Comparison of serial and parallel simulations of a corridor fire using FDS

L Valasek
Slovak Academy of Sciences/Institute of Informatics, Dubravská cesta 9, 845 07 Bratislava, Slovakia
E-mail: lukas.valasek@savba.sk

Abstract Current fire simulators allow to model the course of fire in large areas and its impact on structure and equipment. This paper deals with a comparison of serial and parallel calculations of simulation of a corridor fire by the FDS (Fire Dynamics Simulator) system. In parallel case, the whole computational domain is divided into several computational meshes, the computation on each mesh is considered as a single MPI (Message Passing Interface) process realised on one computational core and communication between MPI processes is provided by MPI. The aim of this paper is to determine the size of error caused by parallelization of computation, which occurs at touches of computational meshes.

1. Introduction

Current fire simulation systems are capable to utilize a rapid progress of computational power of contemporary computers and model fires and their effects also in large areas. However, parallelization can introduce inaccuracies into calculation or even waste simulation results [1-5]. In this paper, error of parallel simulation of fire in a short corridor by FDS is investigated. The FDS (Fire Dynamics Simulator) system [6, 7] is an advanced CFD-based fire simulator intended for simulation of fire in various environments. It numerically solves a form of Navier-Stokes equations for low-speed fire induced flows with emphasis on transport of smoke and heat from fire. The system is capable to utilize various types of parallelization of calculation. In this paper, we focus on MPI (Message Passing Interface) version of parallelization, which is the most efficient [1] and most commonly used. We use the 64-bit MPI version 5.5.3 of FDS for MS Windows installed on a fast multi-core PC. In the MPI approach, the whole computational domain is divided into several computational meshes, the computation on each mesh is considered as a single MPI process assigned to one computational core and communication between MPI processes is provided by MPI. The aim of this paper is to determine the size of error caused by parallelization which occurs at touches of computational meshes.

2. Fire scenario

Let us consider a simple rectangular parallelepiped corridor with the dimensions of 24 m x 4 m x 3 m (length x width x height) with 10 cm thick concrete walls and the OPEN boundary condition on both exits of the corridor. The 20 °C ambient temperature is considered inside and outside the corridor. We do not assume any additional flammable materials inside the corridor, nor any airflow at the beginning of simulation. We consider a 10 MW fire source represented by a 0.4 m x 0.4 m burning surface

1 To whom any correspondence should be addressed.
placed at the 21.8 m distance from the left corridor exit producing the 62500 kW/m² HRRPUA (heat release rate per unit area) from the beginning until the end of simulation. In order to study the impact of parallelization on accuracy of simulation, we placed 239 thermocouples in the 50 cm height below the ceiling in the middle of the corridor. We consider simulation of the 5-minute fire.

3. Simulation results and discussion of errors caused by parallelization

For the purposes of this paper, we realised one sequential simulation 1M using one computational mesh, and three parallel simulations 3M, 6M and 12M using 3, 6 and 12 computational meshes, respectively. In all cases, we use the same 10 cm mesh density. According to the mesh sensitivity study [7] performed, such meshes can be considered as “fine” for all considered calculations already since the 1st s of fire. In the case of 1M, the calculation is realised as a single MPI process assigned to one computer core. In parallel simulation 3M, 6M and 12M, the calculation is realised as 3, 6 and 12 MPI processes assigned to 3, 6 and 12 computer cores, respectively.

The course of fire was as follows. At first, a hot gas induced by the fire began to spread from the fire source towards the ceiling. After the smoke hit the ceiling at the 1st s of fire, it spread towards both exits. The right and left exit was achieved at the 2nd and 8th s, respectively. At the end of simulation, a relatively steady flow can be observed (see figure 1). In figure 1, turbulent flows above the fire and at the front of hot layer below the ceiling, moving fast towards the left exit are highlighted.

