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Multibody Systems Dynamics in Fluid Flow: Geometric Formulations in Lie Group Setting

Abstract

In order to study dynamics of multibody system (MBS) moving in ambient fluid in computationally efficient manner, we adopt geometric modeling approach of fully coupled MBS-fluid system, incorporating boundary integral method for calculating added masses, and time integrator in Lie group setting. Our aim is to explore numerical advantages of such an approach in comparison to the standard procedures that - most commonly - comprise full volume discretization of the fluid domain and solving fluid and solid dynamics on different meshes.

By assuming inviscid and incompressible fluid, the configuration space of the coupled MBS-fluid system is reduced by eliminating fluid variables via symplectic and Lie-Poisson two stages reduction, without compromising any accuracy. The first reduction exploits particle relabeling symmetry, associated with the conservation of circulation: fluid kinetic energy, fluid Lagrangian and associated momentum map are invariant with respect to this symmetry. Consequently, the equations of motion for the submerged MBS are formulated without explicitly incorporating the fluid variables, while effect of the fluid flow to MBS overall dynamics is accounted for by the added masses to the submerged bodies. In such approach, the added masses are expressed as boundary integral functions of the fluid density and the flow velocity potential. Further reduction of the system is associated with the symmetry based on invariance of the dynamics under superimposed rigid motions. In order to take into account additional viscous effects and include fluid vorticity and circulation in the system dynamics, vortex shedding mechanism is incorporated in the overall model by numerically enforcing Kutta condition.