Numerical modeling and simulation of flow through porous fabric surface

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Background

- What is porosity and permeability
  - Porosity is a measure of void spaces in a material between 0 and 1
  - Permeability is a measure of the ability of a porous material to transmit fluids.
  - Permeability is not only dependent upon the porosity of the fabric

- Why porosity is important
  - Affect the stability of parachute system

- Challenge for porosity simulation
  - Different scales:
    - parachute diameter $\sim 10$ m;
    - pore size $< 1$ mm
  - Fluid-structure interactions
Methodology

- Previous method
  - Model the microstructure and solve the fluid equation at the pore level
  - High computational cost, especially for parachute

- Our method
  - Consider the average aerodynamic motion of canopy surface
  - Low computational cost, robust, easy to be coupled with the current fluid solver

Numerical Model

- Canopy is modeled with spring mesh
  - Incompressible fluid is solved with projection algorithm
  - Interactions are treated with front tracking method
  - The pressure drop is modeled with Ghost fluid method (GFM)
    \[ [p]_\Gamma = \alpha u_\Gamma \cdot n + \beta |u_\Gamma \cdot n| u_\Gamma \cdot n \]
  - Couple GFM with projection method
    - Adding source term to the pressure (Poisson) equation
    - Not affect the symmetry of the coefficient matrix, easy to converge with KSP iterations

Fig. define the two domains
Verification

- Verify the pressure difference
- Put a porous surface on the channel
- Verify pressure difference and velocity profile

Fig. porous surface in the channel

Fig. velocity profile

- $X = 1\text{m}$ and $3\text{m}$

Fig. pressure profile

- $X = 2\text{m}$
Validation

- Verify the Darcy’s law
  - Correct method should be able to reproduce the quadratic relationship between pressure drop and velocity

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Parachute Simulation

- Calculate drag force and drag coefficient

**Fig. Parachute channel test**

**Fig. drag force**

**Fig. drag coefficient**
Comparison

- Vorticity field with and without porosity

**Fig. drag force with and without porosity**
Summary

- Proposed a numerical scheme for the computation of permeability of the parachute and its dynamic response
- Coupled projection method and GFM in the front tracking framework.
- Advantages: efficient and robust
- Future: fully folded parachute inflation, robust fabric collision treatment
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