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Algebraic Multigrid Solvers for Weighted Least-Squares Finite Elements with Application to Particle Imaging Velocimetry Analysis

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The combination of ultrasound and microbubbles injected into the blood makes it possible to noninvasively obtain 2-dimensional velocity data inside the left ventricle of the heart. A long term goal is to translate this velocity data into information about energy loss, pressure gradients, and overall health of the heart, but this goal requires a full 3-dimensional velocity field. The question that we seek to answer is whether the 2-dimensional velocity data can be incorporated into a full 3-dimensional computational fluid dynamics simulation in an appropriate and computationally practical way. For addressing this problem, we examine the potential of least-squares finite element methods (LSFEM) because of their flexibility in the enforcement of various boundary conditions and their natural compatibility with multigrid solvers. By weighting the boundary conditions in a manner that properly reflects the accuracy with which the boundary values are known, we develop the weighted LSFEM. The potential of weighted LSFEM is explored for two different test problems: the first uses randomly generated Gaussian noise to create artificial 'experimental' data in a controlled manner, and the second uses experimental particle imaging velocimetry data. In both test problems, weighted LSFEM produces accurate results even for cases where there is significant noise in the experimental data and provides excellent computational scalability when used with a parallel algebraic multigrid solver.