![Figure 1. Vertical gas temperature slices at the 6th and 300th s of fire with selected thermocouples highlighted: temperature values vary from 0 °C (blue) to 1000 °C (red).](image)

For the purposes of analysis of errors introduced into simulation by parallelization, we calculate the mean values of temperatures on 239 thermocouples obtained by calculations 1M, 3M, 6M and 12M, and compare the values obtained by parallel calculations with the values obtained by the sequential calculation. Figure 2 shows the differences between the mean values obtained by the parallel calculations and the sequential calculation as well as the values of their absolute values. For individual parallel calculations, these curves represent errors at selected thermocouples caused by parallelization. For simplicity, they are denoted by $e_{i,j}$ and $|e_{i,j}|$, $j = 3, 6, 12$. In figure 3, graphs of relative errors $r_{i,j}$ and $|r_{i,j}|$ corresponding to the errors $e_{i,j}$ and $|e_{i,j}|$, $j = 3, 6, 12$ are illustrated.

It follows from analysis of the curves in figure 2, that the considered thermocouples can be divided into three groups according to behaviour of errors of the calculation parallelization, depending on their distance from the fire source. The 1st group consists of the thermocouples placed in the distance smaller than 16 m from the left exit. This corresponds to the first 2, 4, and 8 meshes in the 3M, 6M, and 12M calculation, respectively, which are numbered from left to right from the left exit. The errors caused by parallelization at this group of thermocouples are relatively low and have a relatively very similar course (see e.g. the course of the errors over the <8 m, 14 m> interval in figure 2), whereby an increase of fluctuations towards the fire source can be observed. The 2nd group consists of the thermocouples located in the distance from 16 m to 19.2 m from the left exit, whereby the last thermocouple corresponds to the point from which the tendency of the $e_{i,3}$ curve changes from ascending to descending (see figure 2). It can be also observed that the course of all three analysed errors is qualitatively very similar. The 3rd group consists of the thermocouples lying on the right from the last thermocouple of the 2nd group. The course of errors at these thermocouples is characterized by high fluctuations, which partially change a relatively very similar qualitative behaviour of individual errors, in spite of high fluctuations of their values (see figure 2). These fluctuations are caused by high fluctuations of temperatures in the area, where the thermocouples are located (relatively close to the fire source).
Figure 2. Course of errors $e_{1,j}$ and relative errors $r_{1,j}, j = 3, 6, 12$ caused by parallelization

Figure 3. Course of absolute errors $|e_{1,j}|$ and absolute values of relative errors $|r_{1,j}|, j = 3, 6, 12$

It follows from figure 2 and figure 3 that relatively small errors of the mean values of temperatures caused by the calculation parallelization occur on the first two groups of thermocouples reaching values not exceeding 2% or 5% at the most of the thermocouples. This behavior corresponds to the places where relatively small turbulent flows occur. At the rest of thermocouples, i.e., in a neighborhood of the fire source, the error of mean values is increasing, but does not exceed the value of 9%. This error increase is related with stronger turbulent flows in places, where fast moving hot and cold gases mix each other. In the figures, it can be also seen that fluctuations of the errors of temperatures mean values as well as the corresponding relative errors above the fire source are relatively not very high, which is a consequence of the fact that the space above the fire source is already heated with only a small amount of cold air. The figures also show that the relative errors above the fire source rarely exceed 5%.

