Investigation of Flow in Data Rack

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Abstract: The main purpose of this paper was to set up a functioning numerical model of data rack verified by an experimental measurement. The numerical model will serve for the flow simulation inside the data rack. For the aim of experimental verification of the server model, a PIV (particle image velocimetry) method was used. The server model was projected based on the original Rack Workstation Dell Precision R5400 (2U rack space). The flow rate in each channel was implemented with the help of pressure loss, which was set up so that the server flow rate corresponded with the measured values. The verification of the correct functioning of the numerical model of the server was carried out together with verifying the numerical model of a small data rack. The experiment was compared with the numerical model for the case of data rack (12U rack space) fitted with two 2U rack workstations Dell Precision R5400, on which the simulation of several phases of the entire data rack with given configuration was carried out.

Key words: Data rack, PIV, numerical simulation, flow field.

1. Introduction

The purpose of this paper was to set up a functioning numerical model, verified by an experimental measurement, of data rack fitted with two rack workstations Dell Precision R5400 (Fig. 1), 2U rack space each. The workstations were set in the middle part of the cabinet (Fig. 2) and a 2U-dimensional free space between the workstations was being left. Three suitable compilations of cabinets were being considered for the work purpose. As for the first compilation, the geometry representing a fully opened data rack was considered where the air could flow through the servers and through the entire front of the data rack without limitations. In the second case, the semi-closed compilation was considered with air flowing only through servers and the space between them, with the space not being blanked off. As for the last compilation, the entire space representing the front of the data rack was blanked off and thus the air could flow only through the servers (Fig. 2).

2. Experiment

The main purpose in the experimental part was to determine the appropriate velocity field in the front of the inlet space of the workstation Dell Precision R5400. The velocity field was measured in the 1 cm distance from the front of the workstation. The workstation is usually supplied with the front case panel that was removed (Fig. 3) for the experimental measurement, it was not considered for the numerical measurement either. Another modification of the workstation was not considered. Several measurement planes with a constant 1U rack space (1U = 44.45 mm) were determined in the direction perpendicular to the front of the workstation. The utmost right side of the front of the workstation was chosen to be the initial plane with other measurement planes related to it. In the measurement planes the velocity profiles were measured, consequently constituting the general velocity field.

A PIV (particle image velocimetry) method was used for measuring the velocity fields [1]. A supporting construction was made in order to provide certain aspects during the entire measurement process. The floating support with both laser and camera was placed on the fixed support that was aligned parallel to the
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Fig. 1  Dell Precision R5400 channel setup.

Fig. 2  Compilation of cabinets.

Fig. 3  Workstation with and without front panel.
front of the workstation. Within the floating support the mutual perpendicularity of these two peripheries was provided during the entire measurement. This support was moved in the defined directions along the front case panel of the workstation.

A camera flow Sense 4M (12 bites, 4 megapixels) together with a pulse laser Nd: YAG (Yttrium Aluminum Garnet) New Wave Gemini 120 mJ in pulse was used. Dynamic studio program was used for synchronization and evaluation. For calculating vectors during evaluation, a method of multi step correlation with initial size IA (Interrogation area) 64 × 64 pixels and resultant size 32 × 32 pixels was used. A filter peak ratio, where only vectors with ratio better than 1.1 were accepted within the filter, was used for data validation. All results are time-averaged from 100 measurements.

It was assembled structure (Fig. 4) in which the position of the camera to the laser was firmly fixed on a movable slide. This was achieved by the same positional and angular position of the camera to the laser during the whole measurement. This assembly was then adjusted so that the laser sheet was as much as possible perpendicular to the front face of the workstation. Movable slide is then moved in the transverse direction of the workstations in the above-defined mode.

3. CFD (Computational Fluid Dynamic) Model

The whole geometric model of the workstation was considerably simplified. The complex internal geometry of the workstation (Fig. 5) was replaced by four channels, where a pressure loss was defined for each channel (Fig. 5). The pressure loss was defined in places where ventilators are located in real workstation. Thus, despite considerable geometry simplification, the position of source generating the flow within the whole setup was preserved.

