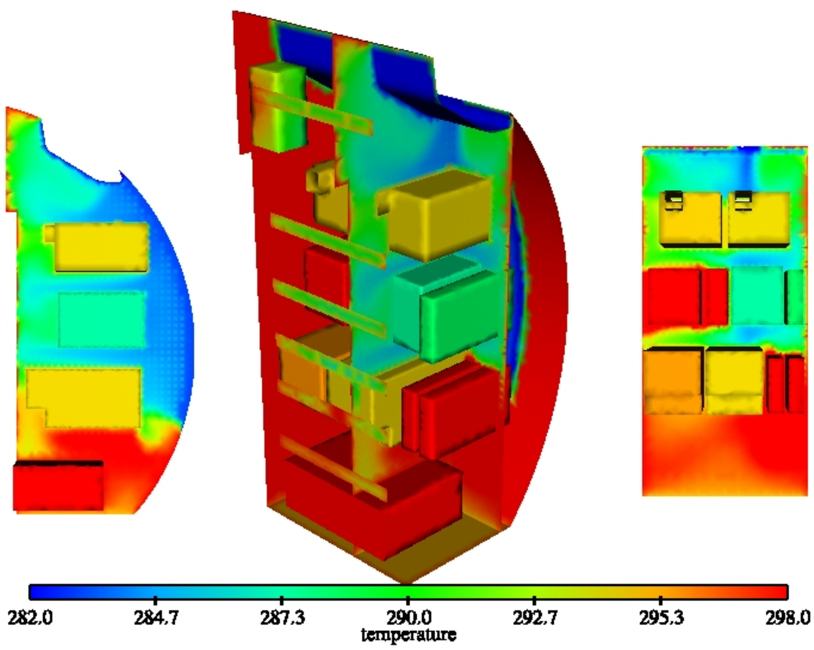

Figure 5b. Temperature distribution(K) for the baseline case results: longitudinal planes.

The velocity field shows a recirculation zone in the lower which traps the air in that region, increasing its temperature. Most of the air escapes through the upper outlets.

