Computer Simulations of Fluid-Structure Interactions

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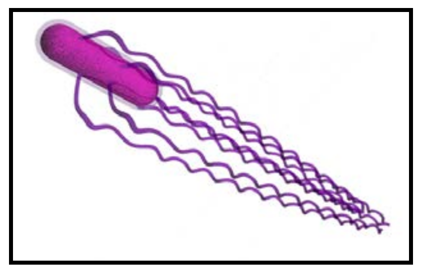
Introduction

(i) Flow-Structure interactions are everywhere



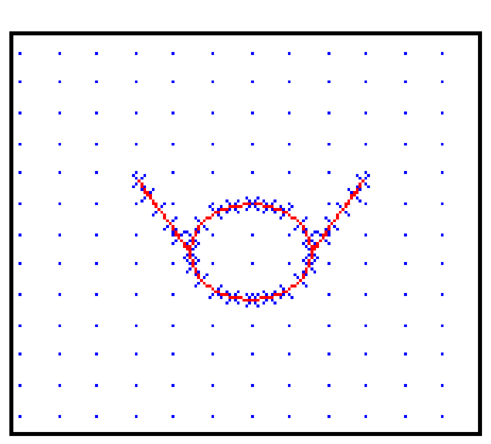
(ii) The problem is difficult to simulate because of the dynamical boundary conditions and coupling

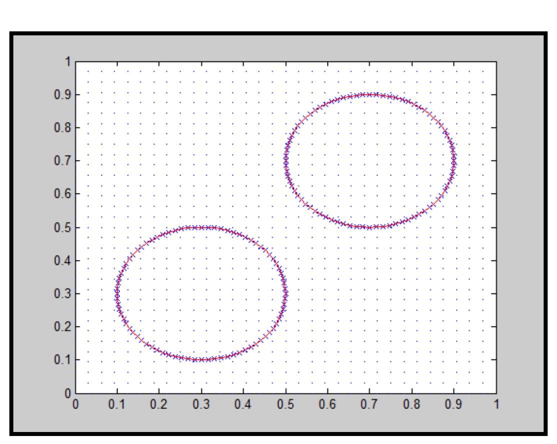
(iii) The boundary conditions are complex because of its curved shape, it's moving in space, and it's deformable.

(iv) The simulation can be depicted using the Immersed Boundary Method

Motivation

We want to use the Immersed Boundary Method to observe the movement of a biological locomotion. We are going to study the effects of swimming gaits, flagella positions, and the swimmer's velocity through a fluid. We will use a two-circle collision as a bench mark problem to illustrate the basic idea behind the Immersed Boundary Method.





Method of Investigation

The Immersed Boundary Method consists of two coordinate systems:

1. Eulerian grid to simulate the fluid
2. Lagrangian Mesh to simulate the boundary

Information between the two coordinate systems will be connected through interpolations. The interpolations will be based on two principles:

1. A no-slip condition for the velocity at the boundary

$$\dot{x}_i(t+1) = \sum_{X} u(\boldsymbol{X}, t+1)\Delta(x_i(t) - \boldsymbol{X})$$

2. Newton's Law that every action will have an equal and opposite reaction

$$f(\boldsymbol{X}, t) = \sum_{i} F_i(t)\Delta(x_i(t) - \boldsymbol{X})$$

The interpolation equations will have set conditions:

- The boundary is two-dimensionally immersed in a three-dimensional space
- The fluid has a constant density and viscosity throughout the entire grid
- The boundary is massless

Variables

$\boldsymbol{X}$: fixed fluid grid coordinates

$x_i(t)$: position of boundary node i

$u(X, t)$: fluid velocity

$\dot{x}_i(t)$: velocity of boundary node i

$f(X, t)$: fluid force density

$F_i(t)$: force acting on node i

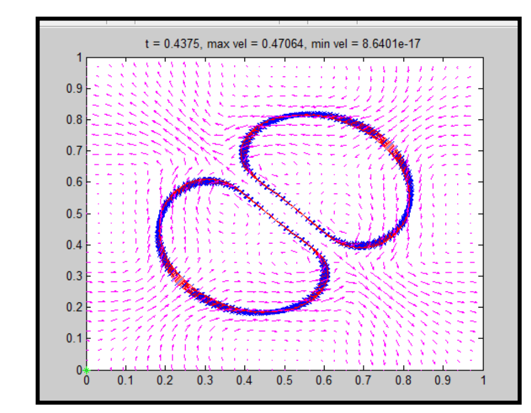
Algorithm

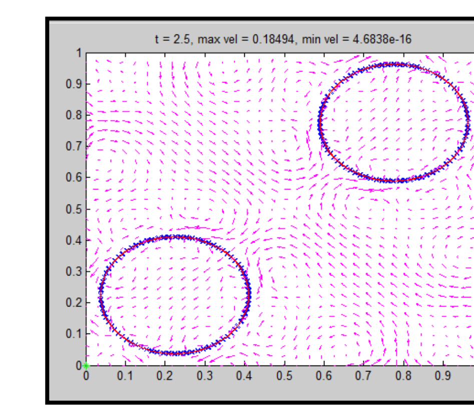
A code was created in Matlab using the C programming language. This code can predict the movement of any object through a fluid given certain specifications.

1. Euclidean mesh is set up and the fluid parameters are defined. The fluid parameters will vary so we can observe the changing velocities of the object.
2. The boundaries are created. In this case, the boundaries are two circles. The radii as well as the location of each circle on the grid are specified.
3. Immersed Boundary points(nodes) are selected around the circles. Each IB point represents a hinge and are linked together by springs. When an IB point is moved, the surrounding springs expand and then contract. This causes the surrounding IB points to move as well.
4. Temporary target locations are selected in order to calculate the force on the boundary. These IB forces can be spread to the Eulerian grid so that the fluid forces can be calculated.
5. External forces are applied so we can observe the two-circle collision.
6. The new IB point locations are updated as well as their new velocities.
7. A time-step loop is used so that we will return to the start of the program and repeat the process.

Results

The simulation for the bench mark problem showed that structures move slower when the density and viscosity of the fluid are increased. When the circles collide, they deform and then bounce back in opposite directions.





Conclusion

Today, there are many applications for the immersed boundary method. The method was first introduced to observe blood flow through heart valves. It can also be applied to how an organism swims and even how air waves affect certain objects. Peskin has developed many uses for the IBM that continues to be expanded upon.

References

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Peskin, Charles S. "The Immersed Boundary Method." (2002): n. pag. Cambridge University Press. Web. 8 Mar. 2015. <http://www4.ncsu.edu/~zhilin/TEACHING/MA798Z/Peskin1.pdf>.