Uncertainty Quantification of a Industrial Scale CFD Application

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For the prediction of physical phenomena or the reliable design of components in engineering applications by means of numerical simulations, the consideration of uncertainties is essential. They result from numerical approximations, uncertain initial and boundary conditions, thermodynamic properties etc. However, Uncertainty Quantification (UQ) of industrial scale applications in the field of Computational Fluid Dynamics (CFD) is computationally expensive. Therefore, the maximum number of computational runs needs to be limited and efficient methods for the reliable prediction of stochastic results have to be applied. In the present work stochastic spectral methods, such as Polynomial Chaos Expansion (PCE) and Karhunen-Loève Expansion (KLE), are used for the approximation of stochastic results and are proven a promising UQ method for industrial scale computational applications. By using a generic test case, different methods were developed and qualified as suitable for the application to engineering applications [1]. Within the scope of this work, the methods were applied for UQ of a application-oriented CFD validation case, which investigates buoyancy-driven mixing processes between two miscible fluids within a vessel of $V \approx 60\,\mathrm{m}^3$, while an underlying natural circulation flow is created by heating the lower and cooling the upper wall sections [2]. As shown in Figure 1b, helium is first injected through a nozzle into the upper part of the vessel, which is initially filled with air. Subsequently, both gases mix due to buoyancy effects. Uncertainties in initial and boundary conditions of the CFD model, which is supposed to predict the underlying flow and transport phenomena, propagate to result quantities, that characterize the mixing process. The progress of the mixing process is determined by the mixture uniformity σ_X.

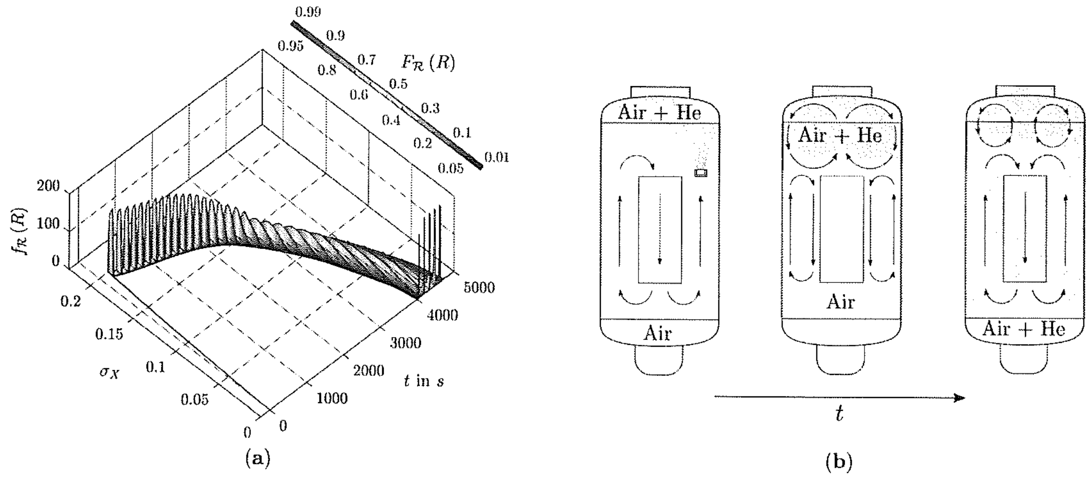

Figure 1: (a) Statistics from stochastic model for mixture uniformity σ_X, (b) Consecutive phases of the mixing process.

Statistics from the stochastic process model are depicted in Figure 1a and comprise probability density functions (PDFs) $f_{\mathcal{R}}(R)$ of the stochastic results at different times as well as the visualization of the cumulative distribution function (CDFs) $F_{\mathcal{R}}(R)$ or quantiles using a color map. During injection, σ_X increases to its maximum value, which represents the inhomogeneous distribution, and decreases to zero after mixing, which represents the homogeneous mixture. This provides information about possible result transients and helps to understand how input uncertainties affect desired results. Future work includes further results quantities with supplemental error estimation and variance based decomposition using Sobol indices.

References

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