2.29 Project

Response of a ball trapped in a funnel by pressure

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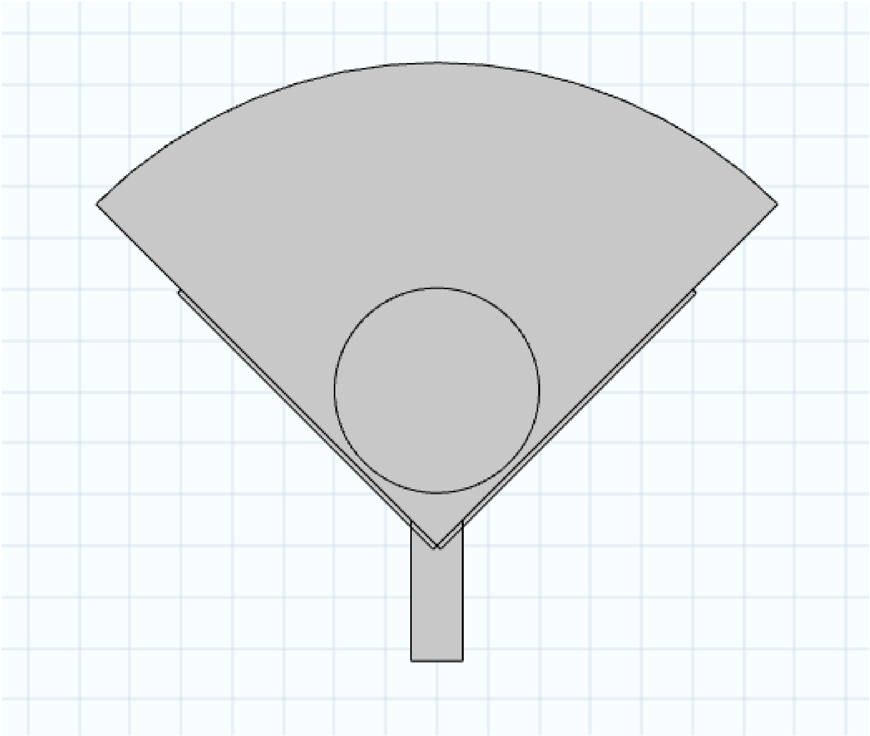
Problem Overview

- A ping-pong ball will be trapped in a furtive due to pressure, which is counterintuitive.
- The theory behind this phenomenon is simple (Bernoulli principle), but to simulate the response of the ball is hard, including:
  - Moving Grids
  - Interactions between the ball and funnel wall
  - Fluid-structure interaction
- The model could be used to control flow flux. (cf. Jalikop et al. 2019, JFS)

