# Development of scheme for solving fluid-structure problem based on loosely coupling method

## 疎結合計算をベースとした流体固体の連成解析の手法開発

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# Purpose

Development of the scheme for solving a fluid-structure problem on biomechanics

## Future

To simulate the interaction between blood wall and blood

# Main scheme of fluid-structure coupling problem

- **Loosely coupling method**

Fluid dynamics analysis with FDM → Structure analysis with dynamic FEM

Fluid dynamics analysis with FDM ← Structure analysis with dynamic FEM

- **Direct coupling method**

CIP method(Cubic-Interpolated Polynomial)

ALE method(Arbitrary Lagragian Eulerian)

# Basic equations of fluid dynamics

Navier-stokes equations

$$\frac{\partial \mathbf{u}}{\partial t} + (\mathbf{u} - \mathbf{u}_0)\nabla \mathbf{u} = -\nabla p + \frac{1}{\mathrm{Re}}\nabla^2 \mathbf{u}$$

Continuity equations

$$\nabla \mathbf{u} = 0$$

# Discretization with FDM

1. **A third-order upwind** in convective term

2. **A second-order central scheme** in other spatial term

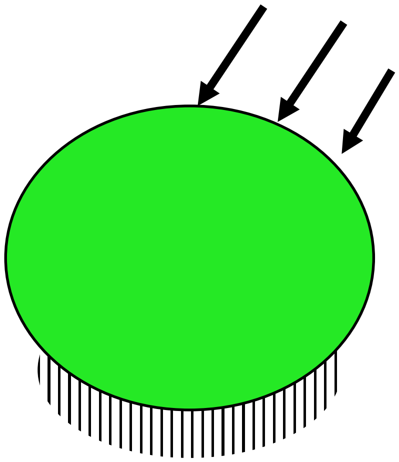
3. **A first-order Euler explicit** scheme for time integrations terms

4. **MAC method** is used to couple velocity and pressure field.

# Basic equations of elastic body(1)

Kinematic equations

$$\sigma_{ij,j} = \rho\ddot{q}_i$$



Geometric boundary conditions

$$q_i = \overline{q}_i$$

Dynamic boundary conditions

$$\sigma_{ij} n_j = \overline{p}_i$$

# Basic equations of elastic body(2)

Discretization with dynamic FEM

$$\mathbf{M}\ddot{\mathbf{q}} + \mathbf{C}\dot{\mathbf{q}} + \mathbf{K}\mathbf{q} = \mathbf{F}$$

Damping matrix

$$\mathbf{C} = \alpha\mathbf{M} + \gamma\mathbf{K}$$

# Direct time integral method

Newmark $\beta$ method

Acceleration

$$\ddot{\mathbf{q}}(t+\Delta t)=\left\{\mathbf{M}+\frac{\Delta t}{2}\mathbf{C}+\beta\Delta t^2\mathbf{K}\right\}^{-1}$$

$$\bullet\left[\mathbf{f}(t+\Delta t)-\left\{\dot{\mathbf{q}}(t)+\frac{\Delta t}{2}\ddot{\mathbf{q}}(t)\right\}\right.$$

$$\left.-\mathbf{K}\left\{\mathbf{q}(t)+\Delta t\dot{\mathbf{q}}(t)+\left(\frac{1}{2}-\beta\right)\Delta t^2\ddot{\mathbf{q}}(t)\right\}\right]$$

Velocity

$$\dot{\mathbf{q}}(t+\Delta t)=\dot{\mathbf{q}}(t)+\frac{\Delta t}{2}\left\{\ddot{\mathbf{q}}(t)+\ddot{\mathbf{q}}(t+\Delta t)\right\}$$

Displacement

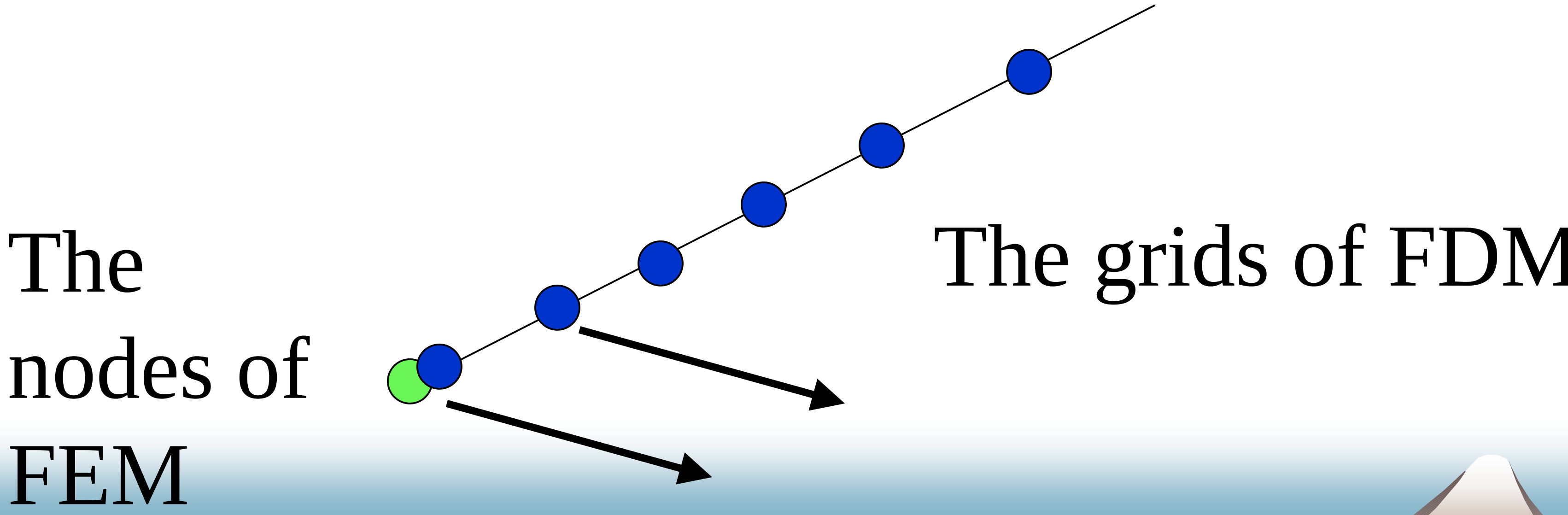
$$\mathbf{q}(t+\Delta t)=\mathbf{q}(t)+\frac{\Delta t}{1!}\dot{\mathbf{q}}(t)+\frac{\Delta t^2}{2!}\ddot{\mathbf{q}}(t)$$

