THE IMPACT OF CAR PARK FIRE ON CONCRETE STRUCTURE
Parallel Computation

Peter Weisenpacher [a], Jan Glasa [a], Ladislav Halada [a], Lukas Valasek [a], Miroslav Dobrucky [a]

[a] Institute of Informatics, Slovak Academy of Sciences, Bratislava, Slovak Republic

Abstract
This study examines the influence of automobile fire in a car park on concrete parts of the structure. In 2009, a series of full-scale fire experiments in open air was conducted, including the fire in automobile interior and its influence onto a vehicle in its vicinity. We performed a set of simulations of this scenario, using the NIST FDS system, version 5.5.3. Comparison with experimental data confirmed the simulation reliability. In this paper, we use material properties of car interior materials established by our research to simulate a car fire in a small part of car park containing two burning cars and its influence on concrete ceiling and a pillar in the vicinity of the cars. We use here the calculation with 48 and more MPI processes to evaluate the ability of high performance computing to solve problems of structural fire safety.

Keywords: computer simulation, automobile fire, car park, parallel calculation

INTRODUCTION

A danger of fires in car parks and other transportation structures is still actual. Flames, radiation, smoke and other toxic fire products constitute a direct threat for human lives. However, there is another danger caused by fire, which endangers both people and property. Structures can suffer from intensive fires with long duration and their destruction could lead to severe damages.

This article is focused on support, which can be provided to fire safety precautions by computer fire simulation. Prediction of the fire behaviour and its impact on structure can be an important part of such precautions. Recently, various fire simulation systems have brought the possibility to use computer fire simulation to better understand the dynamics of such fires and enrich results of full-scale fire experiments, which are usually expensive and less flexible with respect to the change of scenario parameters (Heinisuo et al, 2012). We examine the influence of automobile fire in a car park on some concrete parts of the structure. In 2009, a series of full-scale fire experiments with several cars in open air was conducted in testing facilities of Fire Protection College of Ministry of Interior of the Slovak Republic in Povazsky Chlmec. These experiments included a fire in car interior and its influence onto a vehicle in its vicinity.

We performed a set of sequential and parallel simulations of this scenario using the NIST FDS simulation system, version 5.5.3 (McGrattan et al, 2009). The simulation results compared with the experimental data confirmed the simulation reliability and significant performance increase of parallel computation. In this paper, we use material properties of dominant flamable materials in car interior established by our research to simulate car fire in a small part of a car park containing two burning cars and its influence on concrete ceiling, pillar and joist in the vicinity of the cars. The computational domain does not include walls. As our previous research (Weisenpacher et al, 2012) has confirmed the reliability of parallel FDS simulation, we use here cluster computation with 48 and 72 MPI processes to evaluate the ability of high performance computing to solve problems of structural fire behaviour.

1 FULL-SCALE EXPERIMENT OF AUTOMOBILE INTERIOR FIRE

The full-scale experiment of automobile interior fire and its spread onto another near standing car (Fig. 1 and 2) was carried out in November 2009 in Povazsky Chlmec (Svetlik, 2010, Polednak, 2010). We used new functional automobile Kia Cee'd with only slightly damaged passenger compartment (scorched driver's seat). The right front and left rear side windows were broken in order to increase the oxygen supply. The second automobile, an older model of BMW, was located lengthwise in the 50 cm distance. Three thermocouples were used to detect the gas temperature: in the interior of the first automobile above the driver's seat, above the roof and in the luggage compartment. One thermocouple was located at the BMW bonnet side. The fire behaviour observations were recorded by digital cameras and an infra-red camera. The fire was ignited by burning of a small amount of gasoline (about 10 ml) poured onto a cloth placed onto the back seat behind the Kia driver's seat (under the broken window).

Fig. 1 Ignition of experimental fire

Fig. 2 Experimental fire behaviour

After several dozens of seconds, the fire became visibly more intensive and after 2 minutes the whole passenger compartment started to burn and flames reached over the roof through the broken windows. During the next minutes, the rest of the windows were broken and the temperature inside the interior reached the value of 1000 °C. After 7 minutes, a rubber sealing of the nearest BMW window ignited. After 12 minutes the fire was suppressed.