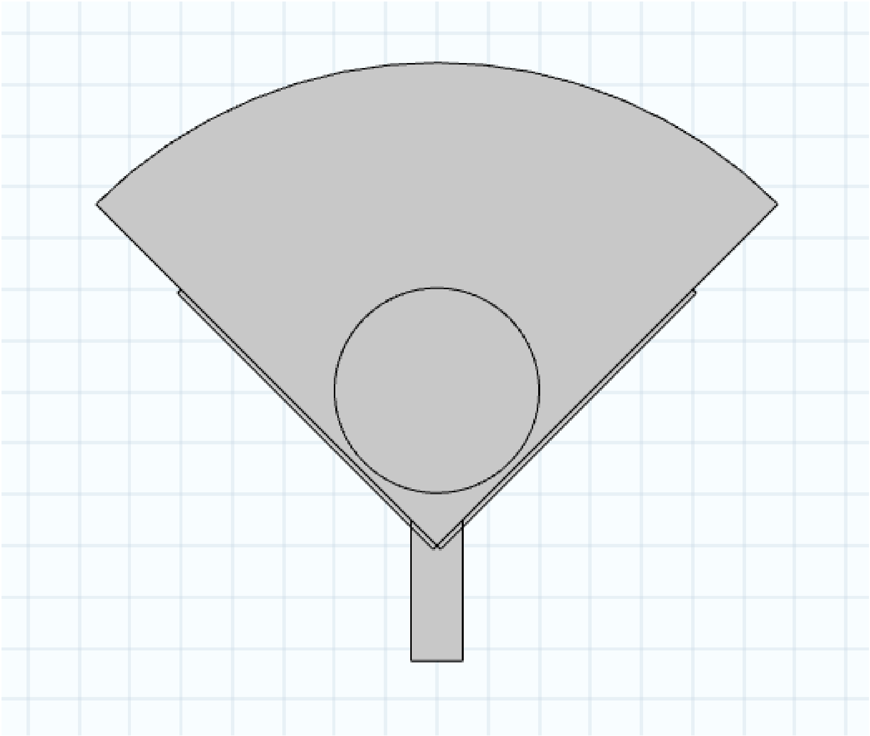
Solver and model set-up

- Solver: COMSOL Multiphysics 5.4
- Model:
  - Start with 2-D space.
  - Funnel open angle: $2(90° - \alpha)$
  - Solid ball with diameter: 4cm
    (It's a pretty heavy ball!)
- Material:
  - Air
  - Acrylic plastic for the ball and funnel wall.



Physics

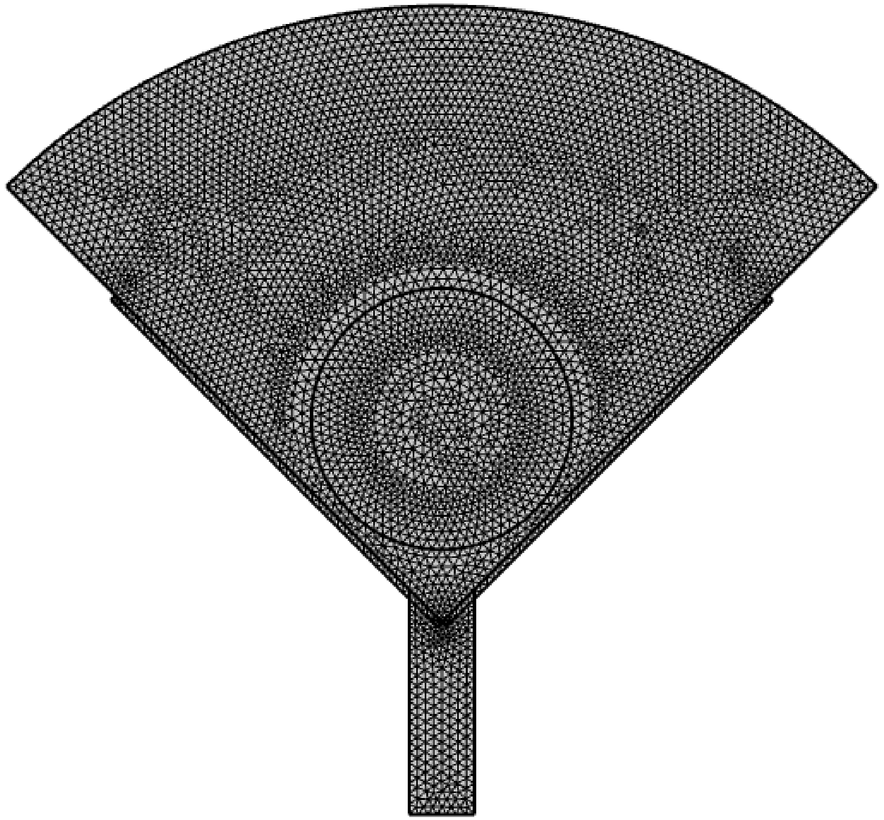
- Solid Mechanics
  - No gravity
  - Rigid ball
  - Fixed wall
  - Contact pair
- Turbulent Flow (Re=7000)
  - $P = P_a$ or open at sector edge
  - Inlet speed: $U_0 \cdot step(t)$
- Fluid-Solid Interaction
  - Fully coupled



