Mitteilung

Projektgruppe/Fachkreis: Numerical Simulations

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Thema: **Conjugated Heat Transfer in a Generic Aircraft Cabin with a Coupled Finite Volume and Particle Method**

Ausgangssituation: The thermal comfort of passengers is the essential design objective in the cabin air ventilation layout for modern civil passenger aircraft [1]. The heat flux in an aircraft cabin depends on many physical factors, for example solar radiation, electrical equipment, heat release of the passengers and the interior. Our focal point is the influence of the monuments, for example seats, which are heated up and, if the room temperature drops, returning their heat to the environment. This effect is of major importance for the control of environmental control systems (ECS), since the reaction to a changed heat inflow will be delayed. Usually, only the heat flux in the cabin air is simulated with stationary boundary conditions for the ECS and radiation models for the monuments. Solving the Reynolds averaged Navier Stokes equations with a buoyancy term for the cabin air and additionally the heat transfer inside the monuments both with finite volume methods would be very time consuming. A solver which solves the heat transfer inside the monuments in linear time reduces the runtime significantly.

Ziel: The goal is to analyse the heat flux in a generic aircraft cabin, where the focal point is the reaction of the monuments to air inflow with varying temperature, i.e. non-stationary boundary conditions. To realize this goal, we develop a combined solver which has linear runtime for the solid parts.

Lösungsweg: The heat flux in an generic aircraft cabin is calculated with a standard finite-volume solver inside the fluid region. The monuments are modelled with a discretisation of their volume, where the discrete points are referred to as particles. These particles must not be equidistant spread and there is no mesh required. We apply a particle diffusion method called particle strength exchange (PSE), see for example [2], which is in fact a vortex method. However, since the method supplies a discretisation of the laplace operator Δ, we can apply it to solve the heat equation

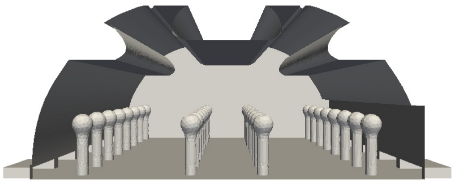
$$\partial_t T = \lambda \Delta T,$$
$$T(t_0) = T_0,$$

where T is the temperature in Kelvin and λ is the coefficient of heat transfer, in the solid part. Let $\mathbf{x}_1, \ldots, \mathbf{x}_n$ be the positions of the particles. The solution in the monuments is then computed by using the discretisation

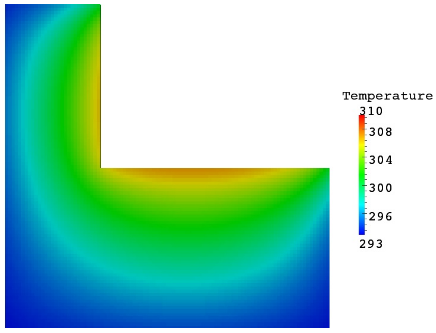
$$\Delta_\epsilon T(\mathbf{x}_p) = \epsilon^2 \lambda \sum_{q=1}^{n} (T_q - T_p) \phi_\epsilon(\mathbf{x}_q - \mathbf{x}_p),$$

for all $1 \leq p \leq n$, and an explicit Euler scheme. Here, ϵ is a smoothing parameter, $\phi_\epsilon : \mathbb{R}^d \to \mathbb{R}$ is a smooth radial kernel, for example a Wendland function (see [3]), and the $\mathbf{x}_p$ are the particle positions. For a good choice of the kernel, the computational complexity can be reduced to linear time. The computational error of the scheme is $(h/\epsilon)^2$, where h is the characteristic distance between the particles. The coupling between the finite volume solver and the PSE method is done over the boundary via interpolation with radial basis functions. Furthermore, the PSE method is not restricted to solve the heat equation in only one material. Therefore different materials will be simulated to create a more realistic aircraft cabin.

Ergebnis: The generic aircraft cabin used is displayed in figure 1(a). It consists of 24 monuments, where the heat equation is solved with the PSE method. The hot and cold air inlets are on the ceiling, the outlets are on the bottom. An example for the heat diffusion with the PSE method is given in figure 1(b). Here, the solution after 5 seconds in a cold generic seat is displayed. The seat and the seat back are heated (310 K) while the remaining boundaries are cooled by the cabin air (293 K). The developed process chain ensures that the heat flux over the boundaries of the monuments is conservative. It successfully combines the two independent solvers to model the heat flux in the cabin.



(a) The CAD-model of the generic aircraft cabin.



(b) PSE solution for the cold seat after 5 seconds.

Literatur:

[1] ASHRAE Standard 55-2004. Thermal Environment Conditions for Human Occupancy. Atlanta: ASHRAE.

[2] P. Poncet. Finite difference stencils based on particle exchange schemes for improvement of vortex methods. *Journal of Turbulence*. 2006. Vol. 7, No. 23.

[3] H. Wendland. Piecewise polynomial, positive definite and compactly supported radial functions of minimal degree. *Advances in Computational Mathematics*. 1995.Vol. 4, No. 1, pp 289-396.

Weiteres Vorgehen: Since the PSE approach also holds for the Lagrangian ansatz for convection, the developed solver is not restricted to model only the heat diffusion in the solid part. There are many applications possible, for example heat exchange between fluids, heat dissipation of a brake disc of a car and fluid concentrators. Besides the validation with numerical simulations, the validation with experimental data is also rewarding. Starting from the new solver, existing models for the conjugated heat transfer could be improved.

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