Preliminary research on virtual thermal comfort of automobile occupants

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Abstract. Numerical simulation of climate conditions in automotive industry for the study of thermal comfort had become more and more prominent in the last years compared with the classical approach which consists in wind tunnel measurements and field testing, the main advantages being the reduction of vehicle development time and costs. The study presented in this paper is a part of a project intended to evaluate different strategies of cabin ventilation for improving the thermal comfort inside vehicles. A virtual thermal manikin consisting of 24 parts was introduced on the driver seat in a vehicle. A heat load calculated for summer condition in the city of Cluj-Napoca, Romania was imposed as boundary condition. The purpose of this study was to elaborate a virtual thermal manikin suitable for our research, introduction of the manikin inside the vehicle and to examine his influence inside the automobile. The thermal comfort of the virtual manikin was evaluated in terms of temperature and air velocity.

1 Introduction

Computational Fluid Dynamics (CFD) methods are applied nowadays more and more in all stages related with conception of a motor vehicle. Among them, a particular interest for us represents the use of numerical simulations in predicting the thermal comfort of automobile occupants. In the last years regardless of the vehicle brand, an increased attention is oriented to the thermal comfort of the automobile occupants. The number of people spending a significant portion of their time in transportations is rising, and hence, there is an increasing demand for thermal comfort while traveling.

A more comfortable climate in automobile in almost all cases will work towards reducing driver's stress and thus contributes to a safer driving. In addition, today's demands for energy efficiency and performance, have led to an increased interest in investigating and analyzing the system and design requirements for good quality of the vehicular environment.

However, there are a few constraints which are making difficult this task: demands in increasing the fuel economy and tendency to use more glass in automobile design being among them. In order to achieve the thermal comfort inside the automobile a first step will be to evaluate the heat load that enter in the occupant's area. Is important that this evaluation to be obtained in the early stage of the vehicle design and this can be accomplished using CFD method, studies in the literature successfully applied this method [1-7].

The common interpretation of "thermal comfort" regards the state of a person that would express a feeling of wellbeing regarding the thermal conditions in an occupied space. However, thermal comfort is a term difficult to define and a universal definition of its meaning is almost impossible to obtain [8]. Nevertheless, it is the tangible interest of engineering applications that motivated a never-ending quest of quantitative models for estimating, predicting or classifying the state of thermal comfort in occupied spaces. Almost all these attempts are focusing on the physiological component. Most of them are relying on the assumption that the state of thermal comfort might be ensured when the heat produced in excess by the human body through its metabolic sources is dissipated in the environment and the thermoregulatory system intervention is infinitesimal. This way it is universally accepted nowadays that an environment is considered comfortable from the thermal point of view, when 80% to 90% of people from that environment do not express thermally dissatisfaction [9-12].

Achieving thermal comfort assume that both psychological and physiological factors are fulfilled with some degree. The air velocity, thermal radiation and temperature fields are among the most important factors that influence thermal comfort, thus in order to improve the design of a vehicle in terms of thermal comfort it is necessary to investigate the air-flow field and the temperature distributions inside the automobile.

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2 Material and method

2.1 Geometry

In a previous study [4], we evaluated a simple approach of calibrating and validating a CFD model that reproduces the thermal environment and the flow dynamics inside a simple vehicular cabin. In this new study, a virtual manikin was installed in the automobile on the driver's seat. For this purpose, we studied tens of virtual manikins available on the web, we tried to pose them in driving position. We failed with almost all the geometrical models for the virtual manikins from different reasons. We succeed with one virtual manikin by reconstructing parts from his body, an image with the reconstructed virtual manikin in driving position is presented in Fig. 1a. The construction of the virtual manikin was made taking into account other real thermal manikins developed in our laboratory [13]. The virtual manikin was split in 24 parts (Fig. 1b) related with the anatomic parts of a real human.

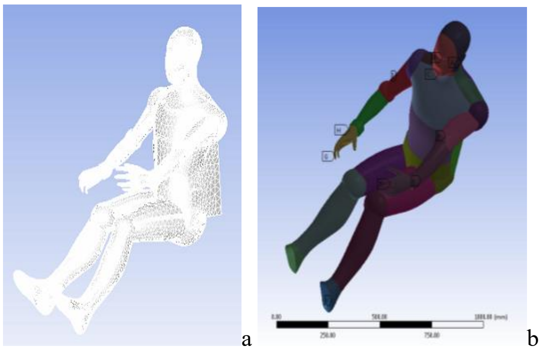


Fig. 1 Virtual thermal manikin used in this study

The studied vehicle geometry was built in SolidWorks. The virtual manikin was introduced into the vehicle studied in [4] with the purpose to simulate the presence of the driver (Fig. 2 and Fig. 3).

