Computational Modelling of Leading Edge Erosion of Turbine Blades by Droplets and Solid Particle Impact

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Vision and Objectives

To develop an open-source framework for modelling erosive impact of particles/ droplets with wind turbine blades.

The Problem

The erosion of wind turbine blades due to rain droplets and solid particles is becoming more severe due to the increase of the size of wind turbines and their tip speed making impacts more destructive. At the minimum this increases the drag. Worst case, it compromises the structural integrity of the blade. In order to better understand this phenomena a comprehensive study of the impact damage mechanisms must be conducted. This will be accomplished using a High-Fidelity simulation framework.

The Model

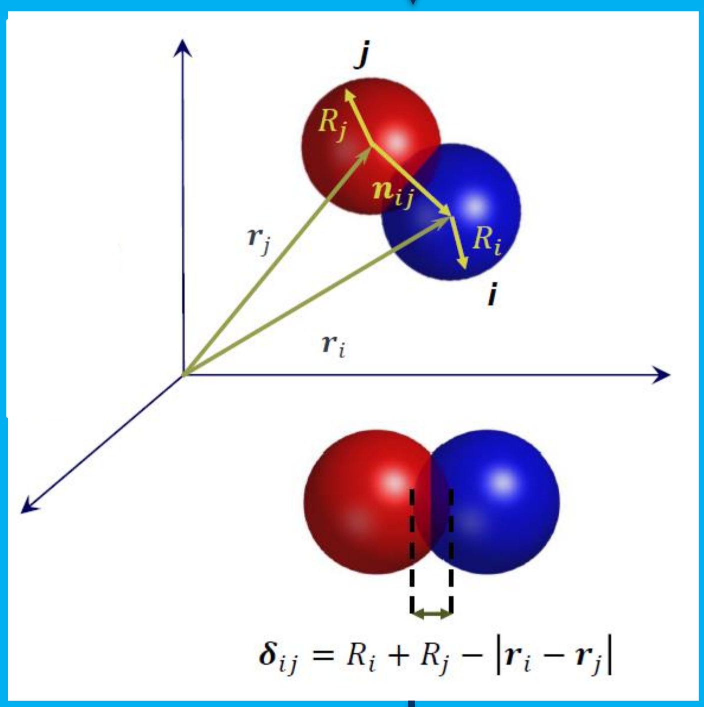
Using a fictitious domain method to solve the Naiver Stokes equations and Discrete Element Method for the impact, a fully resolved model is being developed in 2D and 3D that can accurately predict erosion from particle and fluid impact.

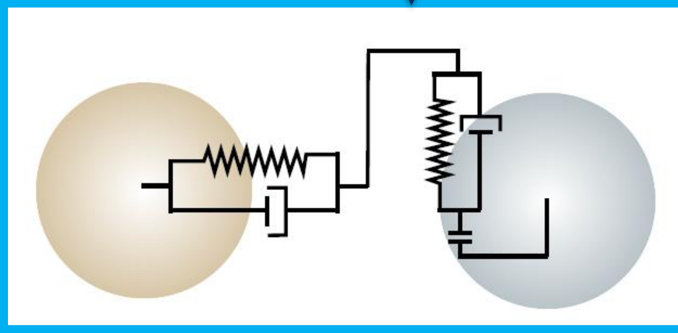
With solid particles in 2D a Peridynamic model will be implemented to model the erosion.
This will then be expanded into 3D where the following step will be to model fluid impact.

Discrete Element Method

- Uses soft collision model.
- Forces between particles/wall can be modelled using a spring and dashpot.
- The model considers normal and tangential forces.

$$\boldsymbol{F}_{n_{ij}} = k_n \delta_{ij} \boldsymbol{n}_{ij} - \gamma_n m^* \boldsymbol{v}_{n_{ij}}$$
$$\boldsymbol{F}_{t_{ij}} = k_t \boldsymbol{u}_{t_{ij}} - \gamma_t m^* \boldsymbol{v}_{t_{ij}}$$





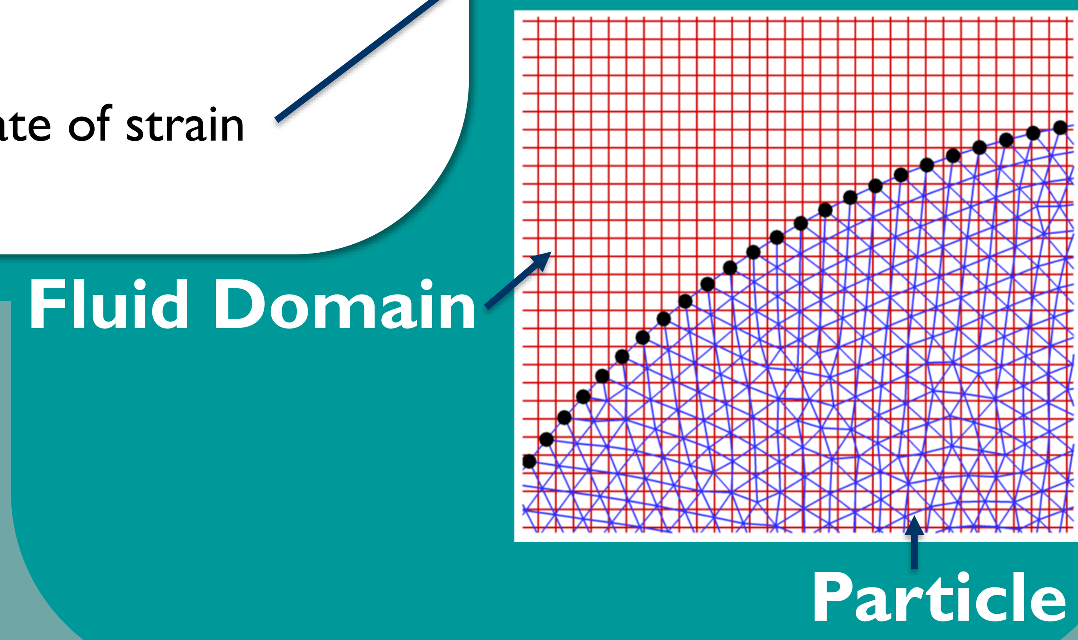
Fictitious Domain Method

- Particle is covered in Lagrangian grid. The domain is treated as a variable property fluid. → $\phi = \Theta_p \phi_p + (1 - \Theta_p)\phi_f \quad \phi \in \{\rho, c_p, \kappa\}$
- Navier-Stokes and continuity equations are discretised for a variable property. →

$$\frac{\partial \rho u_i}{\partial t} + \frac{\partial \rho u_i u_j}{\partial x_j} = -\frac{\partial P}{\partial x_i} + \frac{\partial}{\partial x_j}\left[\mu_f \left(\frac{\partial u_i}{\partial x_j}\right)\right] + f_{B,i} + f_i,$$
$$\frac{\partial \rho}{\partial t} + \frac{\partial \rho u_i}{\partial x_i} = 0.$$

- Consequent: particle momentum transport naturally governed by NS equations.
- Momentum conservation is satisfied through NS equations
- Projection of the velocity field onto a rigid field by setting rate of strain tensor to zero

$$\frac{1}{2}\left(\frac{\partial u_i^R}{\partial x_j} + \frac{\partial u_j^R}{\partial x_i}\right) = 0, \ \forall x \in \Omega_p$$



Initial Simulation Results

Particle released and impact on a wall