Reduced coupled multibody fluid system dynamics in Lie group setting

Zdravko Terze*, **Viktor Pandža*** and Dario Zlatar *

Chair of Flight Vehicle Dynamics, Faculty of Mechanical Engineering and Naval Architecture, University of Zagreb, Zagreb, Croatia

Abstract. The paper describes a computationally efficient method for simulating dynamics of the coupled multibody-fluid system that utilizes symplectic and Lie-Poisson reductions in order to formulate fully coupled dynamical model of the described multi-physical system. The multibody system (MBS) dynamics is formulated in Lie group setting and integrated via geometric integration method that operates in MBS state space, while effects of the fluid flow are accounted for by the added masses to the submerged bodies calculated by boundary element method. In order to take into account additional viscous effects - and include fluid vorticity and circulation in the system dynamics for a submerged kinematical chain with sharp edges - vortex shedding mechanism is incorporated in the overall model.

Introduction

The conventional approach to simulating dynamics of multibody system (MBS) moving in ambient fluid most commonly includes large fluid domain discretization, which leads to the inefficient calculation of large amount of fluid data, that are usually not of the prime interest, since we are mostly concerned with effects that the fluid exerts on the MBS. In order to circumvent this, we adopt a geometric modeling approach for a coupled MBS-fluid system, incorporating boundary integral method for calculating added masses, and time integrator in Lie group setting [1]. The configuration space of a multibody system (MBS) is modelled as a Lie group. By assuming inviscid and incompressible fluid, the configuration space of the coupled MBS-fluid system is reduced via symplectic and Lie-Poisson two stage reduction [2], without compromising accuracy. The similar approach is taken in [3], however with additional assumptions of zero vorticity and smooth rigid bodies. By using introduced reductions, it is possible to reduce the problem of coupled MBS-fluid simulation to the exterior Laplace problem with Neumann boundary conditions. However, in order to take into account additional viscous effects and include fluid vorticity and circulation in the system dynamics, vortex shedding mechanism needs to be implemented.

Results and discussion

The test case MBS consists of three rigid bodies - two initially stationary ellipsoid-shaped and one rotating almond-shaped - connected by revolute joints and submerged in fluid at rest. The boundary value problem for the test case is implemented in open source platform BEM++ [5]. After solving the boundary value problem, the vortex is added in the flow in order to enforce the Kutta condition and the resulting plots for the horizontal and vertical fluid velocity components are shown in Fig. 1.

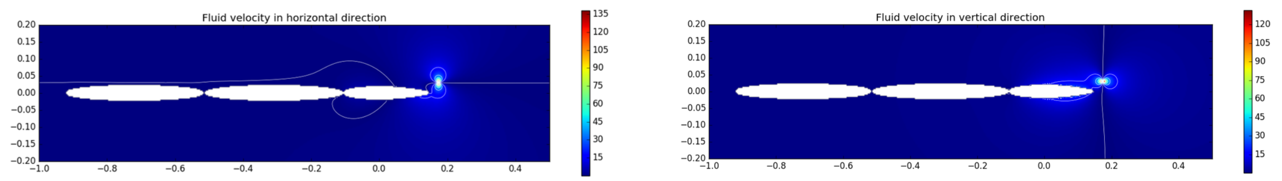

Figure 1: The values of the horizontal and vertical fluid velocity around the MBS consisting of three rigid bodies.

By discretizing only the boundary of the bodies, the numerical burden in reduced significantly. In the case of potential flow with zero circulation, this leads to the description of the coupled MBS-fluid system without explicit fluid variables. In the case of MBS comprised of bodies with sharp edges, the fluid variables are required only to describe vortical effects. Because of the improved efficiency, this model is well suited for application in design optimization of the complex systems motion that includes fluid flow.

Acknowledgement

This work has been fully supported by Croatian Science Foundation under the project IP-2016-06-6696.

References

[1] Terze Z., Müller A., Zlatar D. (2015) Lie-Group Integration Method for Constrained Multibody Systems in State Space. *Multibody System Dynamics* **34**:275-305.

[2] Bloch A.M. (2003) Nonholonomic Mechanics and Control. Springer.

[3] Kanso E., Marsden J.E., Rowley C.W., Melli-Huber J.B. (2005) Locomotion of Articulated Bodies in a Perfect Fluid. *J. Nonlinear Sci.* **15**.

[4] Terze, Z., Pandža, V., Zlatar, D. (2020) Lie Group Dynamics of Multibody System in Vortical Fluid Flow, in Lacarbonara, W., Balachandran, B., Ma, J., Tenreiro Machado, J.A., Stepan, G. (Eds.) Nonlinear Dynamics of Structures, Systems and Devices, Proceedings of the International Nonlinear Dynamics Conference (NODYCON 2019), Volume I, Rome, 2019.

[5] Śmigaj W., Arridge S., Betcke T., Phillips J., Schweiger M. (2015) Solving Boundary Integral Problems with BEM++. *ACM Transactions on mathematical software* **41(2)**:6:1–6:40.