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Development of virtual 3D human manikin with integrated breathing functionality

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Development of virtual 3D human manikin with integrated breathing functionality: *The presented paper concerns the stages of design and development of a virtual model of breathing human manikin. The breathing process is accomplished by preliminary developed compact pneumatic system, which provides the possibility for human breathing cycle simulation. The proposed virtual model is used for numerical analysis and assessment of the microclimate parameters indoors. It is also suggested as additional functionality of the real sophisticated thermal manikins. The created virtual model realistically reflects the size of a standard person and allows fully accurate positioning of the hands and legs in space. The virtual concept is reduced to simplified, but anatomically realistic component forms. This supports significantly the future development of a real prototype. The presented work is supported by "RDS" at TU-Sofia, as part of the activities under the "Perspective leaders" project, with Contract № 161ПР0004-02, entitled: "Integration of schematic solution of pneumatic system, for simulating the breathing cycle of human occupants, in virtual model of breathing manikin".*

Key words: *Indoor Environment, Indoor Air Quality, Thermal Manikins, Experimental Studies, Breathing Cycle, 3D Modelling.*

INTRODUCTION

The thermal manikins are quite important tools in the engineering practice, as they represent accurate models of the human body and make it possible to simulate different levels of physical action, as well as some human activities such as breathing, sweating, sneezing, coughing and others [1, 2]. They are very complex instruments and are used also to study the convective flows around human bodies in different conditions, without excessive risk of exposure to the people themselves. However, experimental studies with real thermal manikins are expensive, time consuming, require highly skilled labor and are relatively difficult to conduct. Therefore the use of virtual thermal manikins (VTMs), particularly at the design and prediction stage of the indoor environment, seems to be appropriate alternative to the actual thermal manikins' experiments [2, 3].

Therefore, in the recent years, the studies with VTMs are focused in designing additional features, including simulation of the respiration process in humans [2, 4]. However, further studies have shown that breathing as physiological process is still rarely modeled and especially rare are modeled the inhalation and exhalation flows [1, 2, 10]. Most of the efforts in creating VTMs are concentrated in developing their heating functionality. There is a need to conduct numerical study of the interaction between air flows generated by inhalation and exhalation, and the convection flows from the heated surfaces of the manikin. Of particular interest for the development of the breathing functionality of VTMs, would be the determining of realistic position and geometry of the simulated nostrils, which is partly revealed in the current paper.

AIM OF THE PRESENTED STUDY

The aim of the presented study is to model a realistic position and geometry of the outputs simulating nostrils, on the face of a virtual thermal manikin, and also to analyze the behavior of the air flows, generated in the process of breathing. To meet the aim, the following tasks are defined:

- To construct a simplified 3D model of a VTM, with a possibility of simulating different steady-state phases of the respiration process in humans, namely "inhalation" and "exhalation".
- To explore and compare the flows in the VTM's breathing zone at the simulated

"inhalation" and "exhalation" phases.

● To construct a simplified 3D model of a virtual manikin, representing accurately the size of a standard person and allowing completely realistic positioning of the limbs in the space.

METHODS

The research methods used are based on the Computational Fluid Dynamics (CFD). Two studies in stationary conditions are performed, simulating the main phases of the human respiratory cycle - inhalation and exhalation. In both cases, adapted ENGYS® (www.engys.com) version of the CFD code OpenFoam® (www.openfoam.com) is used. Numerical model comprises the RANS method in combination with k-□ SST (Shear Stress Transport) turbulent model [7, 11]. In both simulations, the results converged at approximately 9000 iterations, and additional 1000 iterations were conducted, in order to average and refine the deviations in the values of simulated flow fields. The calculation and linking of the velocity and pressure equations is performed by the "SIMPLE" algorithm. Detailed information for the algorithm and the relaxation coefficients are presented in [3].

