Seamless Integration of an Overset Grid Framework for OpenFOAM: The OPErA Library

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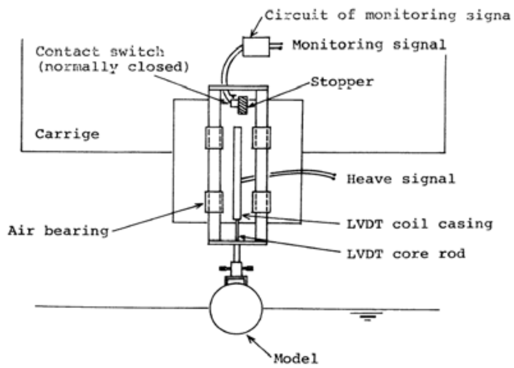
Abstract

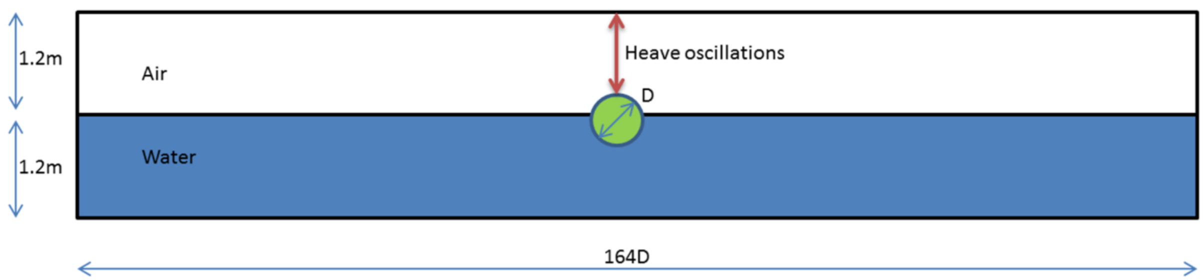
In this work, we describe an overset grid implementation for general three-dimensional unstructured moving grids in OpenFOAM – The ***O***verset ***P***arallel ***E***ngine for Ae***r***odynamics ***A***pplications (OPErA). The algorithm utilizes a variant of the inverse map strategy to search for potential donor cells from overlapping grids. Utilizing a dual-level parallelism approach where MPI is used in conjunction with pthreads, the donor search process is accelerated by a factor of 4. The code is developed independently and is linked to OpenFOAM as a dynamic library providing interpolation support at the level of the linear solver. The presentation will focus on different implementation strategies, various validation and verification studies from single and multiphase flow. In this disclosure, we only present a validation and verification case to demonstrate the use of overset grids for moving body computations. It is hoped that the final version/talk will include more analysis and results on the implementation.

1. *Transient heave oscillations of a floating cylinder in water*

Ito [1] conducted experiments on floating cylinders that were subjected to heave oscillations and obtained good comparisons with potential flow theory for certain cases. The corresponding experimental setup is shown in Fig. 1(a) Consists of a towing tank, a heaving rod and the floating cylinder of diameter$D = 15.24\ cm$. The heave rod is attached to an air bearing to provide smooth heaving motion without any frictional damping. In the experiment, the weight of the cylinder was adjusted so that it is half submerged by adding ballast. For computational purposes, the density of the cylinder was adjusted to 500 kg/m^3 so that it was half submerged in water with a density of 1000 Kg/m^3.



(a)



(b)