$$+\beta\Delta t^3\frac{\ddot{\mathbf{q}}(t+\Delta t)-\ddot{\mathbf{q}}(t)}{\Delta t}$$

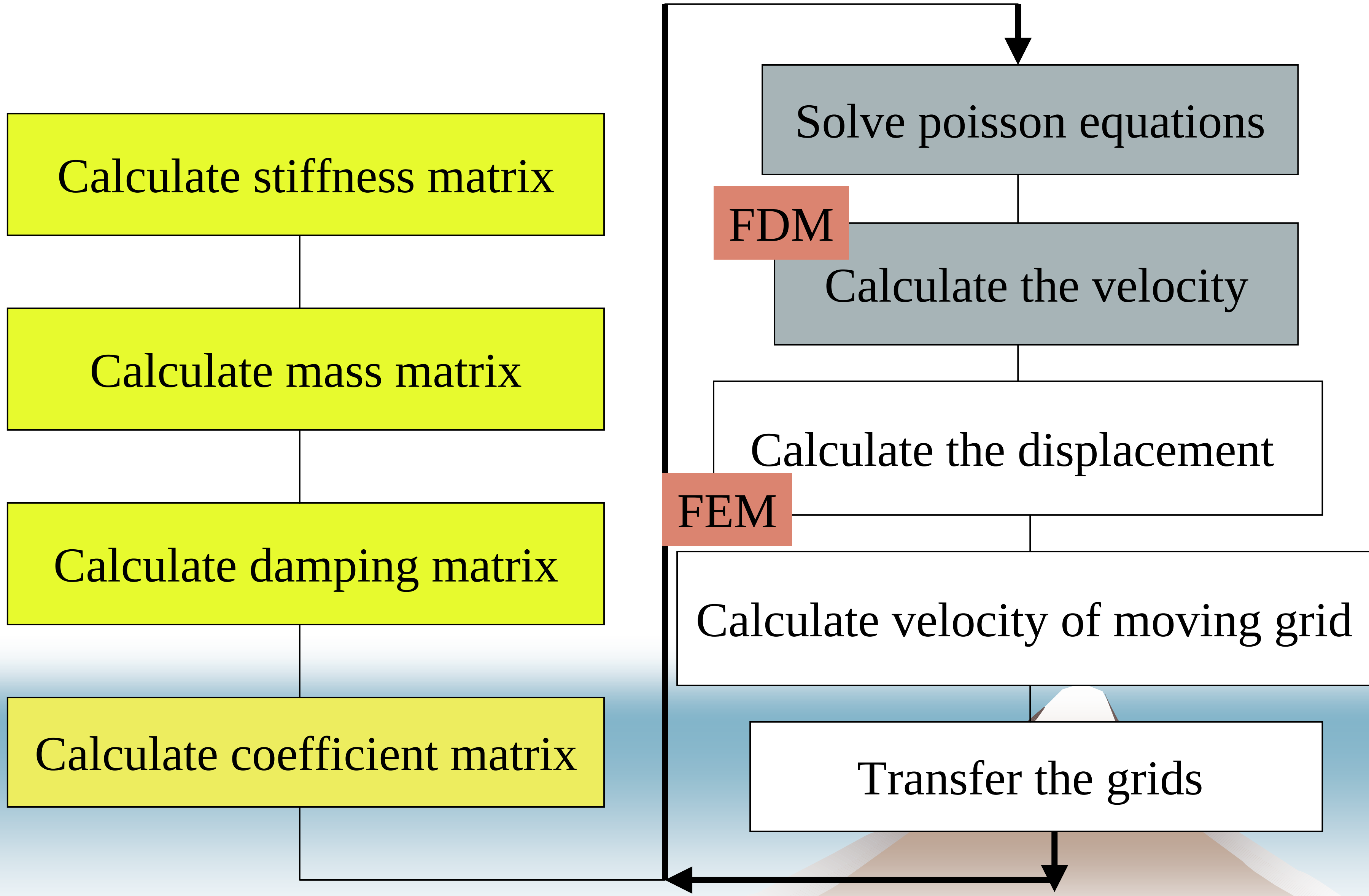
# The Velocity of moving grid

$$u_0 = \frac{x^{n+1} - x^n}{\Delta t}$$

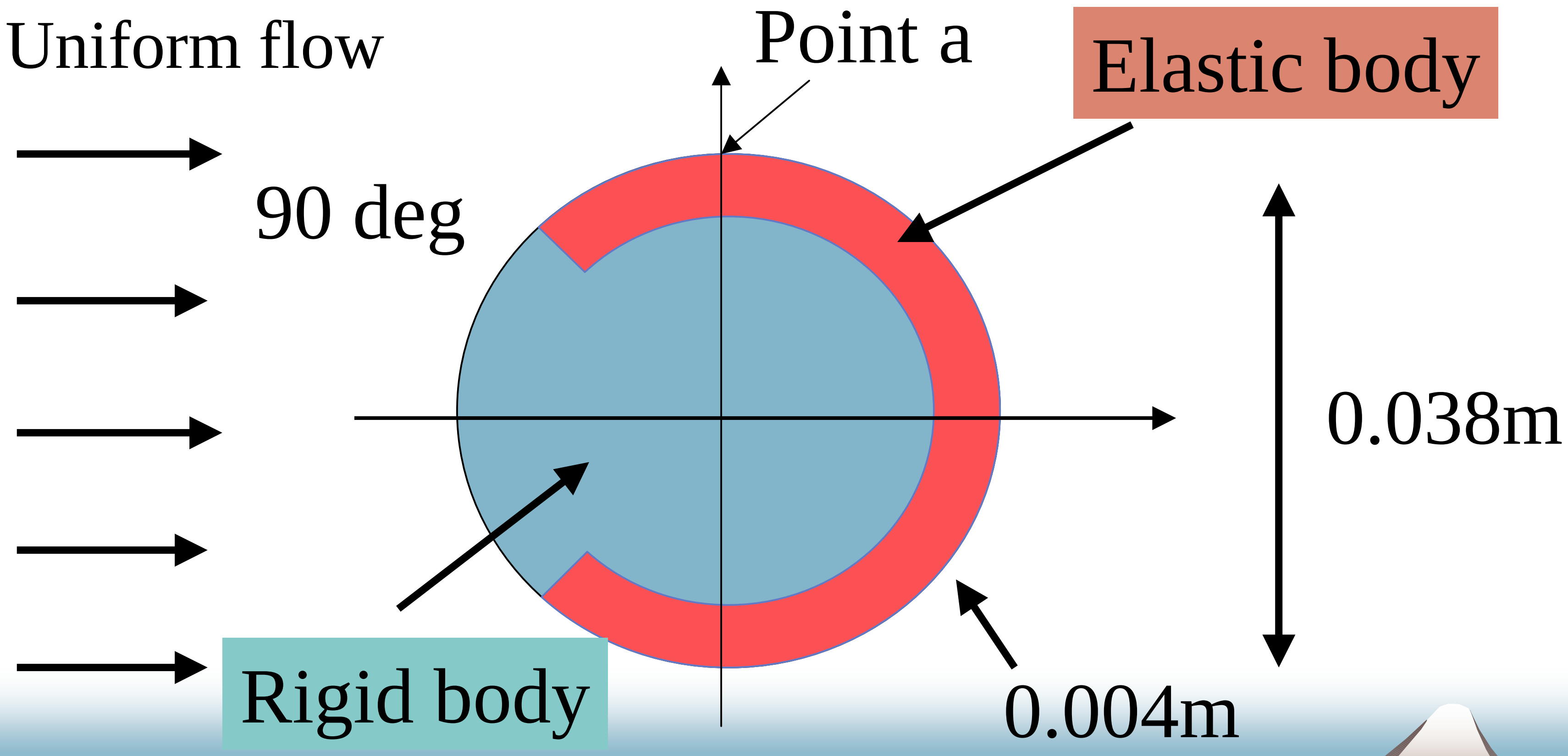
$$v_0 = \frac{y^{n+1} - y^n}{\Delta t}$$



# Flow chart of scheme



# Model of simulation



# Calculation conditions

## Fluid analysis

Reynolds number 10,000