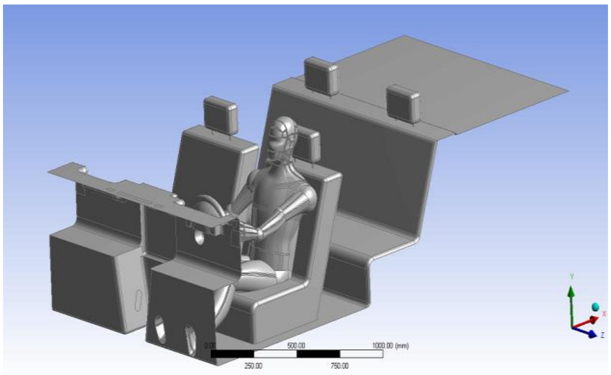


Fig. 2 Isometric view of the studied geometrical model

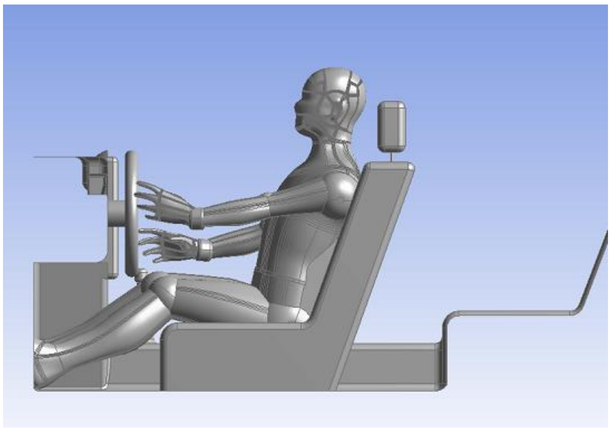


Fig. 3 Side view of the studied geometrical model

2.2 Mesh

The numerical grid was realized in Ansys Workbench. A fine mesh consisting of 6.5 million elements was created based on the experience from the previous studies where we performed the grid dependence test [4]. The boundary layer consists in five layers, with the first cell height of 0.75mm and a growth factor of 1.2.

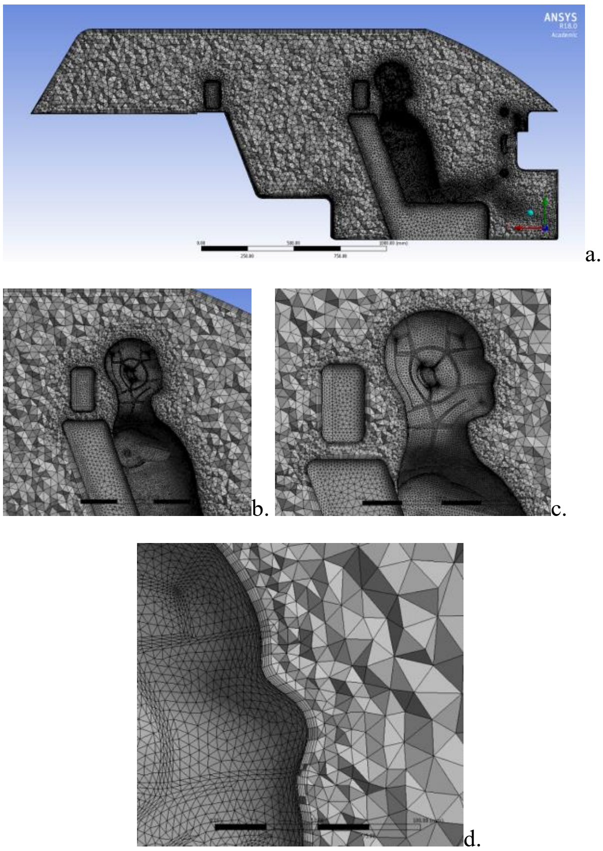


Fig. 4 Tetrahedral mesh used for numerical simulation (different closeups)

2.3 Boundary conditions and setup

The introduction of air in the interior of the automobile was considered through the four air diffusers positioned on the dashboard of the vehicle using the appropriate airflow for the middle level of the air cooling system

(35m^3/h on each diffuser, air temperature: 18°C). The air jet is directed to the sides of the thermal manikin. Findings from previous studies considering the jet impacting into the surface have been taken into consideration in this study [14, 15].