Dimensions and locations of areas representing the inlet to the workstation were adopted for individual channels (Fig. 5). Due to focusing on the cabinet and workstation as a whole, the perforation of the inlet and inlet to the workstation were presented only as a rectangular inlet within the particular channels.

Fig. 4  Experiment setup.
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On account of the approximation of the four-channel solution to the one-channel solution, the wall friction was not considered on all inner channel walls which do not represent the boundary area of real geometry, i.e., walls of the workstation. Thus the flow gives the impression of compactness despite the fact that there happens to be no mutual interaction of flow within the channels.

A simplified geometry was used for the model of the cabinet. The original geometry contained walls with thickness in order of a few millimeters. Due to the very complicated mesh creation for original geometry and due to disproportion between the wall thickness and wall width and height, all the walls in the model were replaced by a zero wall thickness (Fig. 6). The model was hereby considerably simplified while preserving all features of original geometry and it was possible to create a complete structured non-conforming mesh.

The whole volume was divided into several independent parts, which were meshed separately and the interfaces were created between resulting domains (Fig. 7).

The whole model contained 1,052,480 cells and was fully created with the help of hexahedron elements. For parts 1 and 2, an identical topology setting and mesh element size was used. The parts have a one plane of symmetry, but due to the asymmetry of the other parts of the compilation the symmetry condition was not used. For parts 3, 4 and 5 the identical mesh element size was used only.

A k-ε model of turbulence was used for numerical solution. GGI (general grid interface) [2] was used as an interface between particular meshes.

Heat transfer for the numerical model was not considered for this case.
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4. Comparison of CFD and Experimental Data

Four calculations were implemented in order to find suitable pressure loss in particular channels for numerical solution, where mass flow rates for particular channels were compared in the same regions from which the experimental data from the measurement were obtained. The aim was to find such a pressure loss during which the total difference of mass flow rates between the experimental measurement and numerical solution was less than 5%. The pressure loss for fourth channel was not considered due to the general closing, it is mentioned in the chart below only for reasons of completeness of the whole solution (at fourth channel there are hard discs in the real workstation. The flow rate through this region is considerably limited and thus was not considered within numerical solution).

To calculate the mass flow for the numerical solution and experiment in front face of the workstation was used relationship

\[ n \dot{V} = A \cdot \bar{v} \cdot \rho \]  \hspace{1cm} (1)

when speed was due to an equally large elements levels averaged in the calculation according to equation

\[ \bar{v} = \frac{\sum_{i=1}^{n} v_i}{n} \]  \hspace{1cm} (2)

Color map of velocity magnitude at inlet to workstation is shown in Fig. 8. Color maps are for both solutions.

Table 1 represents samples for finding adequate pressure loss for each channel. Iterative solution was used to find appropriate pressure loss. It took four passes to get results that correspond to assumptions mentioned above. Value for each channel was used for every compilation of data racks.

In Fig. 9 is shown comparison between experimental and numerical data fitted to real front area of workstation.

Fig. 10 provides measured and computed velocity profile at inlet to workstation.

5. Results

As results were generated cuts across whole model of data rack. First cut was placed 2 cm behind middle plane as is shown on Fig. 11. Cut was moved because middle plane lies in exact place as one of channel wall. Due this fact the results in this place were inaccurate. Also were created three parallel cuts (Fig. 12). These cuts were placed in the middle of each workstation and in the middle of space between them.

6. Differences between Two Compilations

Difference between two compilations was also created. For comparing were selected fully opened and semi-closed compilations. Results in selected cut which were defined above were compared and their absolute values were plots as a velocity magnitude contours. These results are quite important because we can see and calculate how much air flow through individually parts of data rack.