$$\Delta t = 10^{-5}$$

Newmark method $\beta = 0.25$

## Elastic analysis

Poisson's ratio 0.4

Young 's modulus 11,000[Pa]

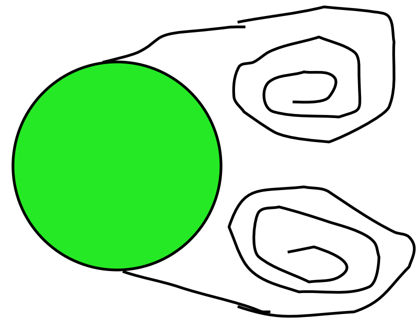
Damping matrix coefficient

$\alpha = 0.02$ $\gamma = 0.05$

**Non dimensional time**

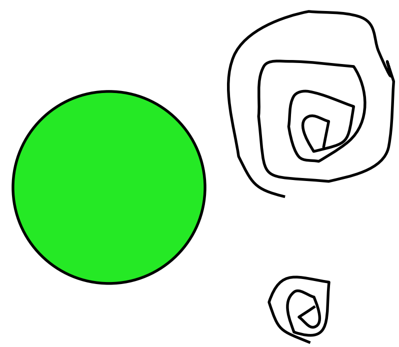
**T＝20.0(case 1), 60.0(case 2), 80.0(case 3)**

