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Numerical characterization of precipitation impingement on rotating wind turbine

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Motivation

- Analyse rain impingement on rotating turbine
- Understand particle impact and distribution on large scale wind turbine blades → IEA 15MW
- Detailed input for blade damage model

Simulation levels

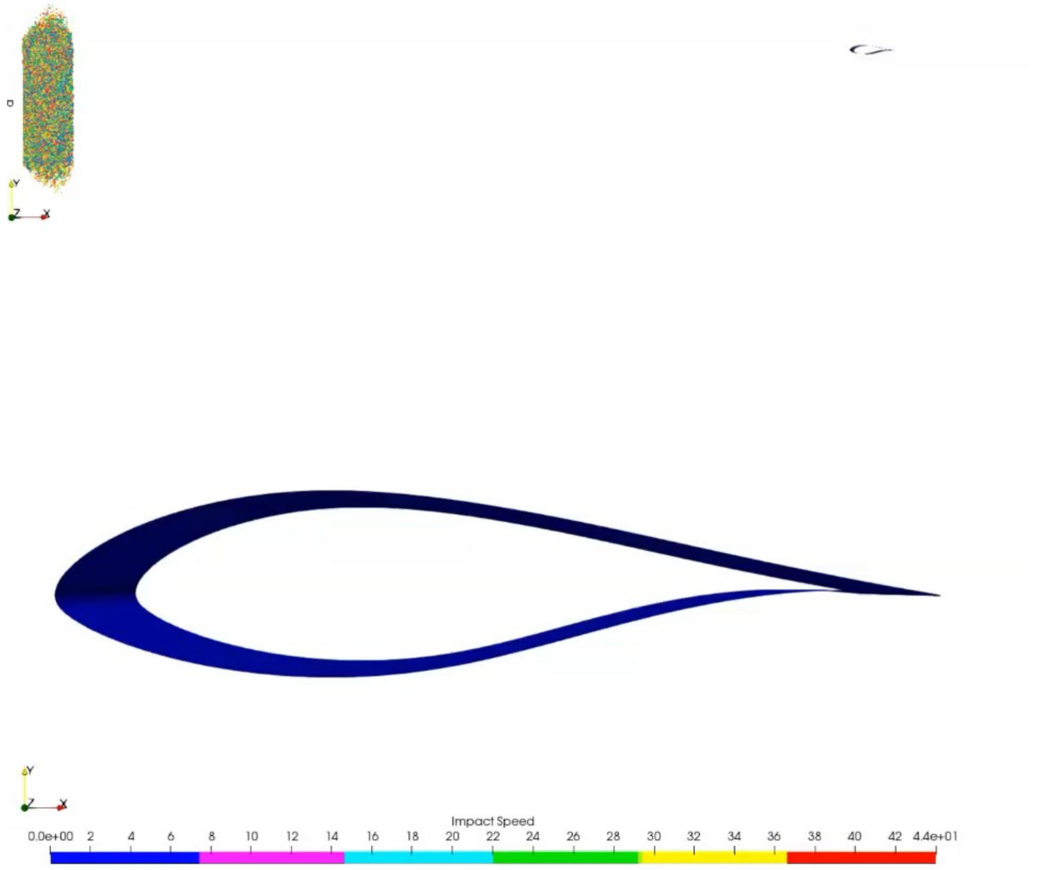
2D airfoil → 3D single blade (MRF) → Full rotor

Methodology

- Lagrangian particle tracking
- One-way coupling: only effect of fluid on the particle is considered
- No interaction/collision between particles
- Fluid domain computed in CFD using steady RANS for the 2D case and 3D single blade MRF case and unsteady RANS for the full rotor using OpenFOAM

