Applications of GSM-CFD to Biomechanics and Fluid-Structure Interaction Problems

G. R. Liu[*] and Jianyao Yao[#]

Department of Aerospace Engineering and Engineering Mechanics,
University of Cincinnati, Cincinnati, OH 45221, USA
liugr@uc.edu

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Recently, gradient smoothing method (GSM) has been applied to solve partial differential equations for both fluid and solid problems. The implementation to solids is in the so-called weakened weak formulation, as such the smoothed point interpolation method (S-PIM) [1] and its simpler version of the smoothed finite element method (S-FEM) [2]. The implementation to fluids is directly performed in the strong form formulation, and it is known as the GSM-CFD [3]-[11]. In our previous research, GSM-CFD has been used to solve the general compressible [3]-[5] and incompressible flows [6][7], biomechanics (bioflow) [8][9] and fluid-structure interactions [10][11].

There are several attractive features of the proposed GSM-CFD solver. First, the GSM-CFD is implemented based on the strong form procedure, but it is with a weak-form flavour. Second, it is locally and globally conservative, because it uses strictly smoothing operations for approximating gradients without the use of any interpolations. Third, the gradient smoothing technique for spatial derivatives calculation is insensitive to type of the mesh and mesh distortion, and this allows the use of both structured and unstructured meshes, and ensures the GSM-CFD solver can still keep high accuracy even on highly distorted mesh. Fourth, the GSM-CFD is flexible, and can be customized to achieve different accuracy levels via choosing the smoothing functions and integration schemes. Finally, the GSM is easy to implement and can be readily coupled with structural solver to form a practical platform for fluid-structure interaction simulations.

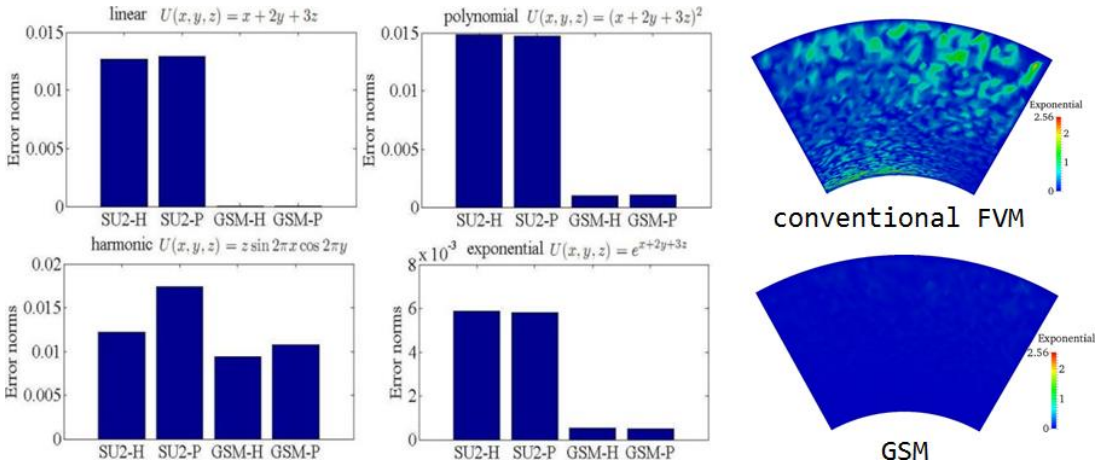


Fig. 1. Accuracy in gradient approximation of functions: comparisons with the most widely used FVM

In this talk, the basic formulations of GSM-CFD are introduced. For the numerical

The 2nd author has recently moved to College of Aerospace Engineering, Chongqing University, Chongqing, China.

implementations, a compact matrix-form GSM and the corresponding data structure are proposed to improve the efficiency of gradient approximations on all kinds of meshes. The numerical results (see
Fig. 1) for gradient approximations are presented to show the effectiveness of the proposed GSM, in comparison with its close counterparts, the finite volume method (FVM). For the CFD solver part, the solutions of benchmark problems for compressible and incompressible flows are presented.