Mesh

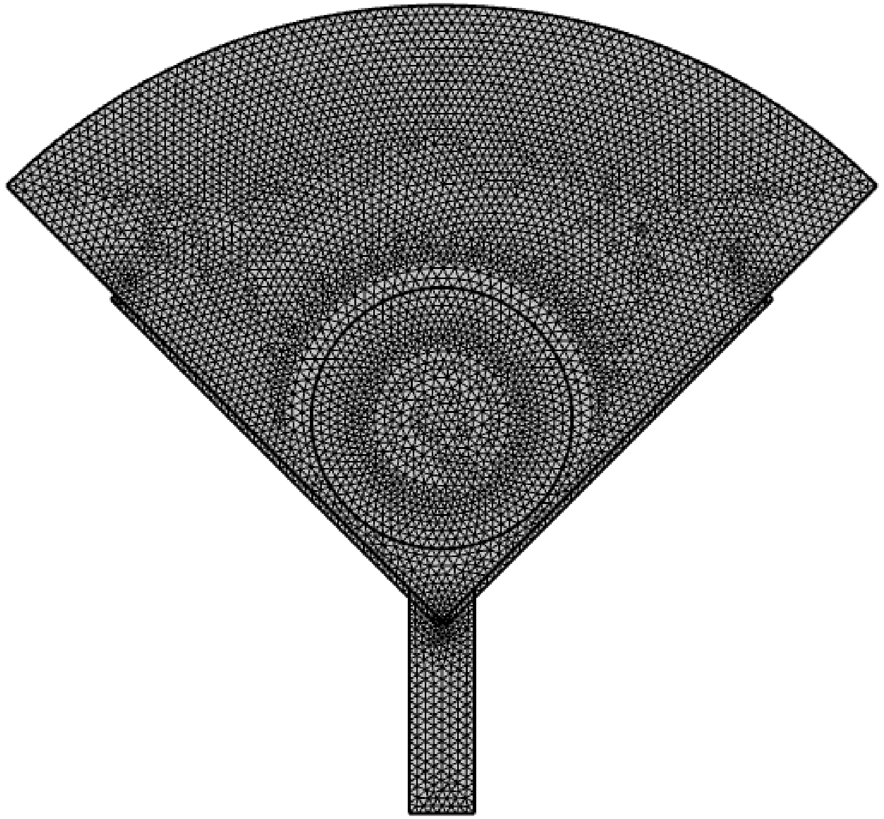
- Free triangular
- Moving grids in sector area

  (I set no boundary layer, because sometimes COMSOL will alert initial mesh satisfies remeshing condition)