![Fig. 8 Velocity filed at the inlet to the workstation.](image-url)
### Table 1  Suitable pressure loss according to mass flow rate.

| Sample #1 | Experiment | CFD | mass flow [kg/s] | delta p [Pa] | mass flow [kg/s] | diff CFD/Exp [%] |
|-----------|------------|-----|-----------------|--------------|-----------------|-----------------|
| Channel 1 | 0.0067     | 10  | 0.0078777       | 17.58        |
| Channel 2 | 0.0078     | 10  | 0.012745        | 63.4         |
| Channel 3 | 0.007      | 10  | 0.0089814       | 28.31        |
| Channel 4 | 0.00043976 | 0   | 0.00048615      | 10.55        |

| Sample #2 | Experiment | CFD | mass flow [kg/s] | delta p [Pa] | mass flow [kg/s] | diff CFD/Exp [%] |
|-----------|------------|-----|-----------------|--------------|-----------------|-----------------|
| Channel 1 | 0.0067     | 10  | 0.00771         | 15.08        |
| Channel 2 | 0.0078     | 5   | 0.0089882       | 15.24        |
| Channel 3 | 0.007      | 7.5 | 0.0074134       | 5.91         |
| Channel 4 | 0.00043976 | 0   | 4.01E-05        | 90.88        |

| Sample #3 | Experiment | CFD | mass flow [kg/s] | delta p [Pa] | mass flow [kg/s] | diff CFD/Exp [%] |
|-----------|------------|-----|-----------------|--------------|-----------------|-----------------|
| Channel 1 | 0.0067     | 8   | 0.0069819       | 4.21         |
| Channel 2 | 0.0078     | 7   | 0.010551        | 35.27        |
| Channel 3 | 0.007      | 8   | 0.0076726       | 9.61         |
| Channel 4 | 0.00043976 | 0   | 4.27E-05        | 90.3         |

| Sample #4 | Experiment | CFD | mass flow [kg/s] | delta p [Pa] | mass flow [kg/s] | diff CFD/Exp [%] |
|-----------|------------|-----|-----------------|--------------|-----------------|-----------------|
| Channel 1 | 0.0067     | 8   | 0.006681        | 0.29         |
| Channel 2 | 0.0078     | 4   | 0.008057        | 3.3          |
| Channel 3 | 0.007      | 6.5 | 0.0066881       | 4.46         |
| Channel 4 | 0.00043976 | 0   | 3.64E-05        | 91.72        |

**Fig. 9** Location of velocity field on the real geometry of the workstation.
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Fig. 10  The shape of the velocity at the inlet to the workstation.

Fig. 11  Position of perpendicular cut through data rack.

Fig. 12  Position of parallel cuts through data rack.
As you can see in Figs. 13–17 shown below the biggest difference is in the middle of data rack. In the cuts number 1 and 3 are shown contours of velocity magnitude through workstations. Because the same boundary and initial condition were used this difference should be almost zero. We can see that in the places where workstations are the differences are not big. The biggest differences are as we expected in the rest of the data rack mainly in the space between workstations.

Table 2 represents volumetric flow rate through workstations and the space between them in the specified distance from the front face of data rack. Also a perceptual ration is calculated against a selected master value. Master value has been chosen as a biggest value for current space.

![Fig. 13 Comparison of velocity magnitude contours in perpendicular cut for each compilation.](image1)

![Fig. 14 (a) Comparison of velocity magnitude contours in parallel cuts for fully opened compilation. (b) Comparison of velocity magnitude contours in parallel cuts for fully closed compilation.](image2)
Fig. 15  Comparison of velocity magnitude contours in parallel cuts for semi-closed compilation.

Fig. 16  Difference of velocity magnitude contours in perpendicular cut for fully opened and semi-closed compilation.