2 FDS SIMULATION OF EXPERIMENTAL SCENARIO

We created an FDS model of the fire scenario including both tested automobiles (see Fig. 3). composed of aluminium alloy sheets, rubber tyres and glass windows. The first automobile also included interior equipment such as seats, dashboard with a wheel and interior lining. The second automobile model included the window rubber sealing in the location, where ignition occurred during the experiment. We used table values for standard material properties such as parameters of aluminium and rubber, and some parameters from (Andreini et al, 2011) for two interior equipment materials ('UPHOLSTERY' for seats and 'PLASTIC' for other equipment) as their first approximation. Finally, we obtained realistic fire behaviour of simulated fire for the parameters given by Tab. 1.

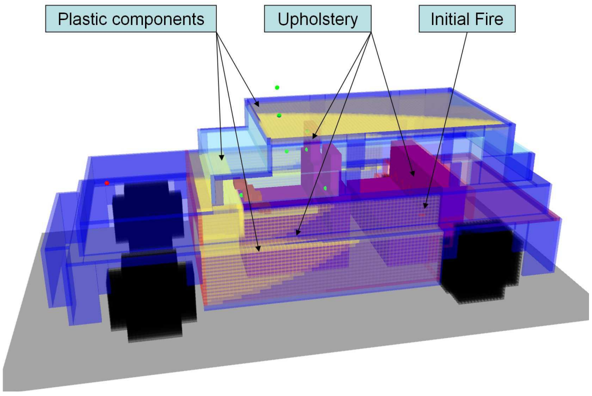

Fig. 3 Automobile interior model

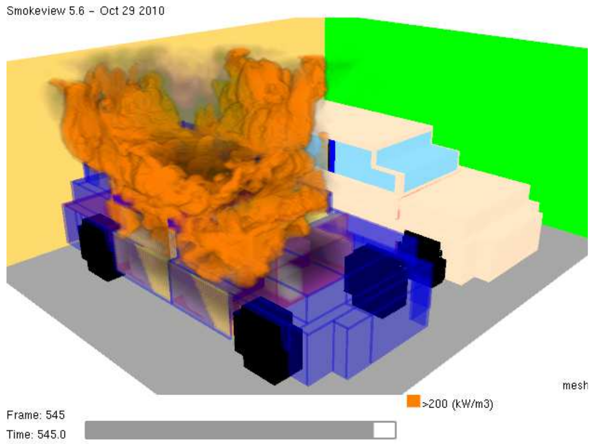

Fig. 4 Simulated fire behaviour

Tab. 1 Optimised properties of car interior materials

Type of Material	T_{ign} [°C]	H_v [kJ.kg^{-3}]	HRRPUA [kW.m^{-2}]	ρ [kg.m^{-3}]
'UPHOLSTERY'	370	4000	200	80
'PLASTIC'	440	4000	250	930

The size of computational domain was 576 x 486 x 240 cm. For the 3 cm mesh resolution, the simulation included 192 x 162 x 80 cells (2,488,320 cells). Qualitative behaviour of the simulated fire was very similar to the fire observed during the experiment (see Fig. 4). Simulation is described in detail in (Weisenpacher et al, 2012). We can conclude that the temperature in the car interior, which was the most important for the results reliability confirmation, was in very good agreement with experimental measurements. The results for exterior thermocouples were less satisfactory. Our results also agree with the main conclusions of the paper (Okamoto et al, 2009), in which the 3 MW HRR peak and 1000 °C interior temperature peak after flashover in the passenger compartment were observed as well as the influence of the windows breakage on burning behaviour, which was also an important factor of our simulation.