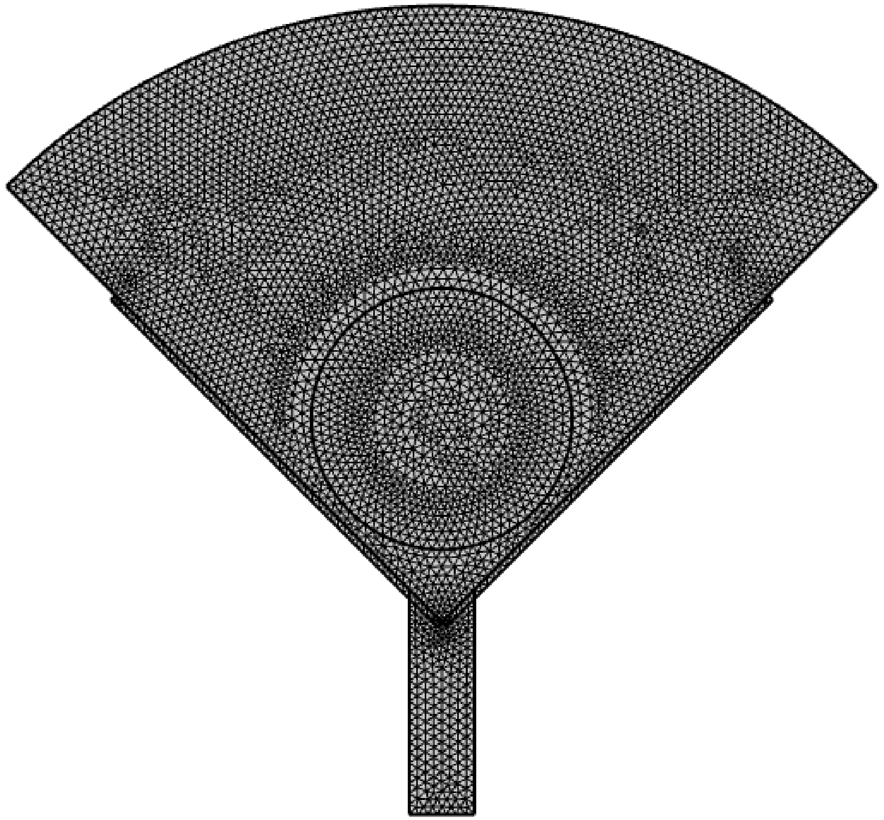
Study

- The ball will hit the wall frequently, which makes the response unstable (from my observation)