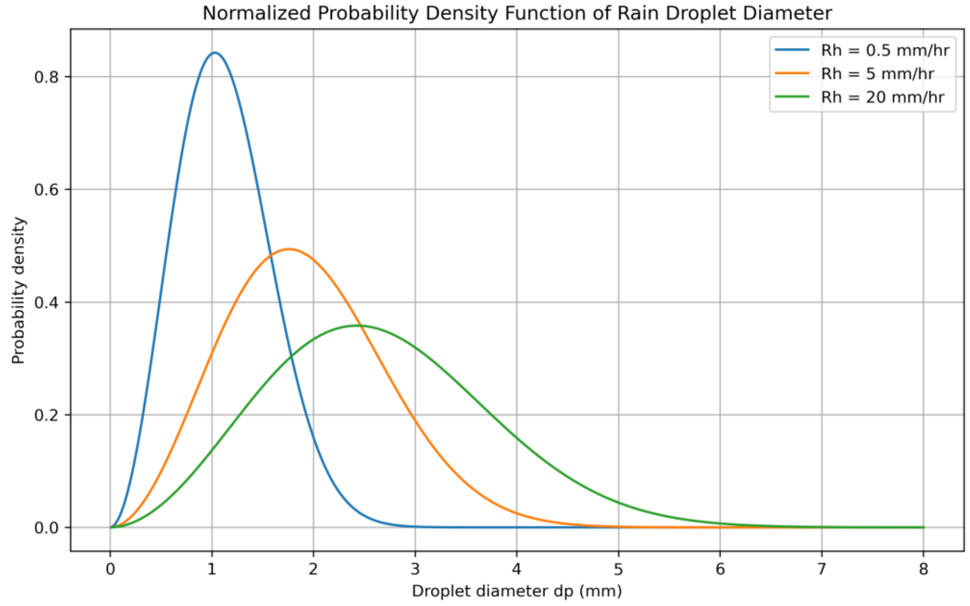
Airfoil under the rain

- 17 seconds simulated
- Inflow particle distribution according to Rh=5mm/hr
- Inflow conditions according to rotor blade in operation of IEA 15MW
- AoA = 6.5°
- Freestream and particle injection velocity 43.2m/s



Rain particle distribution

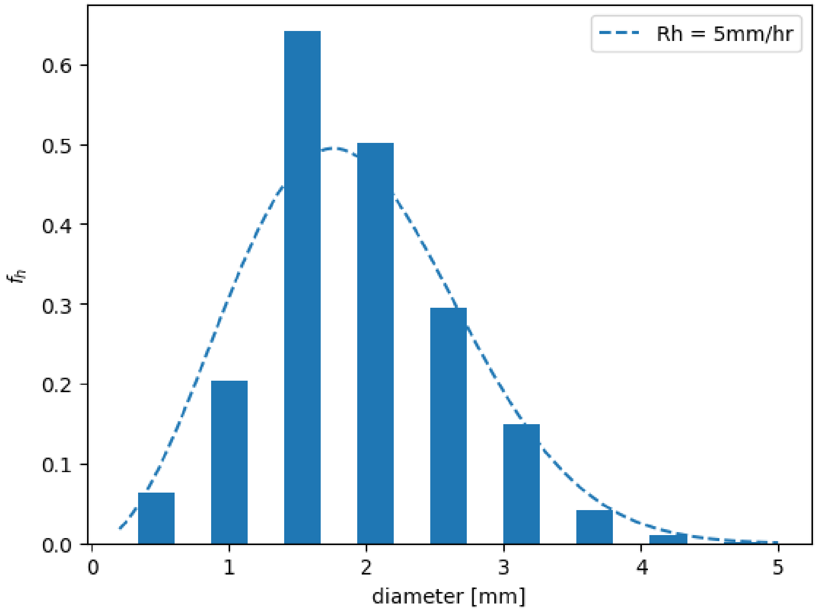
- Rain flow intensity parameter Rh describes amount of rain within one hour
- Droplet diameter distribution depends on Rh
- Rh values of 0.5mm/hr, 5mm/hr and 20mm/hr have been investigated
- 5mm/hr corresponds to “normal rain” (in northern Germany)

