VIV - Force Partitioning Method

Code Review

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Outline

1. General Problem
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2. Implementation
   - Helmholtz Decomposition
   - Auxiliary Potential
   - OpenFOAM
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General Problem

- Method to partition the force contributions
  - Kinetic, Vorticity-induced, Viscous (Primary)
  - Potential, Boundary (Small contribution)
- Arbitrary Direction (Focus $\perp$ flow $\rightarrow$ *Lift*)
- Insight onset and sustencance of VIV

General Problem

FPM Equations

- From Zhang (2015) and Menon (2020)
- Basis of the entire implementation

$$C_i = -\int_B \boldsymbol{n} \cdot \left(\frac{\mathrm{d}\boldsymbol{U}_B}{\mathrm{d}t} \phi^{(i)} \right) \mathrm{d}S - \int_B \frac{1}{2} (\boldsymbol{U}_B \cdot \boldsymbol{U}_B) n_i \, \mathrm{d}S \tag{A 13}$$

$$+ \int_{V_f} \left\{ [\nabla \cdot (\boldsymbol{\omega} \times \boldsymbol{u})] \phi^{(i)} + \nabla \cdot \left[\nabla \left(\frac{1}{2} \boldsymbol{u}_v \cdot \boldsymbol{u}_v + \boldsymbol{u}_v \cdot \boldsymbol{u}_\Phi \right) \phi^{(i)} \right] \right\} \mathrm{d}V \tag{A 14}$$

$$+ \int_B \frac{1}{Re} \left[(\boldsymbol{\omega} \times \boldsymbol{n}) \cdot \nabla \phi^{(i)} - (\boldsymbol{\omega} \times \boldsymbol{n}) \cdot \hat{e}_i \right] \mathrm{d}S \tag{A 15}$$

$$+ \int_{V_f} \nabla \cdot \left[\nabla \left(\frac{1}{2} \boldsymbol{u}_\Phi \cdot \boldsymbol{u}_\Phi \right) \phi^{(i)} \right] \mathrm{d}V \tag{A 16}$$

$$+ \int_\Sigma \left\{ -\boldsymbol{n} \cdot \left(\frac{\mathrm{d}\boldsymbol{u}}{\mathrm{d}t} \phi^{(i)} \right) + \frac{1}{Re} (\boldsymbol{\omega} \times \boldsymbol{n}) \cdot \nabla \phi^{(i)} \right\} \mathrm{d}S. \tag{A 17}$$

The terms in (A 13)–(A 17) above correspond to the final forms for the force components $C_\kappa^{(i)}$, $C_\omega^{(i)}$, $C_\sigma^{(i)}$, $C_\Phi^{(i)}$ and $C_\Sigma^{(i)}$, respectively, shown in § 2.4.

Thus, the final form of the partitioning can be written compactly as

$$C_i = C_\kappa^{(i)} + C_\omega^{(i)} + C_\sigma^{(i)} + C_\Phi^{(i)} + C_\Sigma^{(i)}. \tag{A 18}$$

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Implementation Approach

Helmholtz Decomposition

- find the curl-free and divergence-free component of the velocity vector

$$
\begin{aligned}
\mathrm{u} &= \mathrm{u}_\Phi + \mathrm{u}_v = \nabla\Phi + \nabla \times A && (1)\\
\Rightarrow \nabla \cdot \mathrm{u} &= \nabla \cdot \nabla\Phi + \nabla \cdot (\nabla \times A) && (2)\\
&= \nabla^2\Phi && (3)
\end{aligned}
$$

- continuity equation states that $\nabla \cdot \mathrm{u} = 0$, so:

$$\nabla^2\Phi = 0 \tag{4}$$

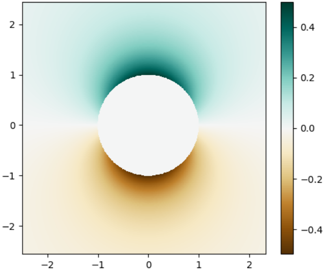
- Φ is therefore the velocity potential (`potentialFoam`)
- $\nabla \times A = \mathrm{u} - \nabla\Phi$