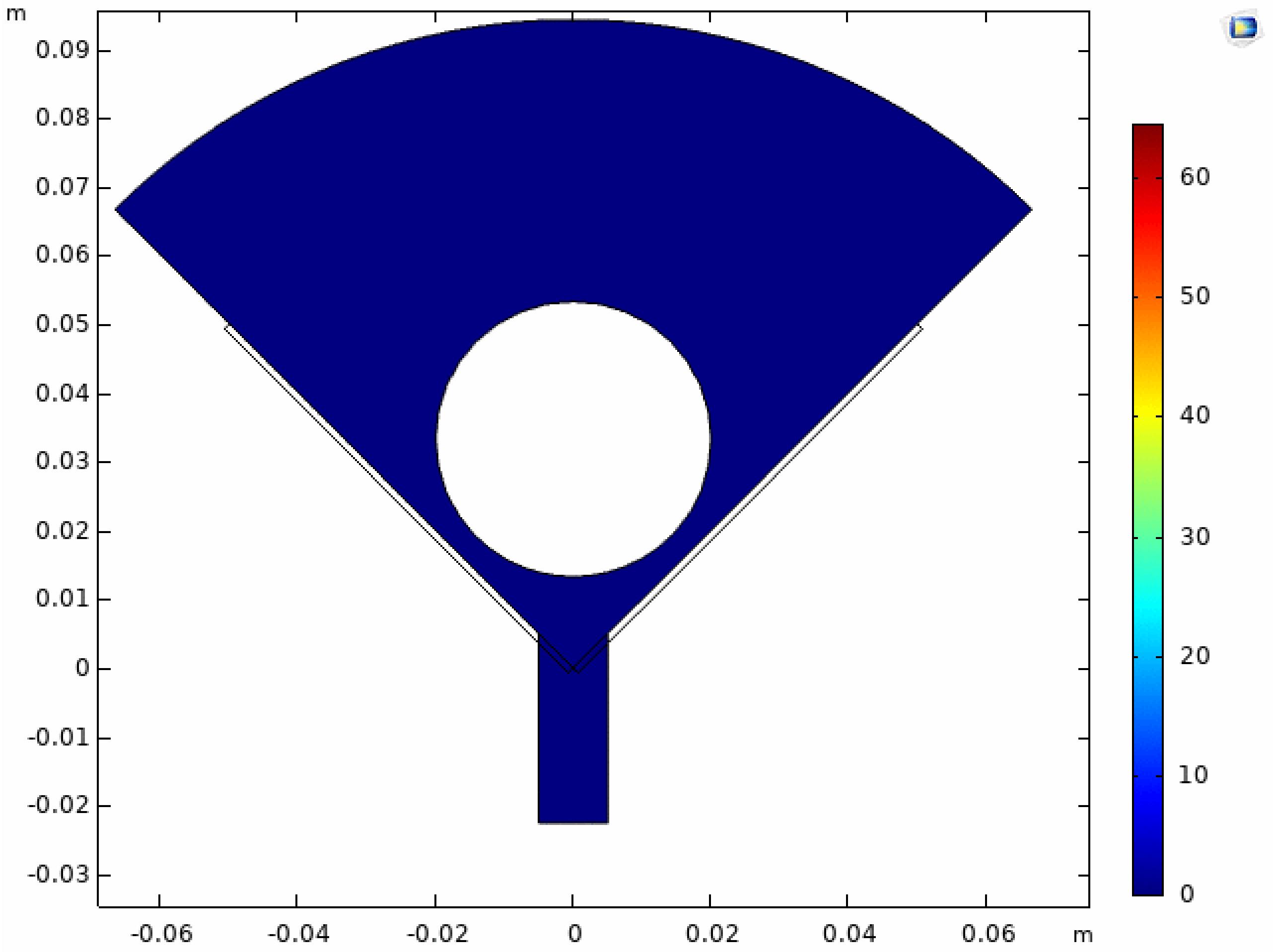
Study

- Method 1: Transient (time-dependent
  - Automatic remeshing
  - Or alternatively, choose 'adaptive mesh refinement'
  - Multiply the inlet speed with a buffered step function.
- Method 2: Steady + Transient
  - Fix the ball, solve for steady results
  - Using the result and mesh of the steady study as initial values, do transient study.
- Solver
  - Pardiso (a kind of direct solver)



