Dynamic Overset Grid Computations for CFD applications on Graphics Processing Units

Dominic Chandar*, Jay Sitaraman*, and Dimitri Mavriplis*
Corresponding author: dchandar@uwyo.edu

* Mechanical Engineering, University of Wyoming, Laramie, WY-USA

Abstract: The objective of the present work is to discuss the development of a 3D Unstructured-Overset grid Computational Fluid Dynamics (CFD) solver on General Purpose Graphics Processing Units (GPGPUs). As an extension of our previous work on 2D overset grid computations for compressible flows[1], the current paper focuses on 3D overset grid methodologies to solve the unsteady incompressible Navier-Stokes equations. To validate the solver, numerical results are presented for the flow past a sphere at different Reynolds numbers. In its current form, the code is capable of solving the conservations equations entirely on the GPU with second order time and spatial accuracy, inclusive of overset grid interpolation. However, computing the donor, fringe, and hole(unused) points are performed in an offline mode and serve as an input to the flow solver. A method of computing these quantities in a dynamic fashion on the GPU is currently being pursued and will be made available for the final paper.

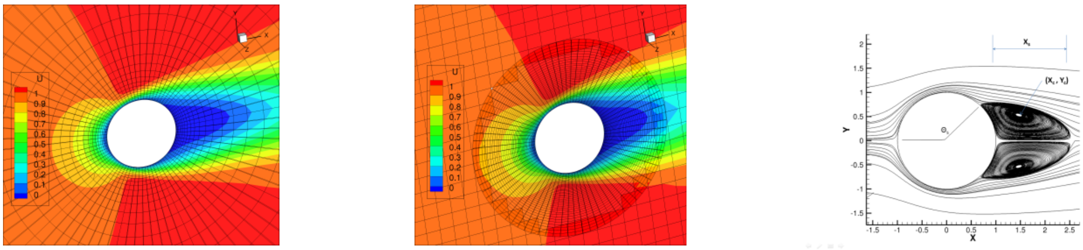
Keywords : Graphics Processing Units, Overset/Overlapping Grids, Finite-Volume methods

1 Introduction

The advent of GPGPUs has spawned a lot of interest in computing high resolution flows in a short span of time. In combination with existing parallel programming techniques, one is able to obtain at least one order increase in speed-up for CFD applications on stationary grids [2],[3],[4]. For moving body applications, if a single grid is used, the grid needs to be regenerated or deformed causing other numerical difficulties. Also, the usage of a single grid for the entire domain would render the computation, time inefficient as most of the flow features are present in the vicinity of the body. The usage of overset or overlapping grid methods for these purposes is quite attractive as each grid can have its own resolution, and one may place finer grids only at specified locations to capture the flow features. In the present work, we demonstrate a modular concept where the domain of interest is represented by several grid systems. Surrounding each body of interest, we generate an unstructured prismatic grid termed as the near-body grid. Each near-body grid is connected to an off-body Cartesian or unstructured grid through fringe points. Solutions at fringe points are obtained from donor grids using Taylors' expansion. The algorithm to determine donor points follows the method in [5]. NVIDIA's Tesla C2070 (Fermi) [6] GPU is used for all computations.

2 Results

The incompressible Navier-Stokes equations are solved using a Pressure-Poisson approach with the convection and viscous terms treated explicitly and implicitly respectively. The details of the implementation can be found in [7],[8]. Figure 1 shows a comparison of the computed x-velocity contours at z=0 for the flow around a sphere at Reynolds number 75 between an overset grid and a single grid. A reasonable comparison is obtained for the current grid configuration. There are minor discontinuities in the solution at the overset boundary downstream of the sphere due to a coarse Cartesian grid. The final paper will include several grid zones with different spacings to overcome this problem. A comparison with the corresponding CPU(serial) version of the code on one processor took 8x more time than the GPU code.



(a) (b) (c)

Figure(1) : (a) Velocity contours at z=0 for the flow past a sphere at Re 75 on a single prismatic grid in comparison with a (b) overset grid. (c) Streamlines along z=0 showing polar separation angle and wake characteristics

Re	**C_d**		**X_c/d**		**Y_c/d**		**X_s/d**		**Θ_s**	
	Present	**Ref**	**Present**	**Ref**	**Present**	**Ref**	**Present**	**Ref**	**Present**	**Ref**
50	1.65	1.62	0.647	0.64	0.215	0.2	0.451	0.4	140.1	139
75	1.31	1.3	0.732	0.7	0.266	0.26	0.78	0.65	132.3	134
100	1.12	1.1	0.811	0.76	0.295	0.3	1.15	1.2	128	129

Table (1): A comparison of the drag coefficient and wake characteristics with reference data from literature at various Reynolds numbers.

We also compare the computed drag coefficient (C_d), polar separation angle (Θ_s), wake width (X_s/d) and the center of the wake (X_c,Y_c)/d, (*d* being the diameter of the sphere) with experimental and numerical computations found in [9],[10]. A good correspondence is obtained for most of the wake characteristics giving us confidence in the numerical procedure.

3 Conclusion and Future Work

At this preliminary stage, a 3D unstructured overset grid solver has been developed and has been validated for stationary problems. The final paper will have more intensive validation studies of the approach with applications towards moving bodies. Detailed GPU performance metrics will also be evaluated. We also plan to implement a dynamic donor search algorithm on the GPU to be used for moving overset grids.

References

[1] K. Soni, D. Chandar, and J. Sitaraman, *AIAA-2011-1268*, 2011.
[2] P. LeGresley, E. Elsen, and E. Darve, *J. of Comp. Phy.*, Vol. 227, pp. 10148-10161, 2008.
[3] T. Brandvik, and G. Pullan, *AIAA-2008-0607*, 2008.
[4] T.R. Hagen, K-.A. Lie, and J.R. Natvig, *Lec. Notes in Comp. Sci.* Vol. 3994, pp. 220-227, 2006.
[5] J. Sitaraman et al., *J. of Comp. Phy.*, Vol 229, pp. 4703-4723, 2010.
[6] http://www.nvidia.com/object/personal-supercomputing.html
[7] D. Chandar, J. Sitaraman, and D. Mavriplis, *AIAA-2011-3222*, 2011.
[8] D. Chandar, J. Sitaraman, and D. Mavriplis, *AIAA-2012-xxxx*, 2012, (To appear in the 47th AIAA Aerospace Sciences Meeting and Exhibit, Nashville, TN, Jan 2012).
[9] G.J. Sheard, K. Hourigan, and M.C. Thompson, *J. of Fluid Mech.* Vol. 2005, pp. 257-275, 2005.
[10] T.A. Johnson and V.C. Patel, *J. of Fluid Mech.* Vol. 378, pp. 19-70, 1999.