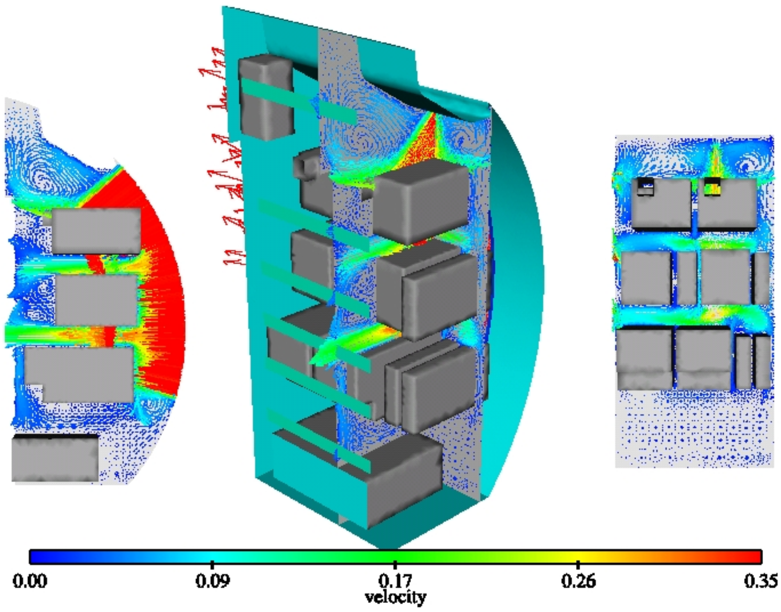

Figure 6a. Velocity (m/s) vectors for the baseline case: transversal planes

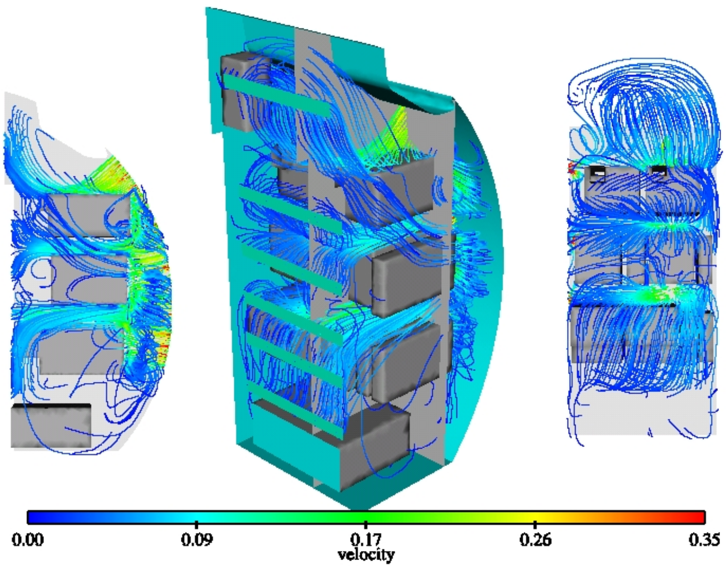

Figure 6b. Velocity (m/s) vectors for the baseline case: longitudinal planes

Considering now a failure of the ventilation system, the exhaust fans and also the derivation from the air conditioning distribution through the slot another simulation was performed. As it can seen in Fig. 7, the maximum temperature on the environment reaches 400 K and is located on a hot spot in center row of electronic devices. This case clearly stresses the need of a dedicated ventilation system to aid heat dissipation by the boxes.

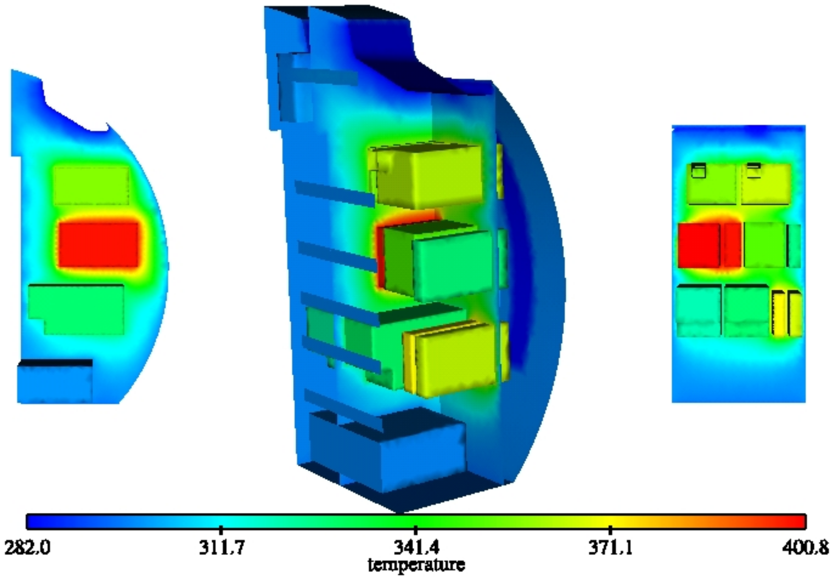

Figure 7. Temperature distribution (K) results for case without ventilation and without cables.

4. Inclusion of the Porous Obstruction (cabling effect).

The sensitivity of the simulation to the inclusion of the cables head loss via porous media is now studied. |Two cases are considered:

i) Similar to the baseline case with a velocity inlet boundary condition: normal velocity to the inlet surface, is applied on the slot and the porous media constant C_0 is varied from 5 to 100000. The constant C_1 is kept equal to 1.

ii) The inflow boundary condition is changed to pressure inlet, allowing the input of a constant pressure along the slot but allows for the accommodation of a variation in inflow velocity. Again the porous media constant C_0 is varied, but in this case from 0.00001 to 100000.

Figure 8 shows the rise of pressure as the porous obstruction is increased, but as it can be seen the temperature remains unaffected (Fig. 9), that is due to the choice of the boundary condition. Since the inlet velocity is kept constant the removal of heat remains at the baseline simulation case level. This behaviour leads to the conclusion that it would be more realistic to impose the pressure instead the velocity on the slot (Fig. 3).

