A FEniCS-based Solver to Predict Time-dependent Incompressible Flows

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Abstract

A new trend in CFD that appears recently for solving industrial problems is to refuse from using commercial general-purpose software in favor of free open source software (FOSS). This allows to construct easy-to-use mathematical tools oriented to solving specific problems with its possible tuning and improvement in the future. The FEniCS (https://fenicsproject.org/) finite element framework provides a widely employed example of such a complete numerical toolkit for solving differential equations of various nature including CFD.

The aim of the present work is to discuss a FEniCS-based solver developed for solving the 2D/3D time-dependent incompressible Navier-Stokes equations. It is based on the Douglas-Rachford algorithm (the method of stabilizing correction/pressure correction method) and employs the Poisson equation to evaluate the pressure with the following correction of the intermediate velocity. Special attention is given to the possibility to predict flows in channels of arbitrary shape. For this aim, various type of boundary conditions have been implemented in the solver (rigid wall, slip wall, symmetry and ”open” boundary conditions).

There are employed the Taylor-Hood (P2-P1) mixed elements, which seems to be the most appropriate in sence of the fulfilment of the LBB-condition and simplicity of use. Three basic formulations of the convective terms were considered: the advective (non-conservative), conservative and skew-symmetric (the half-sum of the two previous) forms. This issue may have essential value for modeling transient flows. Viscous effects were treated via the Cauchy stress tensor in order to omit any questions raised from using the Laplace format.

To validate the numerical algorithm, the method of manufactured solutions (MMS) was applied. Namely, the 2D steady-state manufactured vortex solution was used to evaluate convergence in space for the algorithm. As for time-dependent solutions, the classical 2D corner flow (proposed by van Kan) was predicted numerically in order to study approximation in time. Next, flows in 3D ducts of various shapes (circular, rectangular, tube bundles etc.) have been studied numerically and compared with available analytical or experimental data. The emphasis here is on efficient modeling hydraulics in cores of nuclear reactors and flows in supplement equipment. Some preliminary results of modeling turbulent duct flows using FEniCS have been already published in the paper [1].

References

1. A.G. Churbanov and P.N. Vabishchevich. Numerical investigation of a space-fractional model ofturbulent fluid flow in rectangular ducts. J. Comput. Phys. 321 (2016) 846-859.