Case 1



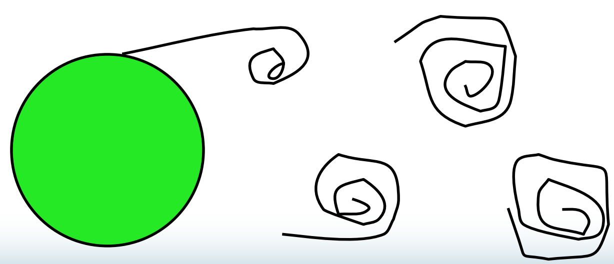
A pair of vortices

Case 2



Pre karman vortex row

Case 3

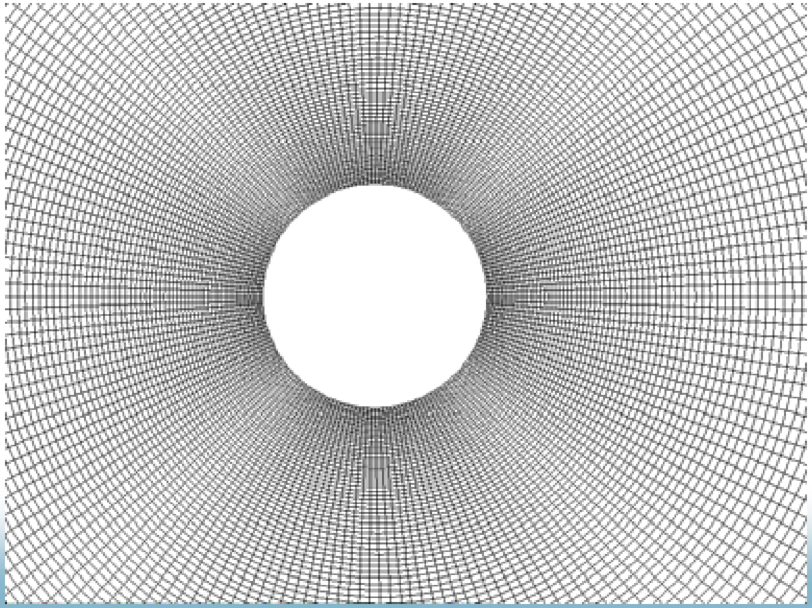


Karman vortex row

# Division of domains for fluid and elastic body

The number of grids