3 FDS SIMULATION OF CAR PARK FIRE

The simulation described in the previous chapter validated the FDS model of scenario in which two cars with elaborated interior equipment are dominant source of fire. An important question connected with this scenario is what would be the impact of such fire on concrete construction of the car park. We elaborated a scenario of car fire in a small part of a car park containing two burning cars. The computational domain did not include car park walls (boundary condition 'OPEN'), only the concrete floor, ceiling and a pillar and joist in the vicinity of the second car. The computational domain size was 864 x 864 x 300 cm with the 3 cm mesh resolution. The simulation included 288 x 288 x 100 cells (8,294,400 cells). As the previous simulation confirmed the reliability of parallel simulations up to approximately 100 MPI processes, the domain was decomposed to 48 and 72 meshes, each of them assigned to specific CPU core. The source of fire (27 x 27 cm area with 1000 kW HRRPUA) was placed on driver seat, under the broken front left window. The simulation included 45 minutes of fire. The HRR was increasing after windows of the first car were broken and fire afflicted

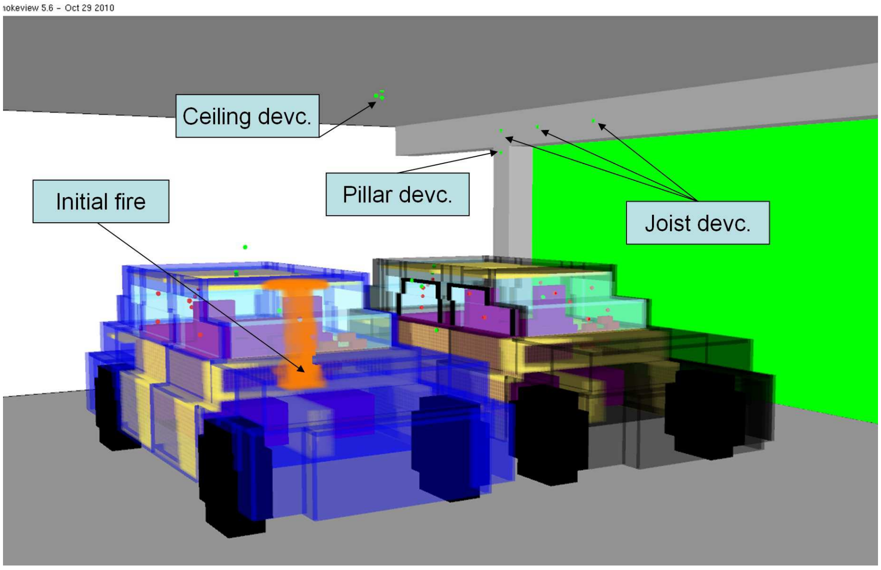

Fig. 5 Simulation configuration: mutual position of automobiles

Fig. 6 Fire behaviour at the 372nd second

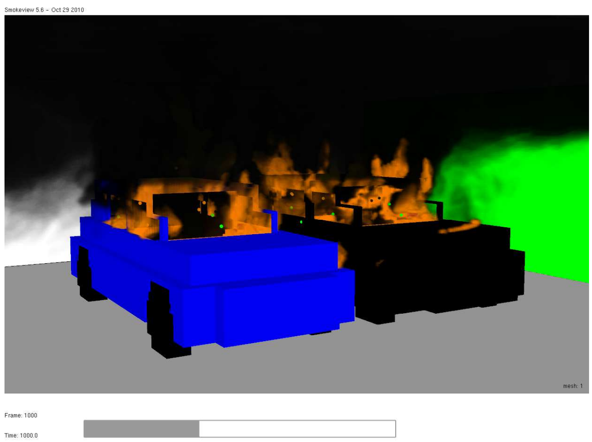

Fig. 7 Fire behaviour at the 1000th second

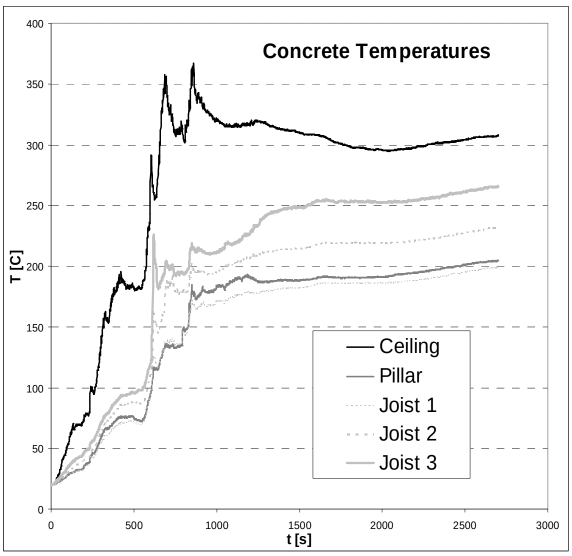

Fig. 8 Concrete temperatures behaviour

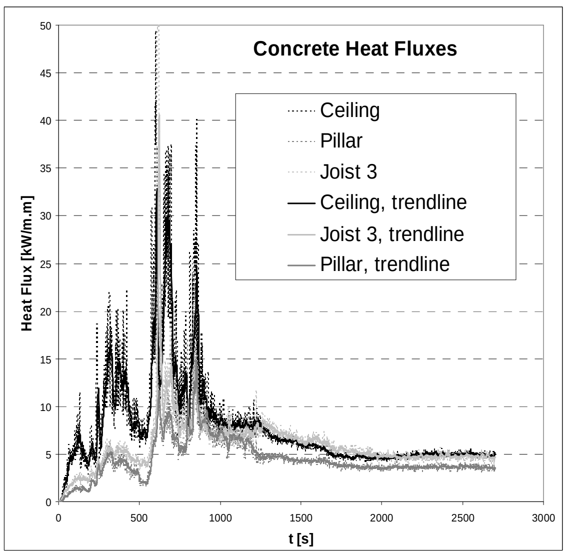

Fig. 9 Concrete heat fluxes behaviour

the second car, until it reached approximately 6 MW at the 15th minute and then it dropped slightly and stabilised above 4 MW. The most important devices measuring temperature and heat flux were placed on the ceiling, pillar and joist (see. Figs. 5-7). These quantities as well as HRR behaviour can be seen in Figures 8-13. Some parameters characterising the fire behaviour and simulation performance are presented in Tab. 2. As some uncertainty concerning material properties of main materials must be taken into account, we performed also a simulation in which the 350 kW HRRPUA for both materials was used. In this simulation, significantly higher HRR was achieved (see Fig. 11).

