

SECTION 1

## Penalty Immersed Boundary Method (PIB)

The Penalty Immersed Boundary Methods is a simple approach try to solve fluid-structure interaction with material bounadary that has mass.

SUBSECTION 1.1

### Rigid Body pIB

One kind of problem pIB can simulates is a rigid body in flow. The key of pIB is to consider two sets of Material Points, denoted as  $X(q, s, t)$  and  $Y(q, s, t)$ . Here  $q, r$  are Lagrangian Coordinate and  $t$  is time.  $\mathbf{X}$  is the true boundary points that interact masslessly with the flow, and  $def$  is called the **Ghost Mass**. It doesn't interact with the flow but only with the Material points  $\mathbf{X}$  through an imaginary spring.

Explanation 1

1. At the start, the Material points' position is updated using fluid velocity interpolated at  $\mathbf{X}$ .

```
1 X_half_top = X_tube_top + dt / 2 * interpolation(u,
           X_tube_top, Num_b, Nx, Ny, dx, dy);
```

2. The force acting to the fluid by the Material is modeled by a spring connecting the Ghost point and material point.

$$\mathbf{F}(q, r, t) = K(\mathbf{Y}(q, r, t) - \mathbf{X}(q, r, t)) \quad (1.1)$$

3. Then spread the force  $F$  to Eucleadian space.
4. Numerically solve the time evolution of fluid using Navier Stokes solver.
5. Update the Material point position  $\mathbf{X}$ .

#### 1.1.1 Implementation : Circle in Flow