182×182

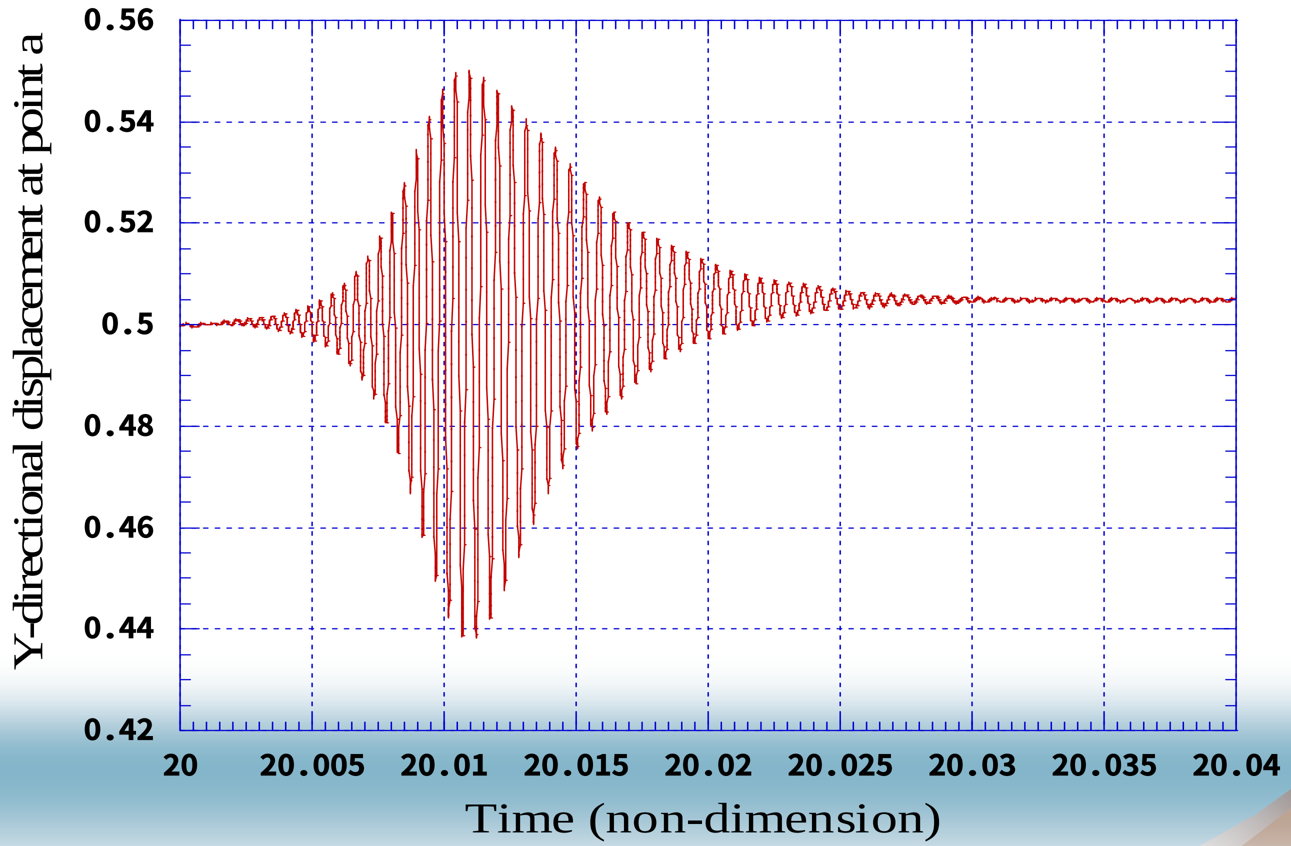


Triangular elements

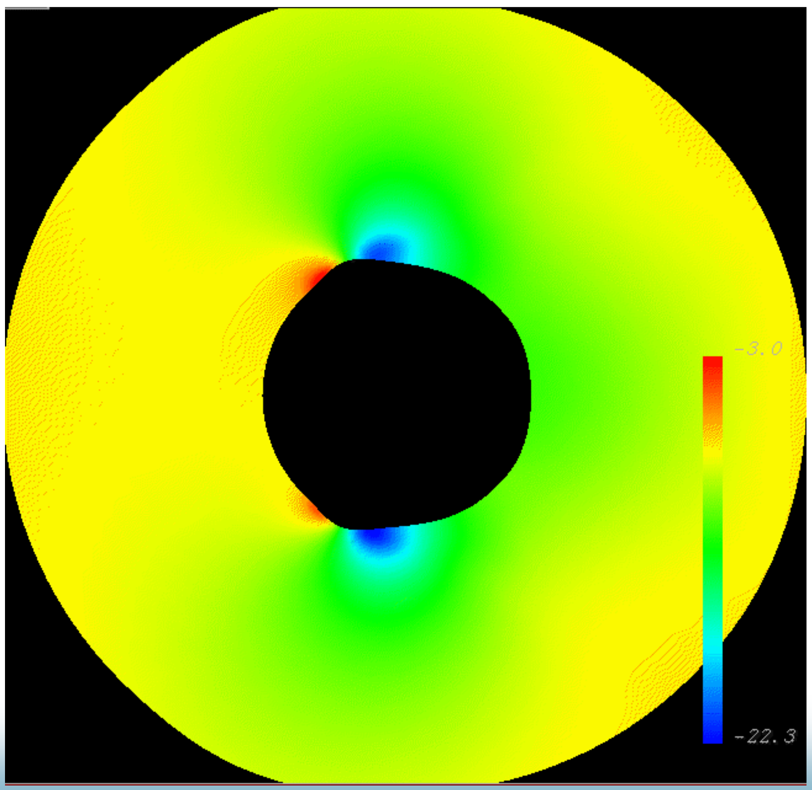
272elements

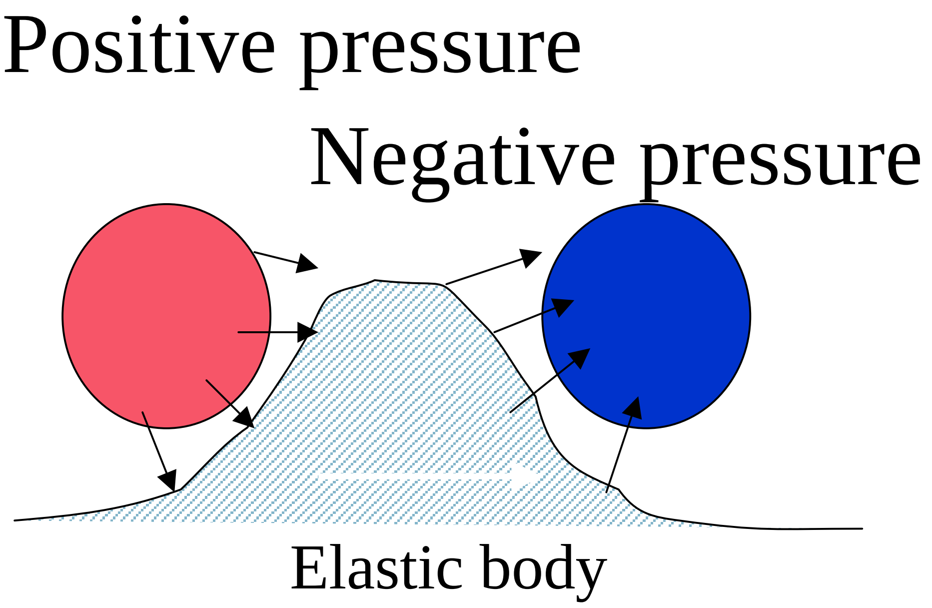
One-dimensional interpolation function for displacement