Figure 1: Setup for the heaving cylinder (a) Experiment (b) Computation

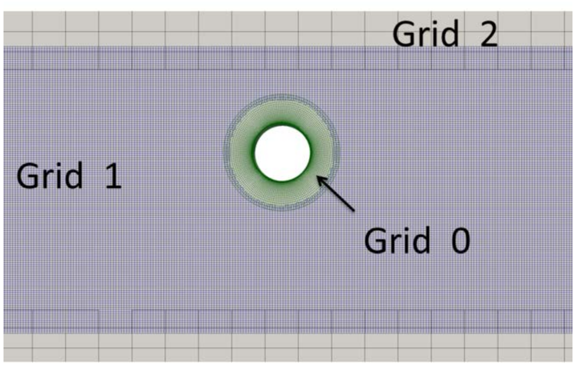


Figure 2: The Overset grid showing different component grids

The cylinder is initially displaced by 2.54cm above its equilibrium position and is allowed to perform heave oscillations. The computational domain has an outer boundary located at $\pm 82D$ and $\pm 8D$ along x- and y-axis respectively (Fig 1b). At $t = 0$ the water depth is 1.2m everywhere. Since in the experiment, the length to diameter ratio was 30.48 a two-dimensional computation is sufficient to reproduce the dynamics of the floating object. As the domain extents are very large, three component grids, $grid0$(7700 cells), $grid1$(59000 cells) and $grid2$(31000 cells) with varying spacing are utilized to minimize the computational overhead. Fig (2) shows a part of the component grids near the cylinder. $Grid0$ corresponds to the cylinder and should be fine enough to resolve the flow physics near the walls. $Grid1$ is coarser than $grid0$ such that there are 1.5 cells of $grid0$ for each cell in $grid1$. $Grid2$ is very coarse and has roughly 169 cells per cell of $grid1$. Computations were performed on 8 cores for a total run time of 2.6s (wall-clock time of 3 *hrs*). For each physical time step, ten inner correctors were utilized to stabilize the interactions between the fluid and the motion of the structure since the mass ratio between the solid and the fluid $m^* < 1$. During each inner corrector, only $grid0$ moves and the grid velocities get updated. Figure 3 shows the contours of the phase (α) when the cylinder hits the water surface at $t = 0.15s$. It is very encouraging to note that the contours are continuous across grids and no unphysical activity can be detected at the overset interface. Figure 4 shows the time history of the displacement as a function of t^* ($t^* = t\sqrt{\frac{2g}{D}}$) in comparison with the experimental results. It can be observed that the computation is able to reproduce the experimental response especially at the peak amplitudes giving us confidence in the overall implementation.

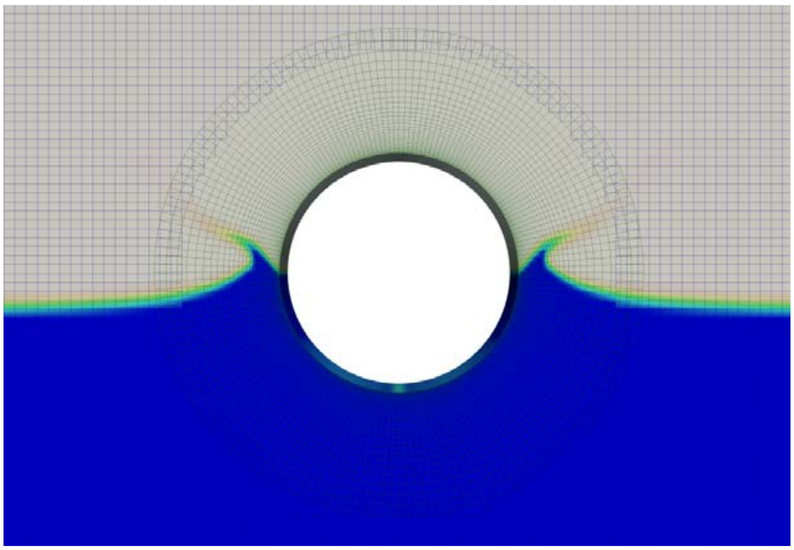


Figure 3: Contours of the phase fraction (α) at $t = 0.15s$

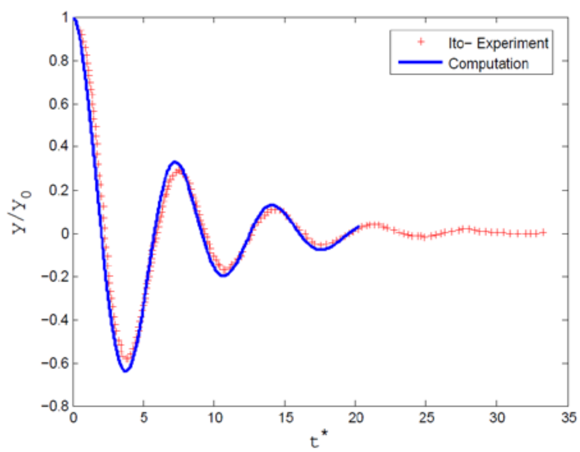


Figure 4: Time history of the displacement of the cylinder

Case 2: Motion of Two Inline Oscillating Cylinders

This problem showcases a very good application of the overset grid method in OpenFOAM. For small rigid body motions, OpenFOAM's default dynamic mesh methodology is capable of simulating such flows with minimal computational effort. However, for large relative displacements of multiple moving bodies, there is no efficient methodology available to solve such problems in OpenFOAM. To demonstrate how the overset grid methodology stands out in comparison with the existing dynamic mesh methods, a suitable test case involving the relative motion of cylinders from Sheng and Wang [2] using an immersed boundary method(IBM) is picked up. The setup for this problem is given in Fig .5.