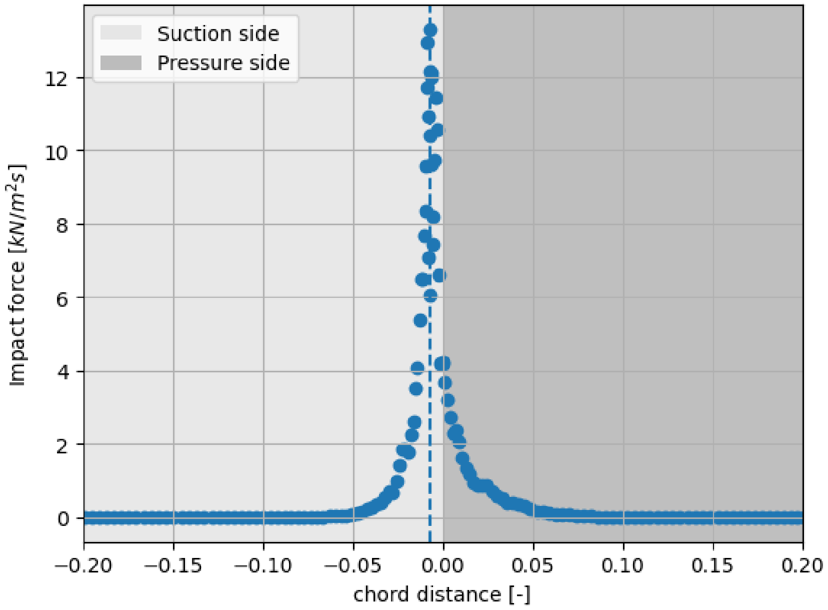


Src: Castorrini et. Al. “Generation of Surface Maps of Erosion Resistance for Wind Turbine Blades under Rain Flows”, Energies, 2022

2D airfoil - Results

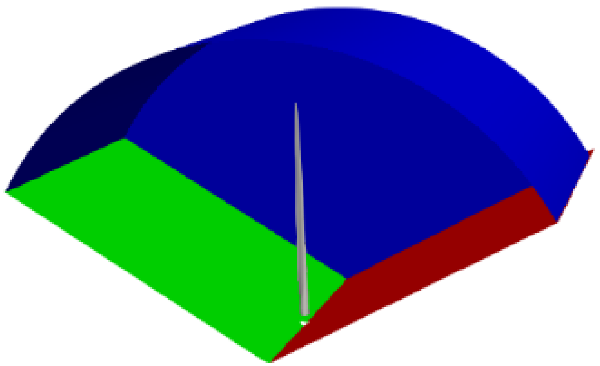
- Particle injection follows theoretical diameter distribution
- Actual hits on the airfoil slightly deviate from theory
- Impact force larger on the suction side

