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A HIGH-ORDER IMPLICIT-EXPLICIT DISCONTINUOUS GALERKIN SCHEME FOR FLUID-STRUCTURE INTERACTION

Per-Olof Persson[*] and Bradley Froehle

University of California, Berkeley, 1089 Evans Hall #3840, Berkeley, CA 94720-3840,
persson@berkeley.edu, http://persson.berkeley.edu

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We present a high-order discontinuous Galerkin Arbitrary Lagrangian Eulerian formulation for the Navier-Stokes equations coupled to various structure models including pitching airfoils, non-linear membranes, and neo-Hookean solids. The solid experiences an external force from the fluid, and the solid displacement provides a deformation of the fluid domain.

In previous work, we solved similar problems using an explicit Runge-Kutta time integrator. While this approach is simple and does not require any coupling matrices, it may introduce undesirable timestep restrictions. On the other hand, a fully implicit time integrator would require forming not only the Jacobian matrices for the fluid and structure problems, but also for the couplings between them.

Here we demonstrate how implicit-explicit Runge-Kutta methods can be used to avoid solving the fully coupled system, with high orders of accuracy in time. We use both the implicit and explicit coefficients of the schemes to form a stage predictor for the force from the fluid applied to structure. The effectively decouples the system into two implicit problems – one for the fluid and one for the structure – which can be solved using standard domain specific methods.

The spatial discretization of the fluid is a standard unstructured-mesh nodal discontinuous Galerkin method with numerical fluxes according to the method by Roe and the compact discontinuous Galerkin method. The deforming domain is handled by a mapping-based approach. A standard neo-Hookean solid model is discretized using continuous Galerkin elements of the same polynomial order as the fluid. The solid experiences forces from from the fluid which are calculated and applied at the Gauss integration nodes on the faces of the solid. The solid displacements provide a deformation of the fluid mesh using Radial Basis Functions or a non-linear elasticity model.

We demonstrate the scheme using several examples, ranging from model problems to verify the high-order accuracy to three-dimensional problems with complex geometries and flow features.