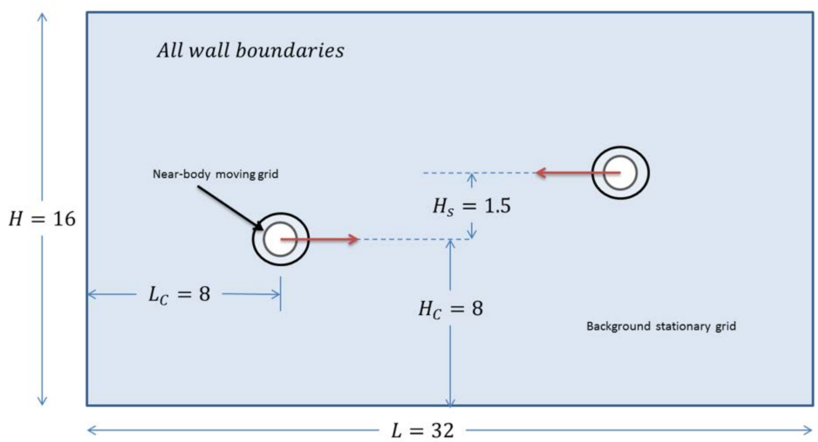


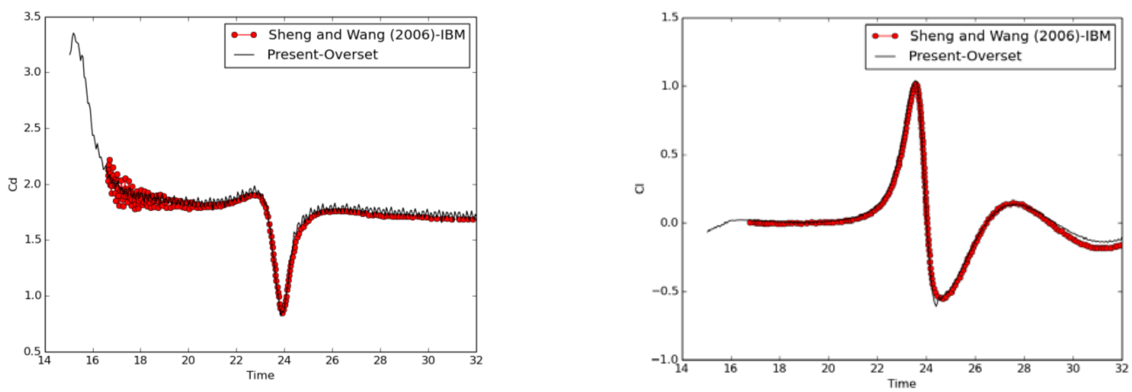
Figure 5: Problem setup for the relative motion of two cylinders

Both cylinders initially oscillate about their starting location in a quiescent fluid till *t = 16* and then they approach each other at constant speeds at Re 40. The motion of the cylinders is governed by the following kinematics:

$$x_{lower} = \begin{cases} \frac{4}{\pi} sin\left(\frac{\pi t}{4}\right), & 0 \leq t \leq 16, \\ t - 16, & 16 \leq t \leq 32 \end{cases}$$

$$x_{upper} = \begin{cases} 16 - \frac{4}{\pi} sin\left(\frac{\pi t}{4}\right), & 0 \leq t \leq 16, \\ 32 - t, & 16 \leq t \leq 32 \end{cases}$$

From the above kinematics, we can infer that the cylinders travel a maximum displacement of about 16D, where D = 1 is the diameter of the cylinders. Each cylinder has one grid partition and the background grid has two partitions making it a total of four partitions to run on. A comparison of the lift and drag coefficients on the upper cylinder are plotted in Fig. 6. Excellent comparisons are obtained between the present overset computation and the computation of Sheng and Wang [2].



(a) (b)

Figure 6: Force coefficients (a) Drag and (b) Lift for the flow past two inline oscillating cylinders

References

[1] Itō, Sōichi. *Study of the transient heave oscillation of a floating cylinder*. Diss. Massachusetts Institute of Technology, 1977.

[2] Xu, S., and Wang, Z.J., *An immersed interface method for simulating the interaction of a fluid with moving boundaries*, Journal of Computational Physics, Vol. 216, No. 2, 2006, pp. 454—493.