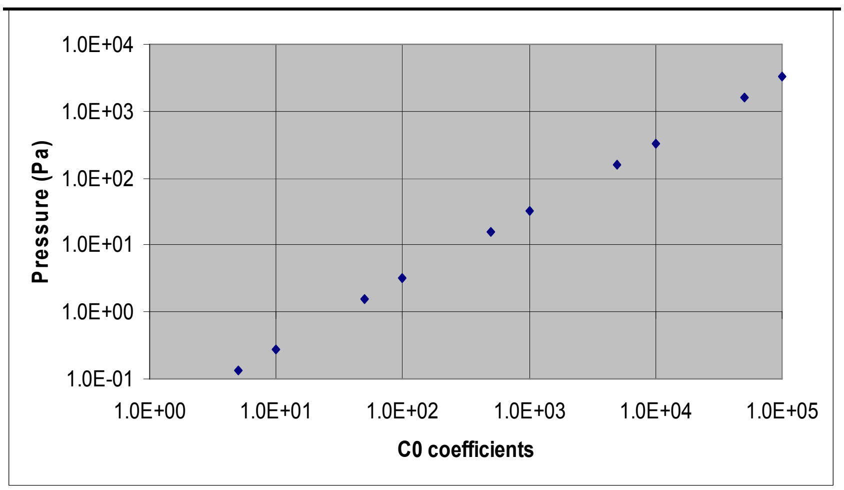

Figure 8. Relation between C_0 coefficients and inlet pressure.

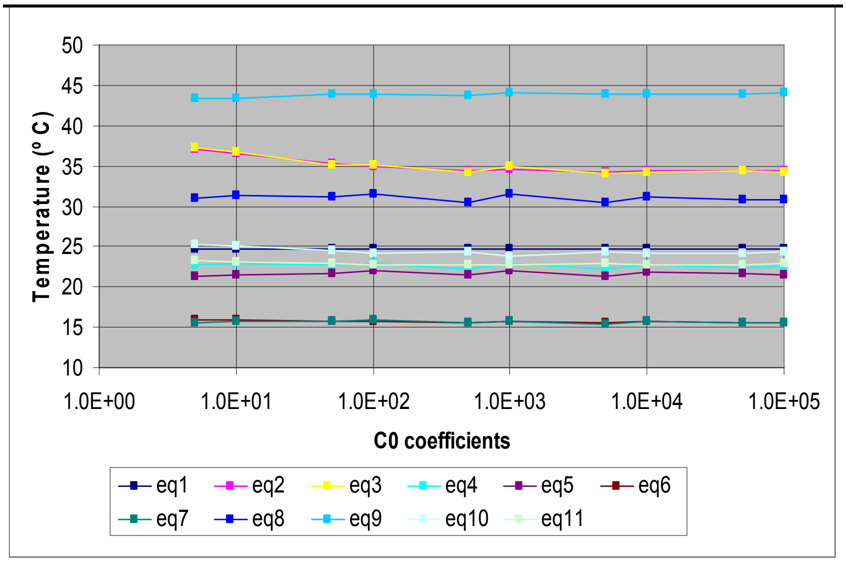

Figure 9. Temperature distribution (K) results for case with constant inlet velocity.

Figure 10 and Fig. 11 show how the velocity and temperature profiles are affected by the porous media obstruction. The increase of C_0 values causes also an increase of average temperature which leads to decrease in the velocity values. For such critical conditions the temperature reaches values above the natural convection case.