GEOMETRICAL MODEL, COMPUTATIONAL GRID, BOUNDARY CONDITIONS

Comprehensive model of a female manikin was revised and adapted for the purpose of the present study, and it is shown in Figure 1. The approximate area of the manikin is 1.8 m^2, and its height is 1.65 m. The nasal cavity was built according to the study of Lin [5] and the opening of the nasal valve area is 0.73 cm^2. The inclination of the nostrils (α) is 45 degrees to the vertical axis of the body of the manikin and the slope of the simulated flows (α) is 15 degrees to the normal of the back wall of the simulated nasal valve [8,10].

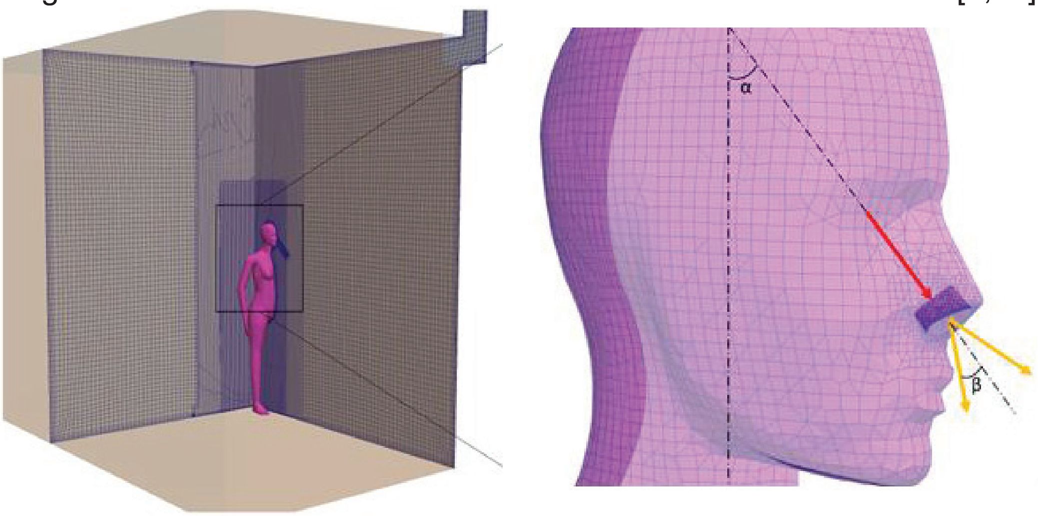

Figure 1. Computational grid and geometrical model of the VTM

Also for the purpose of the study, a 4 x 4 meters rectangular room is constructed, with height of 3 meters. The manikin is placed in the center of the room. In order to adjust the mass balance in the control volume, the room is equipped with a 0,08 m^2 opening in the ceiling level, above the manikin. Since the objective of the study is to model the human breathing process in stationary conditions, there was no ventilation system simulated in the room.

The computational domain is discretized using snappyHexMesh® [11]. The computational grid is made up of 1 140 000 control volumes, based on cells with different shapes. To reduce the computation time, and since the presented case is axisymmetric, only half the computational domain is modeled, and respectively half of the virtual thermal manikin as well. The size of the reference cell in the computational grid is 40 mm, but in order to simulate the precise geometry of the nasal cavity, the size of the cells in this region is reduced to 0,625 mm.

The volumetric flow rate through the nasal valve, the Reynolds number and turbulent flow characteristics into the nostril, are calculated according to the research of Lin and Nigro [5,8]. The value of the turbulent intensity in the presented case is 6.8%. The flow rates, during inhalation and exhalation, are respectively 0.629 l/s and 0.691 l/s, and the temperature of the generated air flow is 36^{o}C. The temperature of the walls of the room, and the air in inside, have fixed value of 20^{o}C, and the pressure in the model is 101 325 Pa.

The boundary conditions, on the surface of the manikin's elements, are adapted from the studies of Nilsson [9, 10]. The coefficients of heat transfer are fixed over the different parts of the body and the heat flux is calculated by considering the total surface area of each element of the manikin. The total heat output is 110 W for the entire surface of the manikin. Details for the coefficients of each element are published in [3].