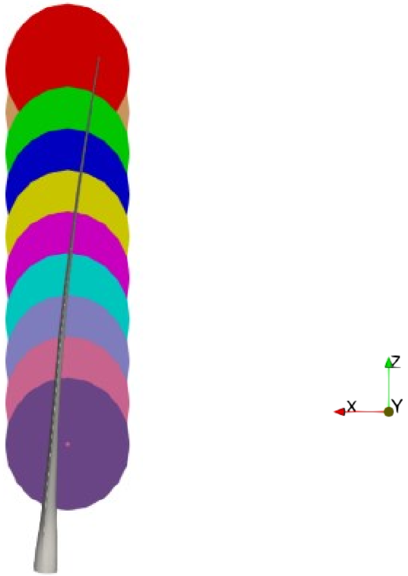


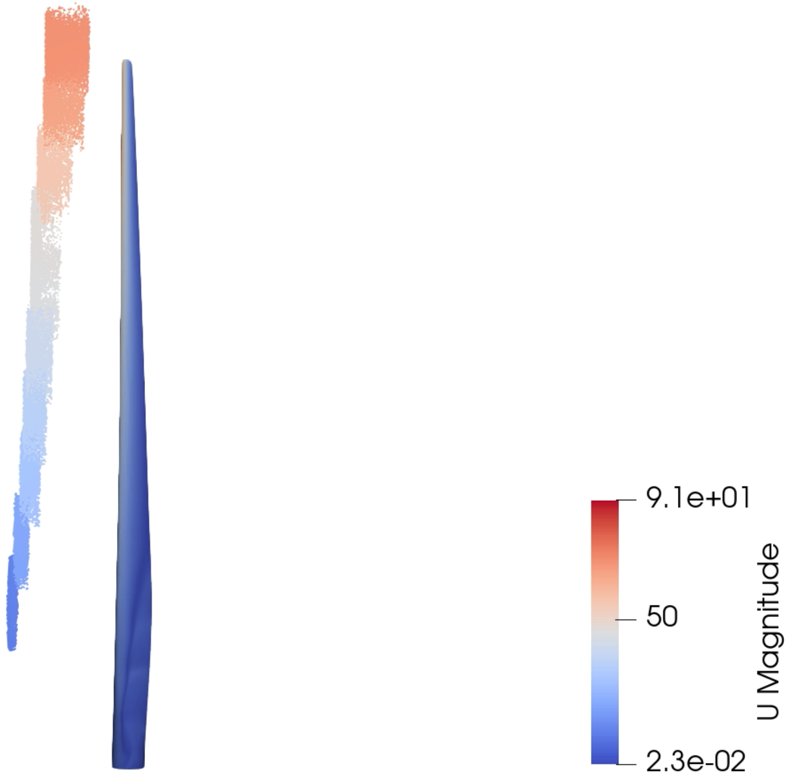


3D blade with moving fluid frame

- 3D MRF simulated for 3600 seconds
- Widely used approach to lower computational costs