# The amplitude at point a in case 1

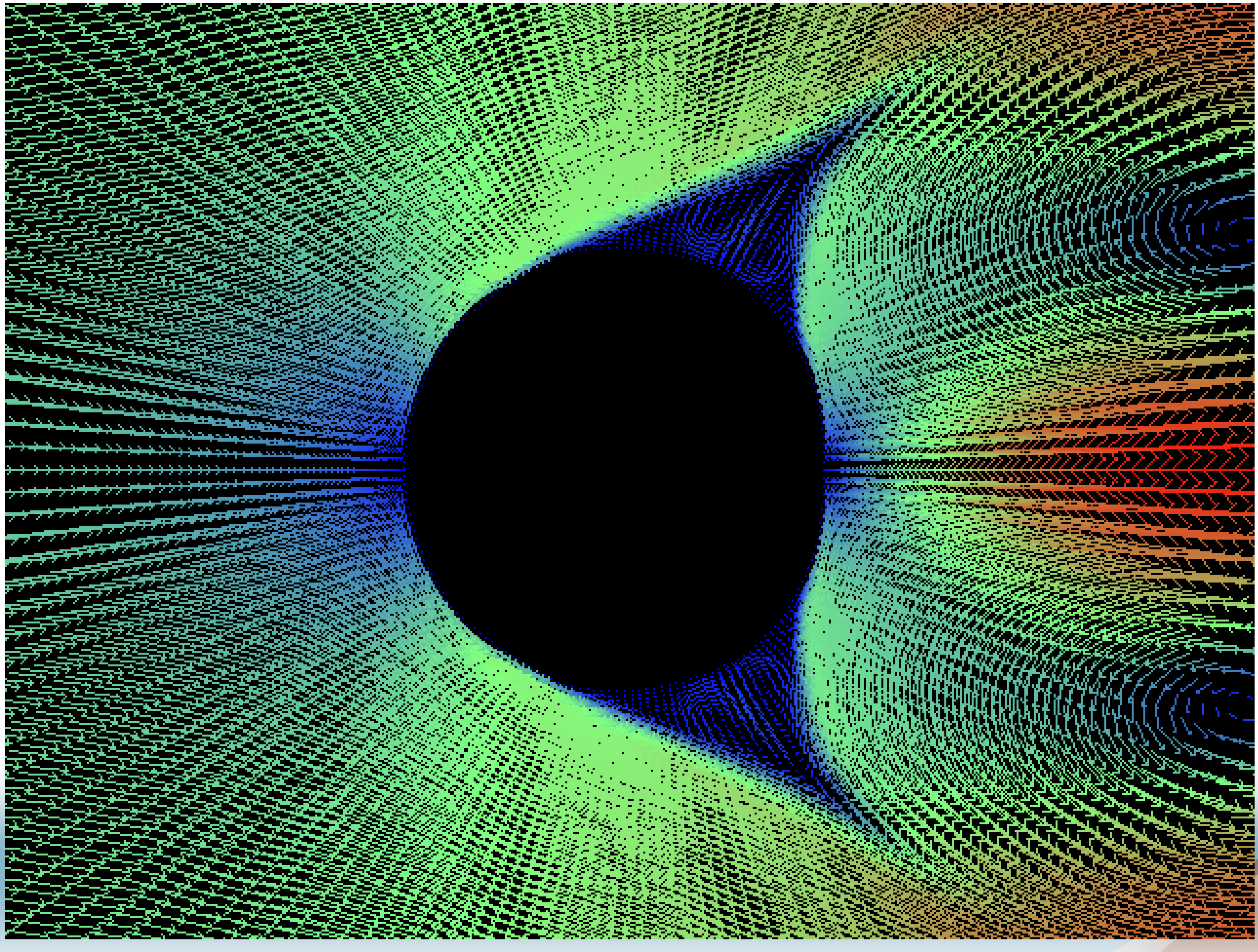


# Generation of traveling wave

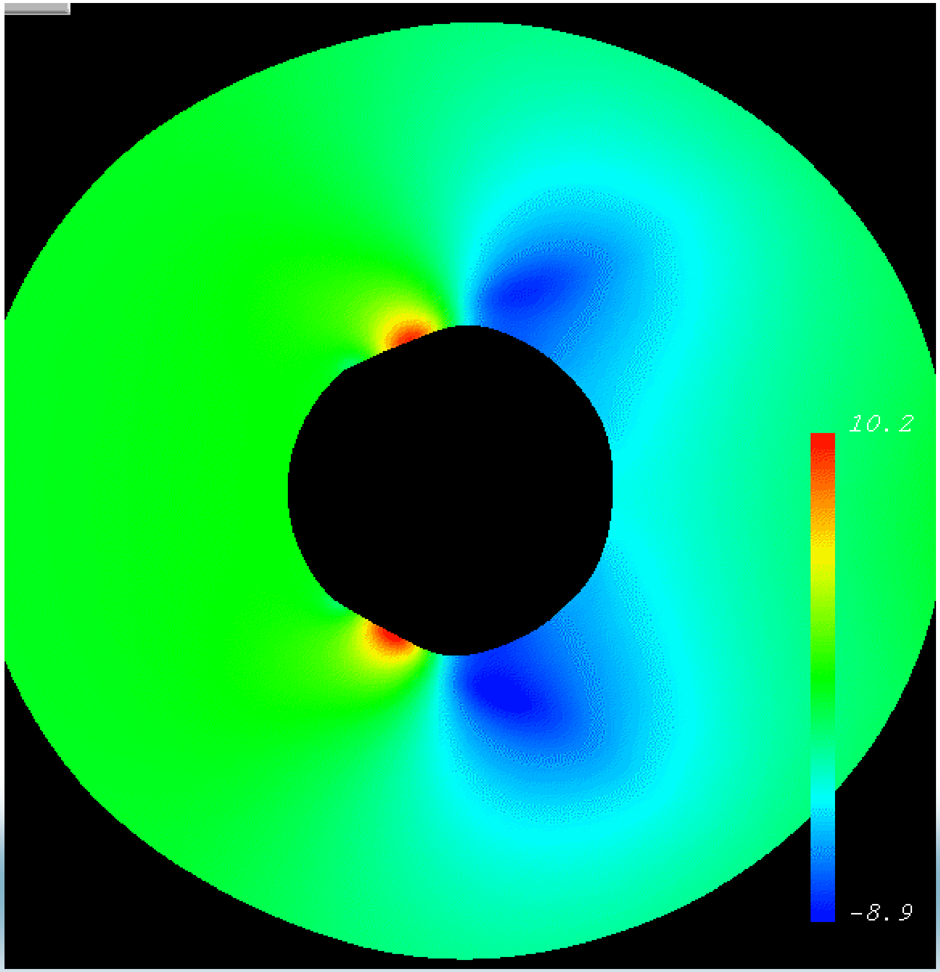


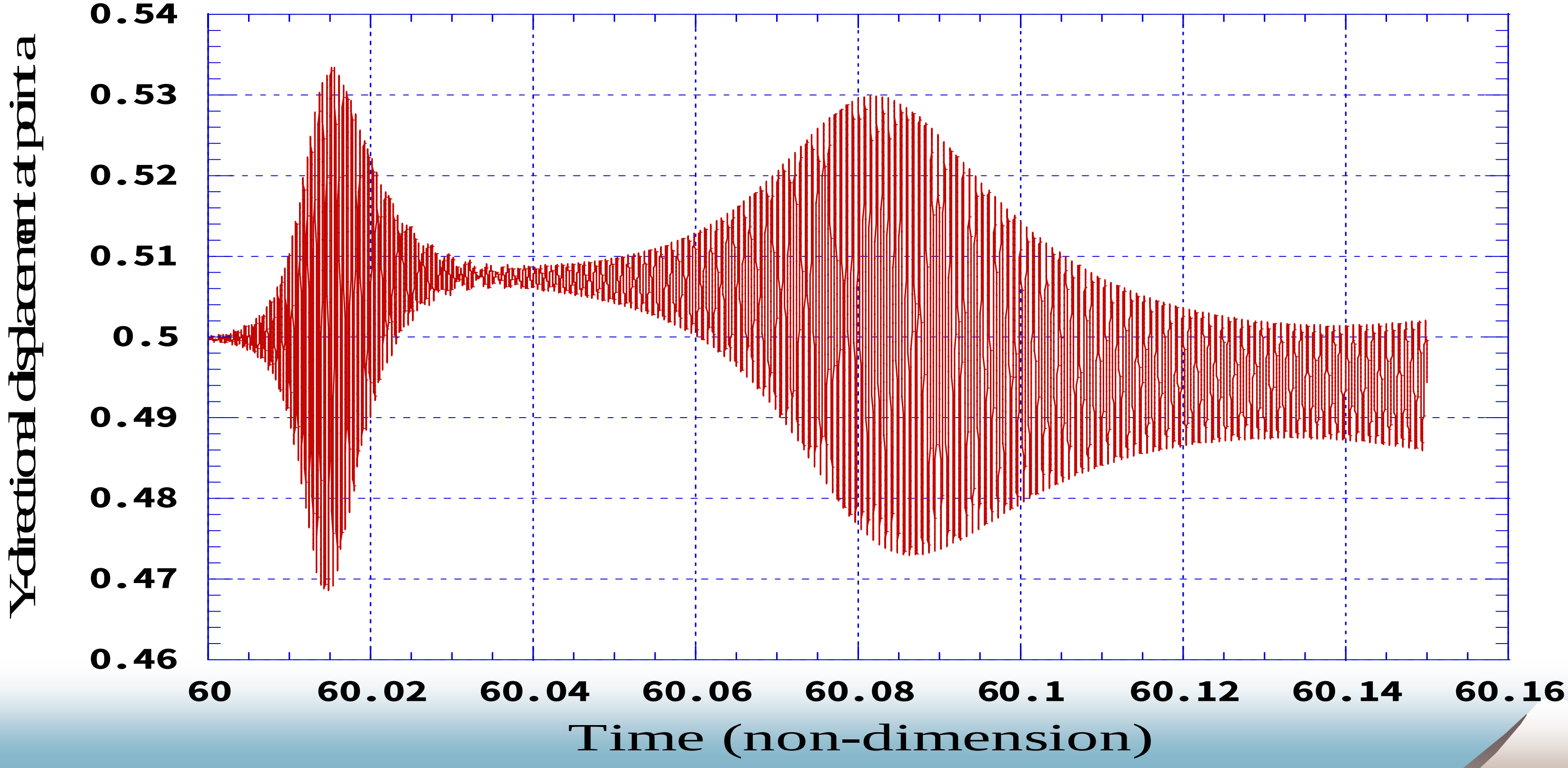