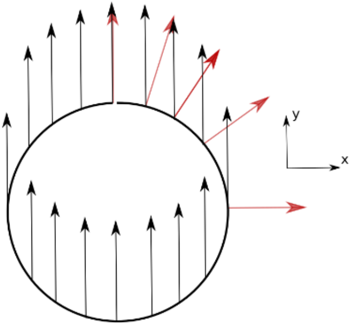
Implementation Approach

Auxiliary Potential

$$\nabla^2 \phi^{(i)} = 0, \qquad \text{with } \mathbf{n} \cdot \nabla \phi^{(i)} = \begin{cases} \mathbf{n} \cdot \nabla x_i = n_i & \text{on } B \\ 0 & \text{on } \Sigma \end{cases} \tag{5}$$

- Gradient of $\phi^{(i)}$ is in the direction of the force partitioning



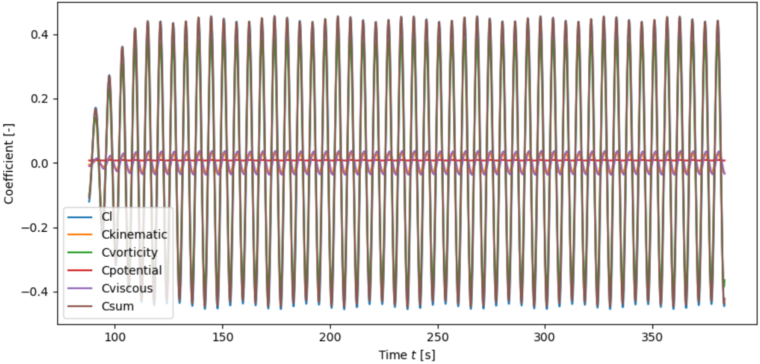


- Boundary condition for the vector $\nabla \phi^{(i)}$

OpenFOAM

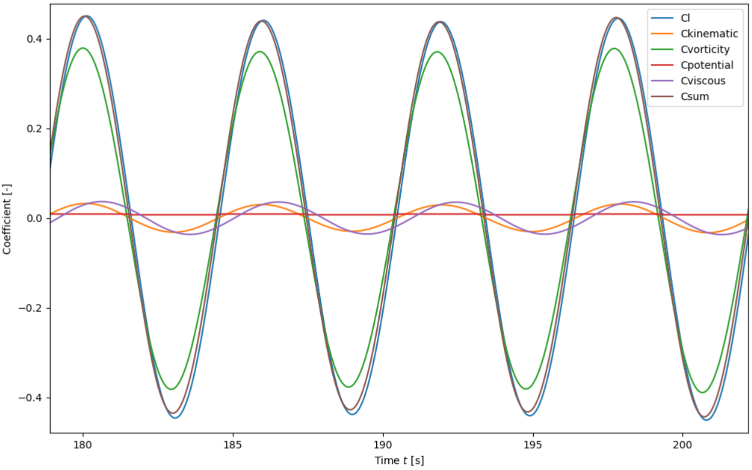
- `vivForcePart`: Force partitioning method
  - Based on `forceCoefficients`
- `vivPimpleFoam`:
  - Combines the `potentialFoam` and `pimpleFoam` solvers.
  - Calculate ϕ and $\phi^{(i)}$
- `vivFixedGradient`
  - Boundary condition for $\phi^{(i)}$ field.
- Plotting Scripts

Preliminary Results



- All coefficients, except for boundary contribution C_Σ (Very small effect).

Preliminary Results



Main Problems (currently)

- Calculating ϕ and $\phi^{(i)}$ field in parallel implementation.
  - I am not sure this is what causes the problem
  - Lately: Fatal MPI errors when running in parallel.
- Implementation of boundary coefficient C_Σ.
- Efficiency
- ...

Let me show you