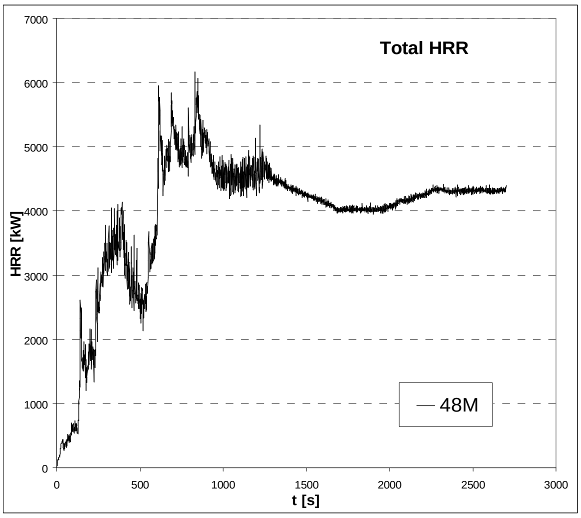

Fig. 10 HRR behaviour for 48M simulation

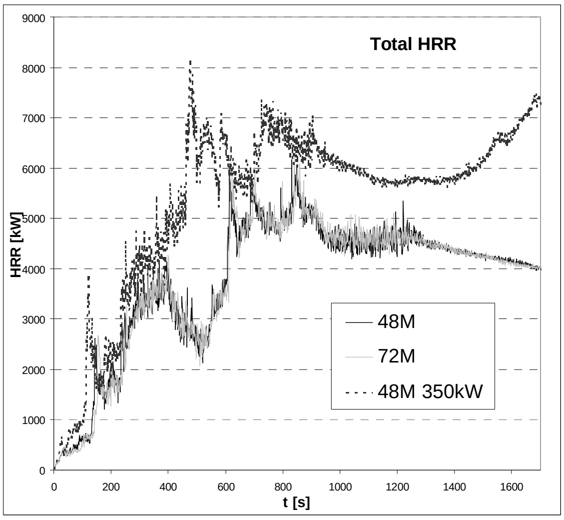

Fig. 11 HRR of different simulations

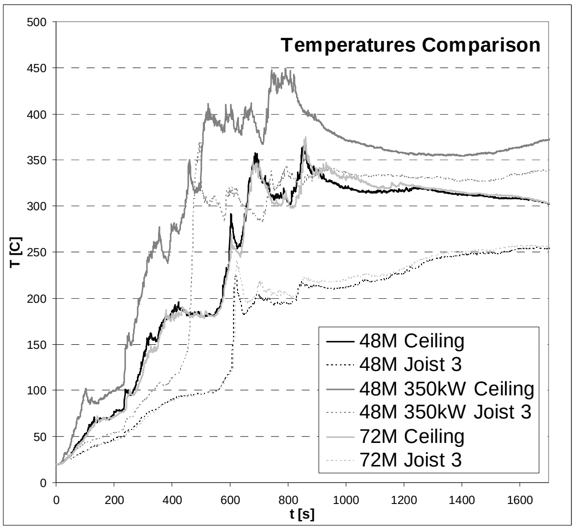

Fig. 12 Temperature behaviour of different simulations

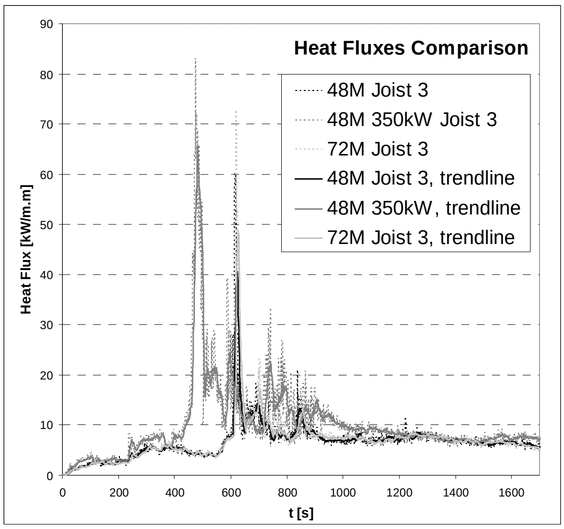

Fig. 13 Heat fluxes of different simulations

Tab. 2 Simulation results and calculations performance. t_{FL1} and t_{FL1} is time of flashover of the1st and 2nd car interior, respectively, t_{IGN} is the time of the 2nd car bodywork ignition, $T_{ceil,max}$ is the maximal ceiling temperature, $t_{ceil,max}$ is the time in which this temperature was achieved and T_{j1700} and q_{j1700} is the temperature and heat flux of concrete joist at 1700th second.

	t_{FL1} [s]	t_{IGN} [s]	t_{FL2} [s]	$T_{ceil,max}$ [°C]	$t_{ceil,max}$ [s]	T_{j1700} [°C]	q_{j1700} [kW.m^{-2}]
48M	28	224	548	367	861	254	5-6
72M	28	233	553	371	862	255	5-6
48M, 350	20	180	403	448	792	338	7-8

3 SUMMARY

The simulations results suggest, that car fire of such extent as was considered in the simulation does not constitute any critical threat for construction stability, which is in accordance with (Zhao et al, 2004). However, the simulations results are strongly dependent on material properties, especially on HRRPUA of interior equipment materials. Further research is required to refine these values in order to increase the simulations reliability. Moreover, the more detailed model of the complete car, not only the passenger compartment is needed to obtain more realistic fire behaviour during the whole period of fire (see the fire behaviour after the 1200th second in Fig. 10). Nevertheless, our simulation demonstrated potential of the FDS computer simulation to contribute to solving problems connected with structural fires even in very complex fire scenarios.

4 ACKNOWLEDGMENTS

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