# Vector line of velocity in case 1



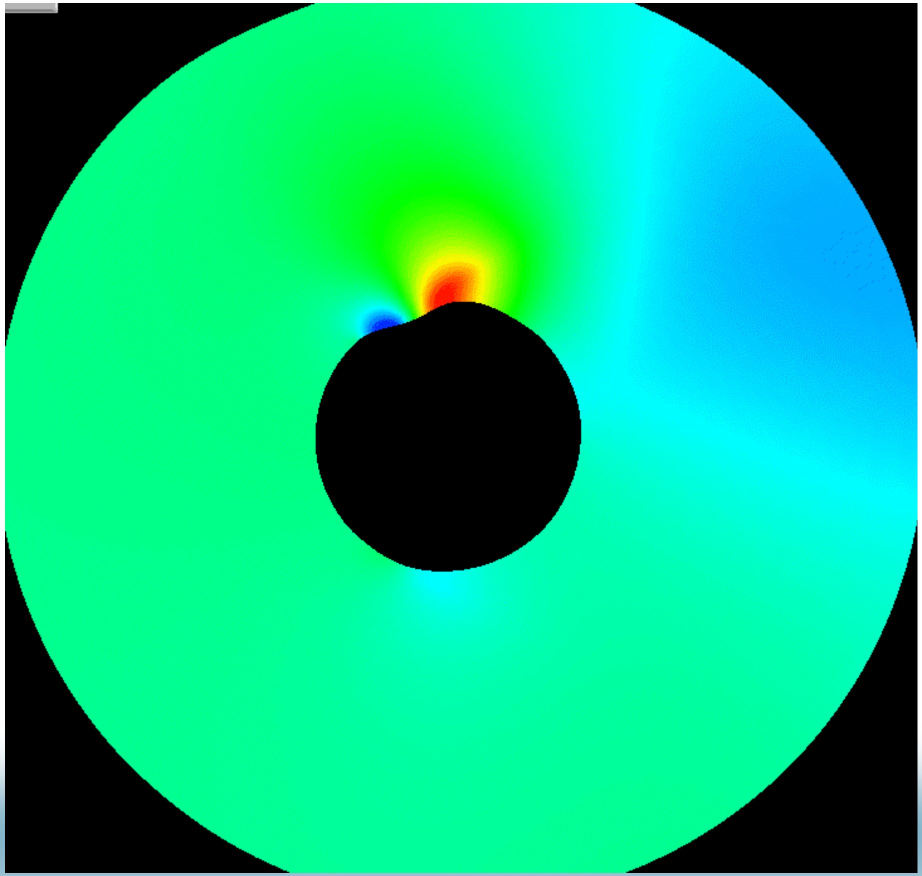
# Deformation in case 1



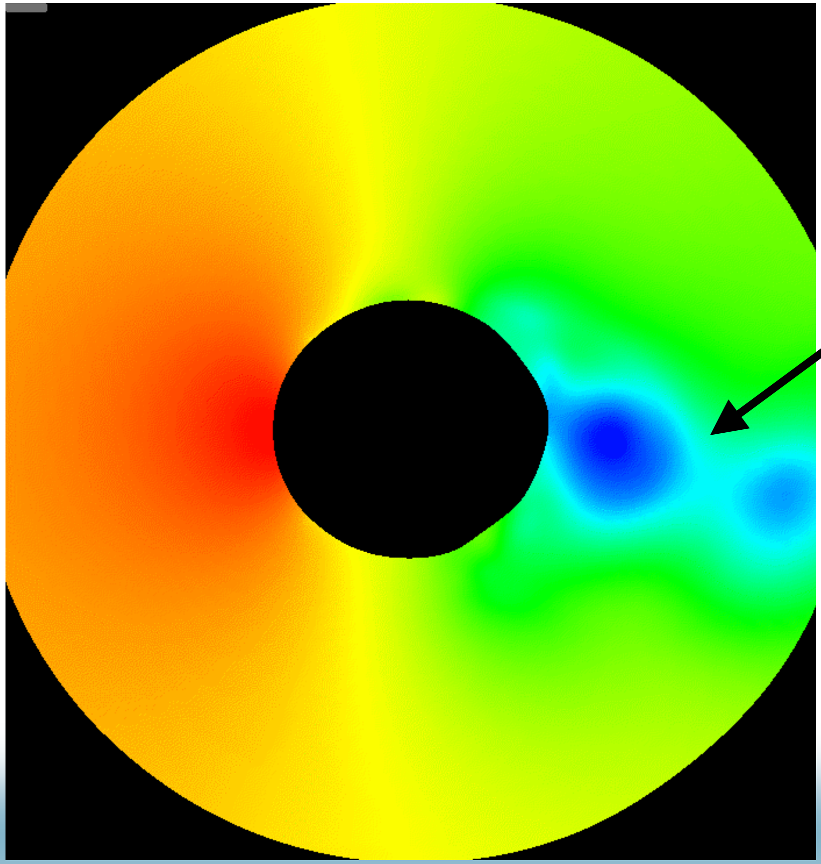
# The amplitude at point a in case 2



# Deformation in case 2



# Deformation in case 3



Karman vortex

# Conclusion

- **We proposed the new scheme based on the loose coupling method for solving a CFS problem.**
- **The circular cylinder with elastic surface in uniform flow is chosen as the example. We indicate the satisfied results.**