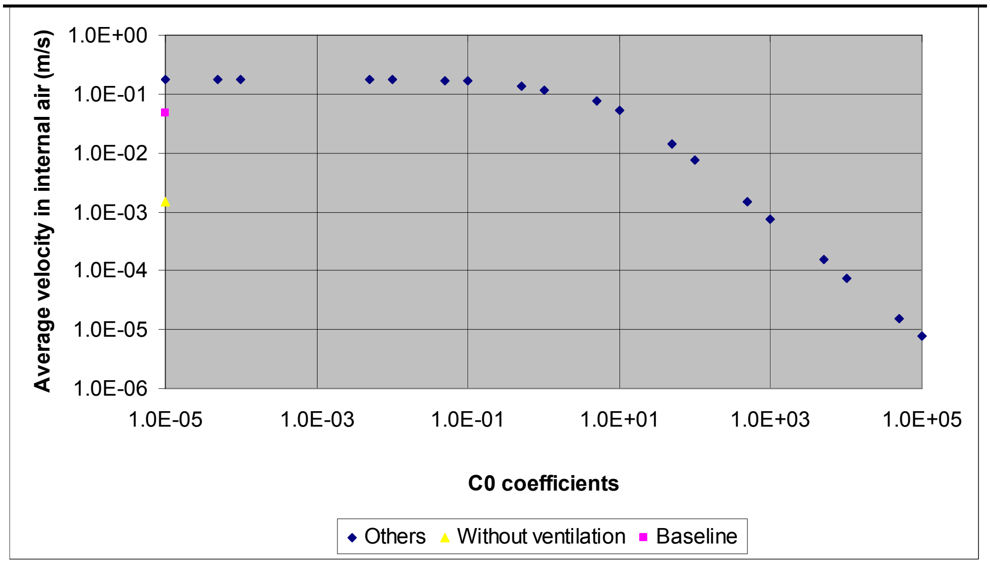

Figure 10. Average velocities for the case with constant pressure.

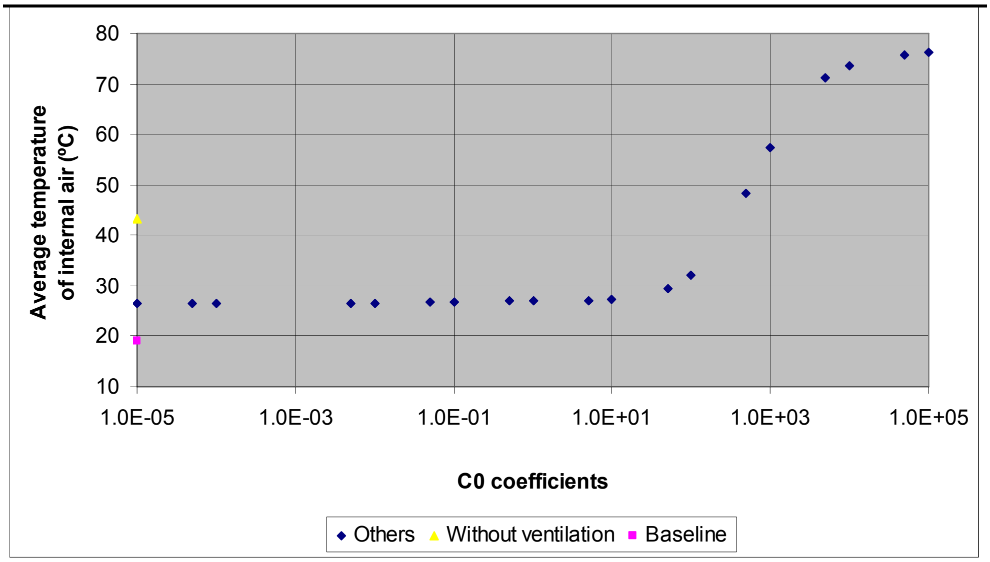

Figure 11. Average temperatures for the case with constant pressure

In Figure 12 it can be seen that the boxes *eq.8* e *eq.9*, which work at higher temperatures, quickly reach an unacceptable level as the porous obstruction increases. At a certain obstruction level box *eq.3* becomes more critical that box *eq.8* and latter the trends reverses again. In Fig.12 it also can be noted that even for very low values of average velocity the temperature remains at acceptable levels.