NUMERICAL RESULTS AND DISCUSSION

Part of the results from the numerical study is presented in Figure 2, by velocity fields' visualization. The results clearly show that the generated air flow by the simulated breathing significantly affects the convective flow and the boundary layer around the warm body of the thermal manikin. This influence is much less visible during inhalation, while during exhalation it is significantly greater. The figures also show that during inhalation, the effect over the free convective flow is located within the breathing zone, and does not cause significant change of thermal plume velocity over the head of the manikin. Conversely, when exhaling, a significant disturbance of the free convective flow around the manikin's body is observed. This disturbance changes the flow over the manikin's head, and reduces the thermal plume velocity.

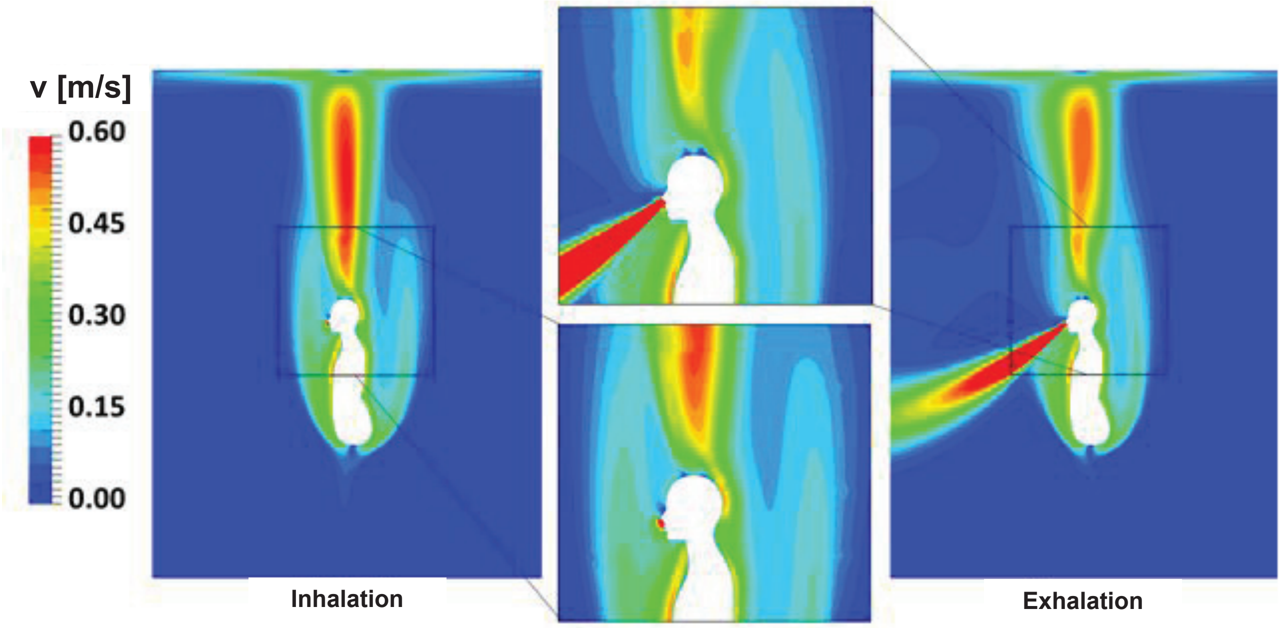

Figure 2. Velocity profiles during inhalation and exhalation (Also presented in [4])

Overall, the results show good correlation with the actual physical phenomena in both simulated cases. In stationary conditions, the simulated results are stable and the calculation time is considerably less, as opposed to the non-stationary simulations. Also, the boundary conditions are simple and the results show the indicative impact of the simulated breathing over the convective flow around the manikin's body.

However, simulations under stationary conditions can lead to over prediction of the resultant impacts. The implementation of transient conditions will illustrate more precisely the dynamics of the simulated processes, and the turbulent air flow will be better predicted in the manikin's breathing zone. Also, transient simulations will allow the implementation of more sophisticated techniques such as Large Eddies Simulation (LES) and Detached Eddies Simulation (DES). These techniques, for example, would allow deeper analysis of the dynamic effect of the surface cooling of the different manikin's parts.