Temperatures on the surface of the manikin body represent the skin temperature on different areas of the human body (Table 1, Fig. 5).

Table 1 Temperatures of the manikin parts

Body part	Foot	Calf	Thigh	Abdomen	Back and chest	Head	Arm	Hand
Temperature [°C]	28	31	32	33	35	37	33	35

Fig. 5 Thermal manikin temperature distribution

A calculated radiative heat flux for the condition in the summer in the city of Cluj-Napoca, Romania was imposed on the windshield (951 W/m^2), left window (966 W/m^2), right window (792 W/m^2), lest doors (389 W/m^2), right doors (52 W/m^2), ceiling (908.6 W/m^2). A mention is that the automobile is heading west in this numerical simulation. The radiative heat flux for each orientation and part of the automobile was calculated using real climatic data for the city of Cluj-Napoca, Romania. An example of result for the solar radiative heat flux on the windshield of the studied automobile can be seen in Fig. 6.

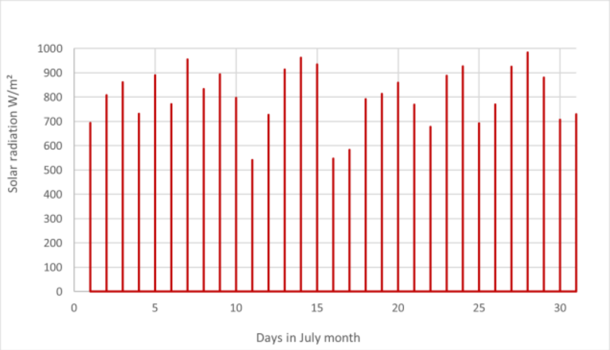


Fig. 6 Solar radiation intensity for the July month in Cluj-Napoca on the windshield

The numerical simulation was carried out in Fluent software [16]. The coupled algorithm was used for the pressure-velocity coupling. Also, a second order upwind scheme was considered for the calculation of the convective terms.

The turbulent model used was SST k-ω, a model which in the field of incompressible flow provides satisfactory results for both free flow and flow near the walls.

2 Results and discussions

As we already stated, the purpose of this study was to elaborate a virtual thermal manikin suitable for our research, introduction of the manikin inside the vehicle and to evaluate his influence inside the automobile.

The numerical validation of the vehicle geometry was studied in the mentioned article [4], a good agreement between the CFD model data and the measured data inside a real vehicle being obtained.

First stage of the numerical simulation was represented by the numerical simulation of the thermal plume of the virtual manikin. For this there was no flow rate from the air distribution system. The only source of heat was the virtual thermal manikin inside the automobile. Temperature field can be seen in Fig. 7a and velocity field in Fig. 7b.

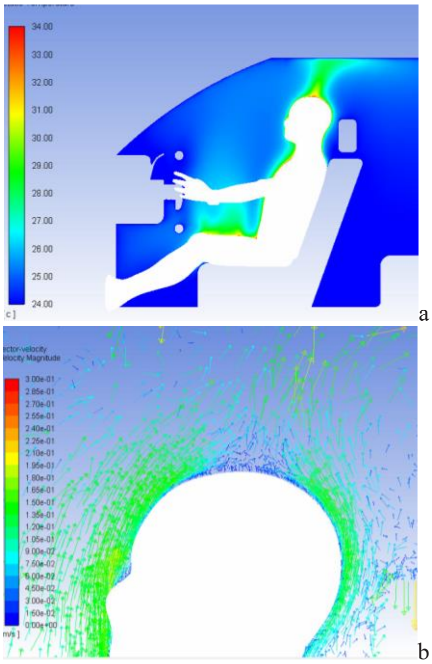


Fig. 7 Thermal plume for the virtual thermal manikin a. temperature field b. velocity vector field

In the second stage, the numerical simulation continued with the boundary conditions presented in the previous chapter. In Fig. 8 we have represented the temperature distribution in the sagittal plane of the virtual thermal manikin along with temperature distribution on the manikin body.