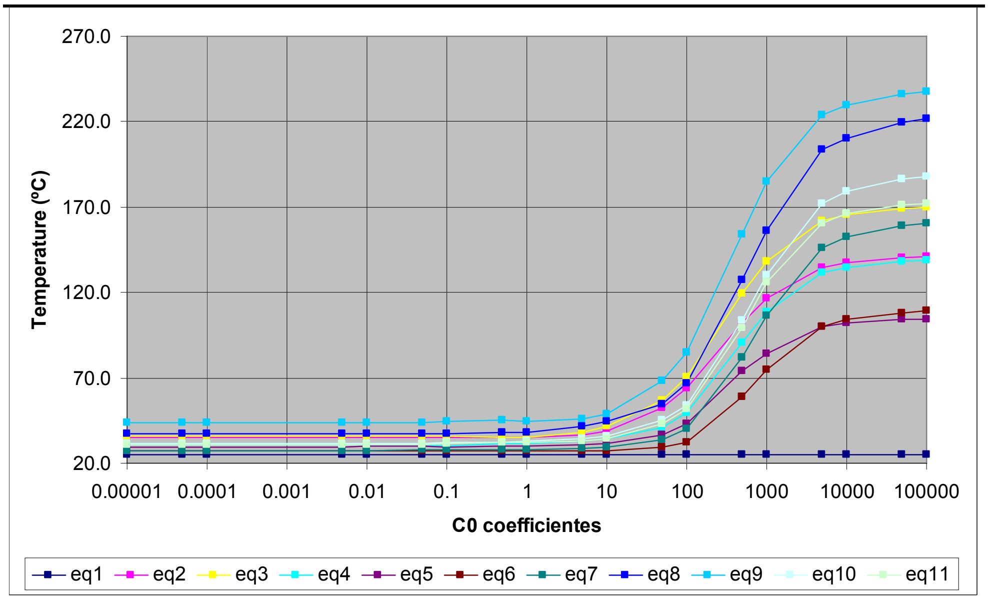

Figure 12. Temperature (K) results for case with constant pressure and with cables

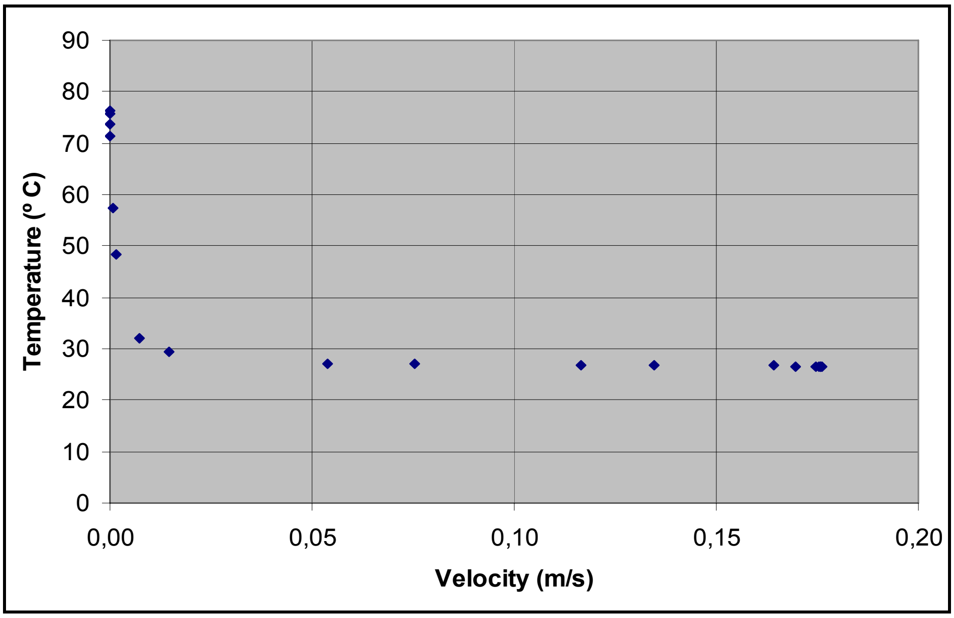

Figure 13. Case with constant pressure and with cables

The results indicate that for C_0 values close to 10, the performance of the system is acceptable causing an average velocity of 0.07 m/s which is comparable to the baseline case. Therefore there is little influence in results on attempting to include the cables which justifies the approach adopted on the baseline model.

5. Final remarks.

This work studied the cabling effect inside an electronic device racks to analyze using a CFd tool. Firstly, a baseline case without cables was solved to be compared with the cabling case (where the wiring effect was modeled as a porous media). Results of the temperature and velocity insice the rack allowed proposing some actions that could improve the boxes ventilation. These recommendations can be summarized as:

- The grills should be centered to frontal face of electronic devices;
- The exhaust fans should be aligned with the sides of boxes not in space between them;
- Redistribution of the equipments with higher heat releases near the entrance.

Future experiments shall be conducted in order to correlate the porous obstruction with actual cable density.

14. References

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