Reduced order modeling of the plume dispersion at Doel Nuclear Power Station

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Abstract

An essential part of the nuclear emergency planning is the estimation of the external dose to the general public after the accidental release of radioactive gases. Close to the source or in situations with complex air flow, e.g. in the vicinity of buildings, Computational Fluid Dynamic (CFD) models can provide an accurate solution to the dispersion problem. However, they are generally too compute-intensive to be of practical use during emergency situations. This can be addressed by applying projection-based model reduction methods. The basic principle behind these methods is the projection of the high order CFD system to a representative lower order system. As such, the pollutant dispersion can be simulated at a much reduced computational cost with respect to the full CFD model without a significant loss in accuracy.

In the current work, the pollutant dispersion is modelled using the Reynolds-averaged advection-diffusion equation. Subsequently, the point-kernel method with buildup factors is used to compute the local gamma dose rate. We set up the reduced order model by moment matching of the transfer function of the original system via a Krylov subspace method for large linear systems. The subspace is constructed by the one-sided Arnoldi algorithm which generates a set of orthonormal vectors through an iterative procedure. The Doel Nuclear Power Station is selected as the subject of this study. In particular, the onset of a periodic release from Doel is simulated on a grid of 4.1 million cells. The reduced model is constructed from only 50 basis vectors. The simulations are conducted using the OpenFOAM simulation platform and the PETSc toolkit.

The Krylov subspace method has shown to be very effective. With a negligible difference in estimated dose rate, it takes 90.35 seconds to simulate 1 second using the full CFD model while this is only 5.44 milliseconds using the reduced model. This corresponds to a speedup of more than 16 000 compared to the simulation with the full model. When the computational effort is looked at, taking into account the required number of CPUs to perform the simulation, the reduction is more than 300 000.

Because of the impressive results obtained, model reduction will be further explored during this remaining year of the PhD. In addition, a model intercomparison study will be set up to evaluate the CFD model against operational models.