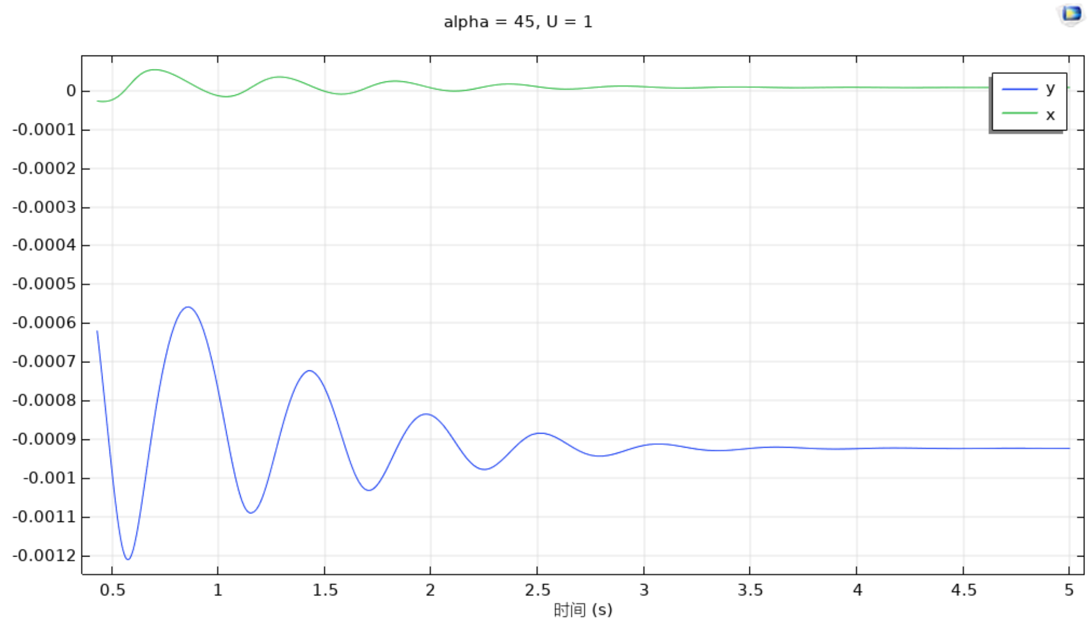
Results

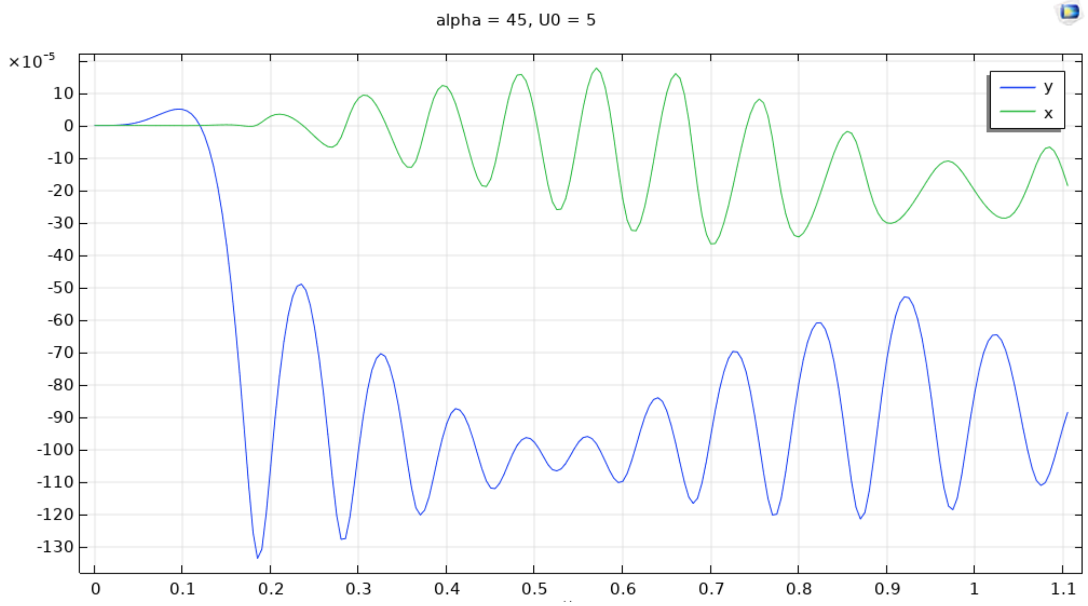
- The pressure force can resist some gravity.
- → 1% gravity upward

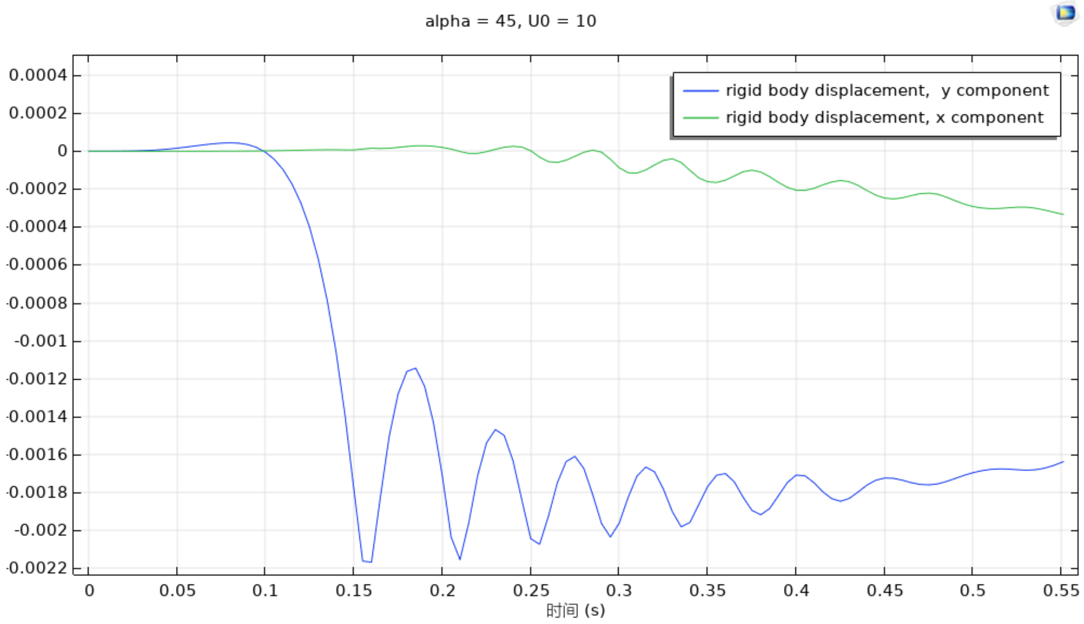


Results

- The higher inlet speed U_0, the greater the ball's frequency and tendency to hit the wall and be blown away.
- The greater the open angle of funnel, the steadier the ball.
- For $\alpha = 45°$ case, $U_0 = 5\mathrm{m}/s$ might be in a transition mode (a second frequency in y direction appears)