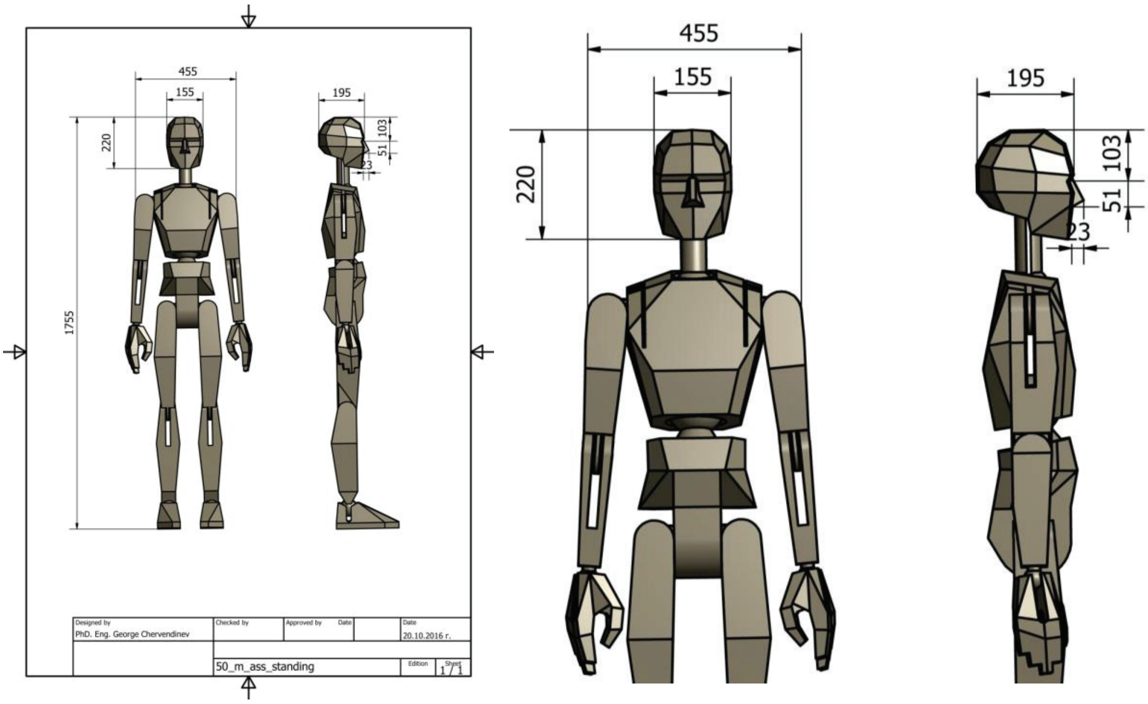

Figure 3. Development stage of 3D model of a virtual manikin, representing accurately the size of a local standard person

Figure 3 shows partly the development stage of 3D model of a virtual manikin, representing accurately the 95th percentile of the anthropometric size of a standard local person. It is designed by the Engineering Design Department at TU-Sofia, and allows completely realistic positioning of the hands and legs in the space. The virtual concept is reduced to simplified, but anatomically realistic component forms, which support significantly the future development of a real prototype. The next stage will be to implement the discussed above breathing flow simulation within this accurate virtual manikin, but under the complex transient conditions.

CONCLUSIONS

● A CFD based, steady state simulation study, of the inhalation and exhalation phases of the respiratory cycle in humans, is designed and performed. The position and the geometry of the simulated nostrils, as well as the breathing flows, are modeled as realistic as possible.

● The results show good correlation with the actual physical phenomena in both simulated cases – the inhalation and the exhalation. In both cases, the generated breathing air flow significantly affects the convective flow and boundary layer around the body of the heated manikin. This effect is more distinctive in the simulated exhalation phase. But simulations under stationary conditions can lead to over prediction of the resultant impacts, so the implementation of transient conditions is recommended.

● The results achieved in the present study, provide new and valuable approach for the integration of various techniques in the development of additional functionalities for the virtual thermal manikins.

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This paper has been reviewed.