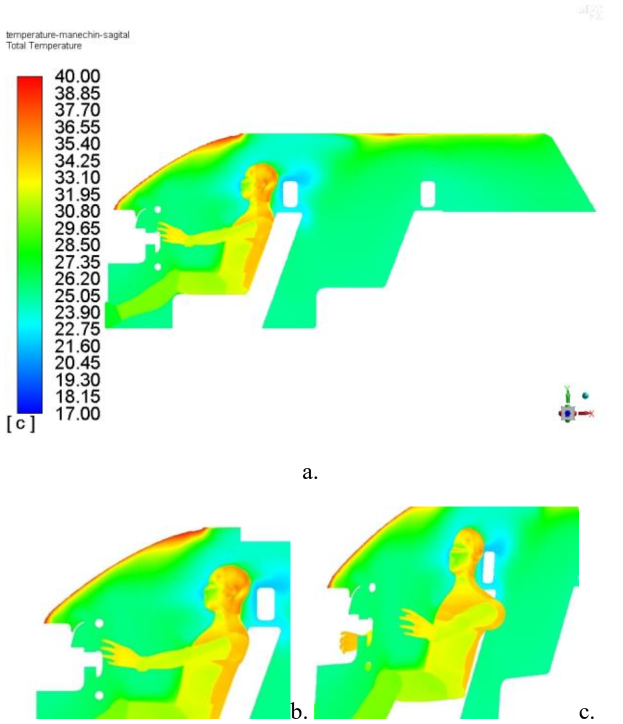
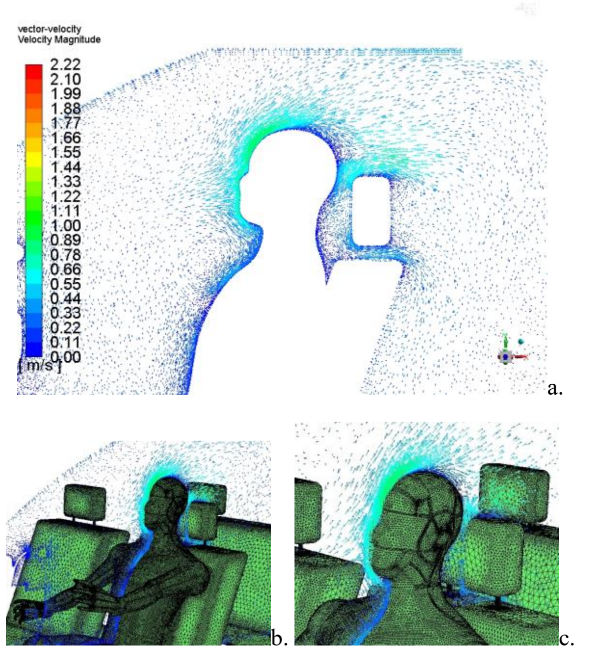


Fig. 8 Temperature distribution in the interior of the car in the sagittal plane of the virtual manikin

In Fig. 9 we can see the velocity field in the sagittal plane for the virtual thermal manikin.



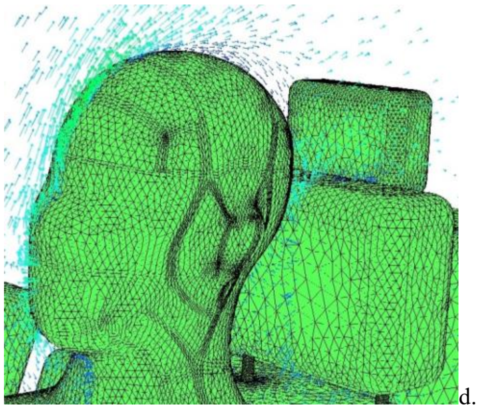


Fig. 9 Velocity field in the sagittal plane of the virtual manikin

3 Conclusions

This study continues the work started in [4] by introducing a virtual thermal manikin in the previously tested automobile interior. The study tries to evaluate a simple approach of a CFD model that models the thermal environment and the flow dynamics inside the interior of an automobile with a virtual thermal manikin present inside the vehicle. The main conclusion is that the virtual model is valid and is ready to be used in the next researches regarding thermal comfort in vehicular spaces.

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