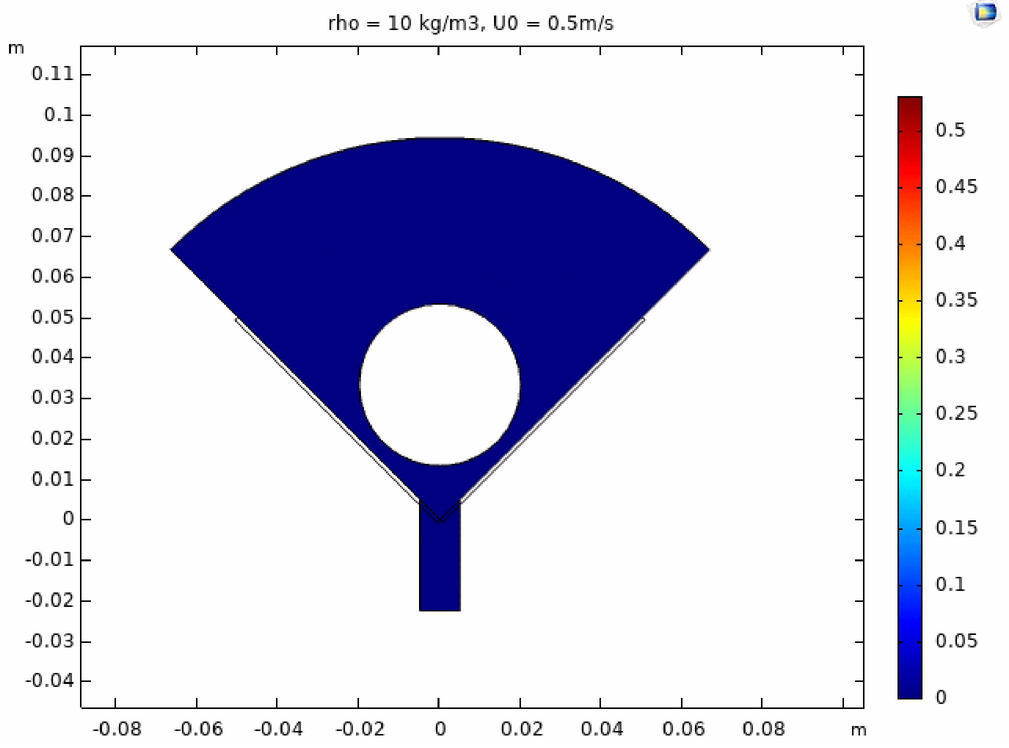

alpha = 45, U = 1
y
x
0
-0.0001
-0.0002
-0.0003
-0.0004
-0.0005
-0.0006
-0.0007
-0.0008
-0.0009
-0.001
-0.0011
-0.0012
0.5
1
1.5
2
2.5
3
3.5
4
4.5
5
时间 (s)


alpha = 45, U0 = 5
×10⁻⁵
y
x
10
0
-10
-20
-30
-40
-50
-60
-70
-80
-90
-100
-110
-120
-130
0
0.1
0.2
0.3
0.4
0.5
0.6
0.7
0.8
0.9
1
1.1


alpha = 45, U0 = 10
rigid body displacement, y component
rigid body displacement, x component
0.0004
0.0002
0
-0.0002
-0.0004
-0.0006
-0.0008
-0.001
-0.0012
-0.0014
-0.0016
-0.0018
-0.002
-0.0022
0
0.05
0.1
0.15
0.2
0.25
0.3
0.35
0.4
0.45
0.5
0.55
时间 (s)