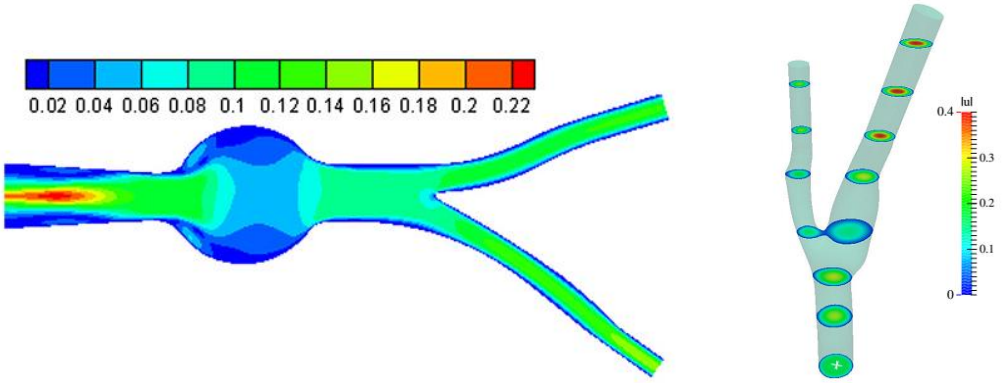
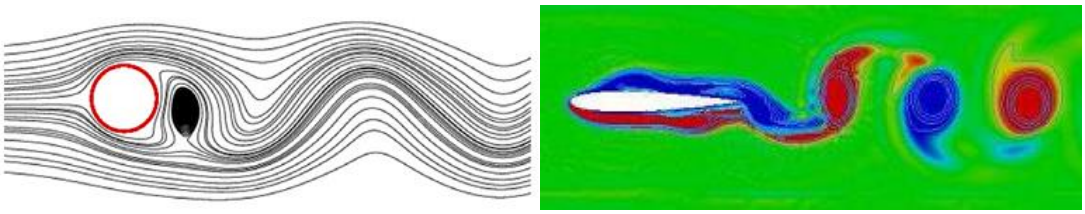


Fig. 2. Examples of 2D [8] and 3D [9] blood flow simulations using the GSM-CFD solver

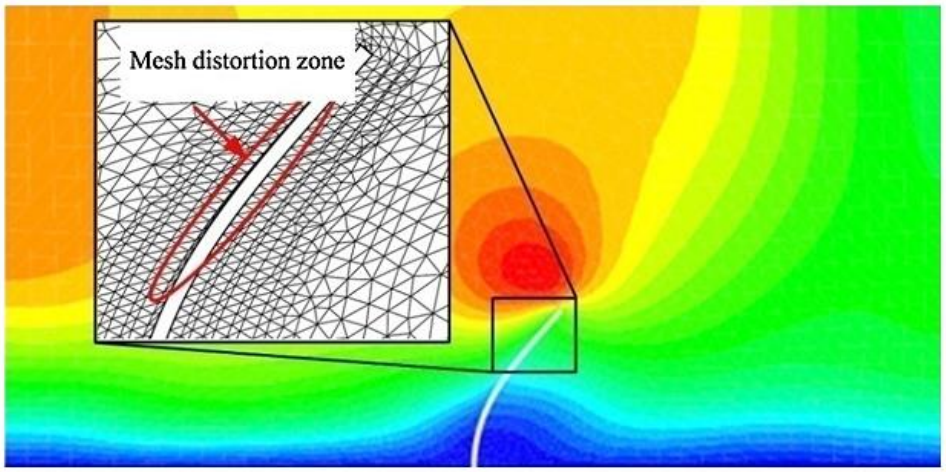
Currently, we mainly focus on the blood flows for biomechanics research. The blood is simulated as incompressible Newtonian flows in the previous study [8][9], as shown in Fig. 2. In this talk, the work on the blood flow simulation will be presented, where we will implemente some non-Newtonian models with our GSM-CFD incompressible solver for better modelling of the blood behaviour.



(a) rigid cylinder [10] (b) plunging airfoil [5]

The GSM-CFD solver is also applied for simulation of flows with moving rigid and flexible structures. Currently, we are developing a FSI simulation platform for rotary aircraft using the GSM-CFD solver. Some results are shown in Fig.3. It is hopeful that we can share some newest simulation results during the conference.

Extensive numerical examples and applications have so far demonstrated that the GSM-CFD solver is accurate, robust, flexible and insensitive to mesh distortion. It can be used for flow simulations in biomechanics and fluid-structure interactions in various engineering disciplance including aerospace engineering.



(c) flexible beam [11]

Fig. 3. Some applications of GSM-CFD solver to FSI problems

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