Fig. 17  Difference of velocity magnitude contours in parallel cuts for fully opened and semi-closed compilation.
### Table 2 Differences between compilations.

| Name of cutting plane | Distance from front face of data rack | Unit    | Volumetric flow rate | Unit    | Difference according to master | Unit |
|-----------------------|--------------------------------------|---------|----------------------|---------|---------------------------------|------|
| Fully closed          |                                      |         |                      |         |                                 |      |
| Bottom part           | 0.042 [m]                            | [m]     | 0 [m³/s]            | N/A     |                                 | [%]  |
| Middle part           | 0.042 [m]                            | [m]     | 0 [m³/s]            | N/A     |                                 | [%]  |
| Top part              | 0.042 [m]                            | [m]     | 0 [m³/s]            | N/A     |                                 | [%]  |
| Sum of bottom/middle/top part | 0.042 [m] | [m] | 0 [m³/s] | N/A | Marked as a master | [%]  |
| Workstation #1        | 0.5 [m]                             | [m]     | 0.03072 [m³/s]      | 100     |                                 | [%]  |
| Workstation #2        | 0.5 [m]                             | [m]     | 0.03049 [m³/s]      | -0.74   |                                 | [%]  |
| Sum of workstations   | 0.5 [m]                             | [m]     | 0.06121 [m³/s]      |         |                                 | [%]  |
| Semi-closed           |                                      |         |                      |         |                                 |      |
| Bottom part           | 0.042 [m]                            | [m]     | -0.00013 [m³/s]     | -       |                                 | [%]  |
| Middle part           | 0.042 [m]                            | [m]     | 0.00387 [m³/s]      | 100     |                                 | [%]  |
| Top part              | 0.042 [m]                            | [m]     | 0 [m³/s]            | N/A     |                                 | [%]  |
| Sum of bottom/middle/top part | 0.042 [m] | [m] | 0.00371 [m³/s] | - | [%] |
| Workstation #1        | 0.5 [m]                             | [m]     | 0.03063 [m³/s]      | -0.29   |                                 | [%]  |
| Workstation #2        | 0.5 [m]                             | [m]     | 0.03021 [m³/s]      | -1.66   |                                 | [%]  |
| Sum of workstations   | 0.5 [m]                             | [m]     | 0.06084 [m³/s]      | -1.95   |                                 | [%]  |
| Fully opened          |                                      |         |                      |         |                                 |      |
| Bottom part           | 0.042 [m]                            | [m]     | 0.00604 [m³/s]      | -       |                                 | [%]  |
| Middle part           | 0.042 [m]                            | [m]     | 0.00327 [m³/s]      | -15.5   |                                 | [%]  |
| Top part              | 0.042 [m]                            | [m]     | -0.00037 [m³/s]     | -       |                                 | [%]  |
| Sum of bottom/middle/top part | 0.042 [m] | [m] | 0.00895 [m³/s] | - | [%] |
| Workstation #1        | 0.5 [m]                             | [m]     | 0.03034 [m³/s]      | -1.23   |                                 | [%]  |
| Workstation #2        | 0.5 [m]                             | [m]     | 0.03008 [m³/s]      | -2.08   |                                 | [%]  |
| Sum of workstations   | 0.5 [m]                             | [m]     | 0.06042 [m³/s]      | -3.31   |                                 | [%]  |

7. Conclusions

The purpose of this paper was to set up a functioning numerical model, verified by an experimental measurement, of data rack fitted with two rack workstations Dell Precision R5400. From results showed above we can say those adequate mass flow rate and pressure jumps were found for numerical solution which corresponds to experimental measurement. Differences between numerical and experimental solution were less than 5%. These results will be used as a starting point for next numerical solutions where the heat transfer will be added to the model. Also another experimental measurement will be made to compare compilations mentioned in this paper with numerical results presented in this paper. Very simple channel system was presented as a replacement for very complicated geometry of real workstation. This model offer lots of ways how to improve it and find better and closer solution to the real workstation.

Data presented in this paper has been also used as a background how important is thoroughly seal all holes and empty spaces in front face of data rack. You can lose lot of cold air even if slightly overpressure is presented in front of data rack. Over pressured compilation wasn’t presented in this paper but there are lots of guides pointing exactly this way.

Acknowledgments

Project (TA01010184/Research and development solutions data racks, cooling and transport systems for data centers) is/was solved with the financial support of TA ČR.

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