Hessisches Kompetenzzentrum für Hochleistungsrechnen

Viscoelastic Flow Simulations

Matthias Niethammer and Dr.-Ing. Holger Marschall

Project Manager
Matthias Niethammer

Principal Investigator
Dr.-Ing. Holger Marschall

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Introduction

The "High Weissenberg Number Problem'' (HWNP) has been a major challenge in computational rheology for the past four decades. It refers to the loss of convergence of all numerical methods beyond some limitingvalue of the fluid elasticity, quantified by a critical Weissenberg number. Although a complete solution is not known until today, effective numerical stabilization methods have been developed to cope with the HWNP. We have developed a generic stabilization library (stabLib) that provides full combinatorial flexibility between different kinds of rheological models on the one hand, and distinct stabilization methods on the other hand [1]. Our library has been implemented by massive use of generic C++ template programming, runtime polymorphism and overloading. It is built on top of the open source library OpenFOAM, which provides a finite volume method on general unstructured meshes.

Methods

Having distinct numerical methods available on one computational platform, we have demonstrated that the stabLib is a powerful tool for benchmarking different methods and for rigorously investigating and comparing the convergence and the accuracy of the predictions over a wide range of Weissenberg numbers. A detailed study was carried out for a set of different stabilization approaches above the critical Weissenberg number in the computational benchmark of an entry flow of an Oldroyd-B fluid in a 4:1 contraction geometry. For this benchmark study, extensive computational resources were used to demonstrate the mesh-convergence of the results of different methods for varying Weissenberg numbers and for different constitutive models. It turns out that the applied methods are robust at high Weissenberg numbers above the critical limit and effectively alleviate the HWNP. Moreover, we demonstrate that all methods converge towards a unique solution when the computational grid is successively refined. A novel finding is that the mesh-sensitivity depends highly on the particular representation of the constitutive equation. Our results suggest that the most accurate results are obtained with the root conformation representation when a small root function is used [1].

Results

Direct numerical simulations (DNS) were performed to study the dynamicsof a rising gas bubble in a viscoelastic liquid. The mathematical formulation of the two-phase flow problem is derived by conditionally averaging the local instantaneous transport equations and applying a volume of fluid (VoF) model to obtain a closed-form one-field representation. The framework is implemented into a finite volume method (FVM) on general unstructured computational grids. We investigate characteristic flow phenomena that occur as a certain critical bubble volume is exceeded, i.e. the jump discontinuity in the steady-staterise velocity and the negative wake. The numerical results are compared to some detailed experimental measurements. For the first time numerical predictions of the bubble rise velocity discontinuity were achieved with a three dimensional VoF model [2].

Reference

[1] Niethammer, M.; Marschall, H.; Kunkelmann, C.,; Bothe, D.: A numerical stabilization framework for viscoelastic fluid flow using the finite volume method on general unstructured meshes, International Journal for Numerical Methods in Fluids, 86.2 : 131-166, (2018) https://doi.org/10.1002/fld.4411

[2] Niethammer, M., Brenn, G., Marschall, H. and Bothe, D. "Three dimensional DNS of a bubble rising in a viscoelastic fluid using an algebraic volume-of-fluid model" (2018): (in preparation)

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