From a thorough analysis of the $e_{1,3}$ error behavior, it can be seen that in the 1st mesh, the error relatively slight decreases and then a rapid increase of the error between the thermocouples located in the last cell of the 1st mesh and the 1st cell of the next mesh occurs. In the 2nd mesh, the course of the error is also decreasing with small fluctuations and then a rapid increase of the error between the thermocouples located in the last cell of the 2nd mesh and the 1st cell of the next mesh can be observed. In the 3rd mesh, the error behavior is strongly affected by turbulences of temperature caused by proximity to the fire source and by mixing of fast moving hot gases and cold air. Similarly, the course of the error $e_{1,6}$ is relatively slightly decreasing in the 1st mesh and then a rapid increase of the error follows between to thermocouples passing through the touch of meshes. In the 2nd, 3rd and 4th meshes, the error slightly increases with moderate fluctuations, which grow with decreasing the distance from the fire source. At the touches of meshes, increase of the error can be observed similarly as in the previous case. The error behavior in other meshes is markedly influenced by turbulent flow from the fire source. The error $e_{1,12}$ has a very similar course to the error $e_{1,6}$. The course of error $e_{1,12}$ in the first
two meshes is probably partially affected by the boundary OPEN condition at the computational domain boundary which causes error fluctuations at the right from the touch of meshes. In seven subsequent meshes, the course of errors $e_{1,12}$ and $e_{1,6}$ is qualitatively very similar. The $e_{1,12}$ error behavior in other meshes can be interpreted similarly as in the previous cases; it is strongly affected by increasing the error fluctuations caused by temperatures fluctuations caused by mixing of fast moving hot gases and cold air in the vicinity of the fire source. The course of the relative errors $r_{1,3}$, $r_{1,6}$ and $r_{1,12}$ qualitatively corresponds to the course of the errors $e_{1,3}$, $e_{1,6}$ and $e_{1,12}$, respectively (see figure 2 and figure 3). The size of fluctuations in individual meshes is related to the distance from the fire source (as it was mentioned above), where the greatest fluctuations/values of the absolute error are concentrated in the 3rd mesh. The course of $|r_{1,3}|$, $|r_{1,6}|$ and $|r_{1,12}|$ is qualitatively the same as the course of the absolute errors $|e_{1,3}|$, $|e_{1,6}|$ and $|e_{1,12}|$, respectively. It follows from figure 3 that the values of the relative errors caused by parallelization do not exceed 5% in the upper corridor part, where turbulent mixing of fast moving hot gases inducted by fire with cold air does not occur.

4. Conclusion

In this paper, we realised three parallel simulations of corridor fire using 3, 6 and 12 computer cores, and sequential calculation with the same density of meshes. In each calculation, the mean values of temperature recorded on thermocouples placed in the 50 cm height below the ceiling in the middle of the corridor were calculated. The size of error caused by the parallelization of calculation, which was obtained by comparison of the mean temperature values calculated by the parallel simulations in regard of the sequential simulation, is described. From thorough analysis of the course of errors, it follows that in the upper part of the corridor, where the flow of hot gases induced by fire is concentrated, the values of relative errors at the thermocouples considered do not exceed 5% in the area, in which turbulent mixing of hot and cold gases does not occur. The error at the left from the fire source is affected by significant fluctuations and large turbulences caused by mixing of fast moving hot gases and cold air. The analysis of simulation results also shows that the size of error does not grow so significantly in places with turbulent flows without mixing of gases with high differences of temperature (above the fire source). Moreover, the analysis also indicates that, although the values of the errors caused by parallelization are not significantly high for relatively low numbers of processors, the problem of impact of parallelization on accuracy of calculation should be carefully investigated, especially in cases, where it is necessary to use more robust parallelization and numbers of processors.

Acknowledgement

This paper was supported by the Slovak Science Foundation VEGA (project No. 2/0184/14).

5. References

[1] Weisenpacher P, Glasa J, Halada L, Valasek L and Sipkova V 2014 Comput. Inform. 33 6 1237-1268

[2] Glasa J, Valasek L, Halada L and Weisenpacher P 2014 J. Phys.: Conf. Ser. 490 012067 DOI: 10.1088/1742-6596/490/1/012067

[3] Halada L, Weisenpacher P and Glasa J 2012 Computer modeling of automobile fires (chapter 9) In Advances in modeling of fluid dynamics InTech Publ. 203-228

[4] Weisenpacher P, Halada L, Glasa J and Astalos J 2014 Influence of parked cars on smoke propagation during car park fire Proc. of the 26th European Modeling & Simulation Symposium Bordeaux 384-391

[5] Zhao Z, Yao H, Liang D and Hu Z 2011 Procedia Eng. 11 723-729 DOI:10.1016/j.proeng.2011.04.719

[6] McGrattan K, McDermott R, Floyd J, Hostikka S, Forney G and Baum H 2012 Int. J. of Comput. Fluid Dynamics 26 (6-8) 349-361

[7] McGrattan K, Klein B, Hostikka S and Floyd J 2009 Fire Dynamics Simulator (Version 5): User’s Guide, NIST Special Publication 1019-5, NIST, Washington