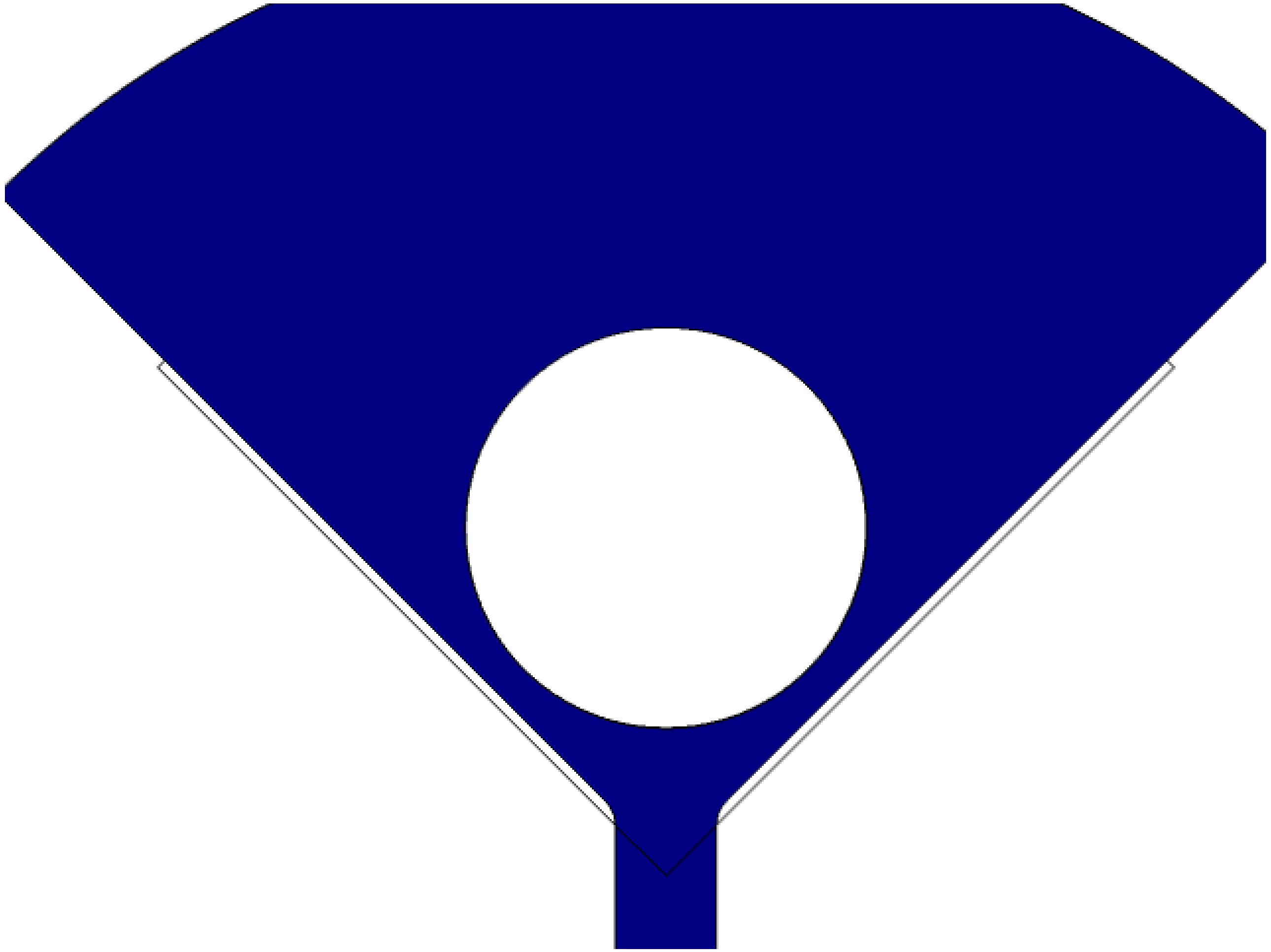
Problem encountered

- If set $\rho = 10\ \mathrm{g/cm^3}$ (real ping-pong ball density), never get fine result. (not convergent of be blown away)
- Thus the solid ball model with original density is chosen.



Problem encountered

- Remeshing is supposed to make the result more convergent.
- Usually using remeshing is faster
- Yet sometimes remeshing diverge, while using original mesh doesn’t diverge, though pretty slow.
- ……



Questions

Thank you !!!