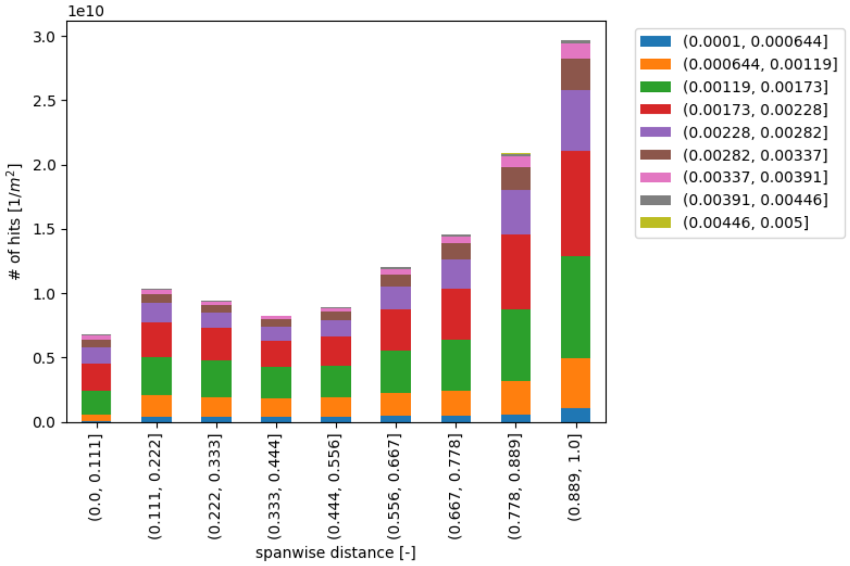


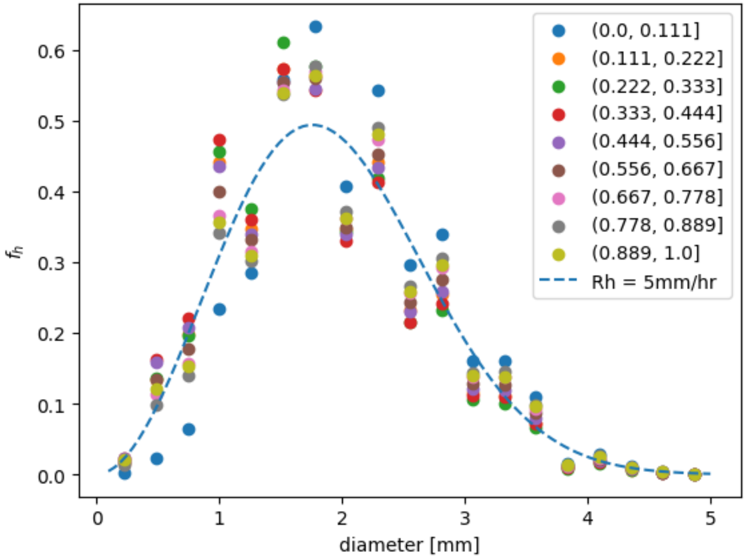


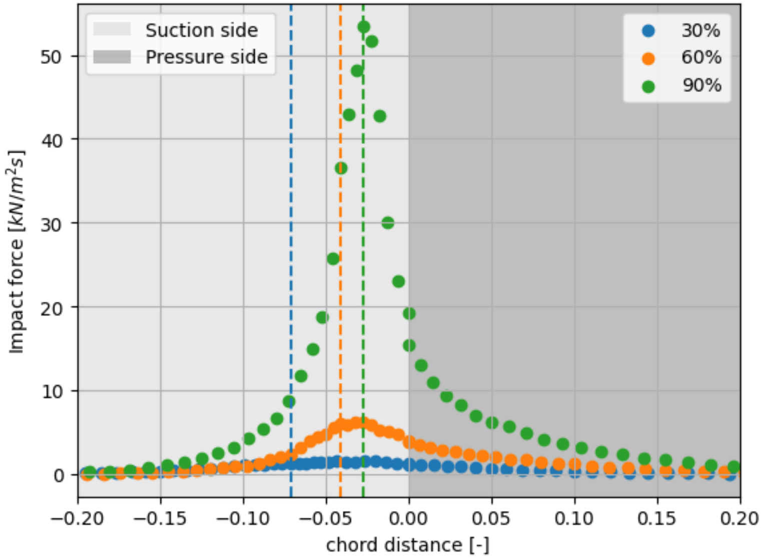


3D blade with moving fluid frame - Results

- 3D MRF simulated for 3600 seconds
- Most hits towards the tip
- Diameter distribution of particles hitting the blade follow theoretical distribution
- Impact force (source of erosion) higher towards the blade tip

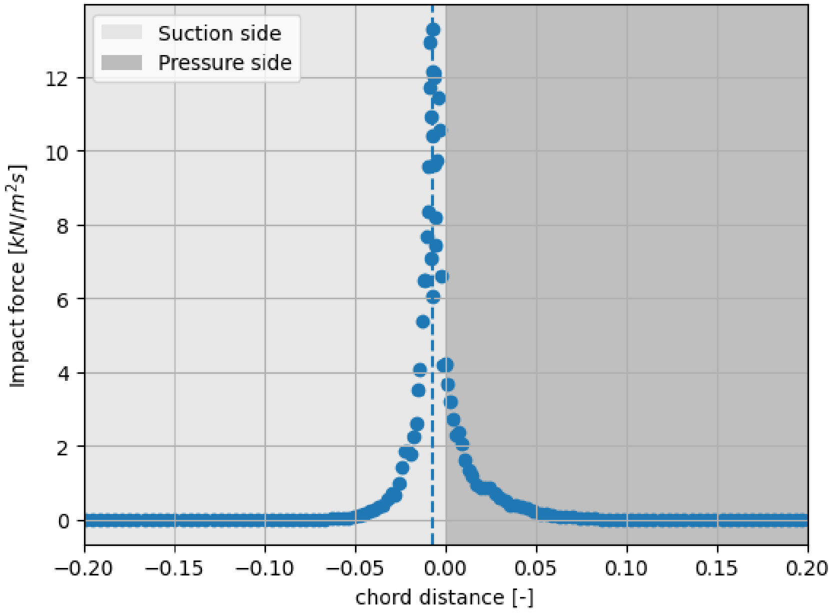


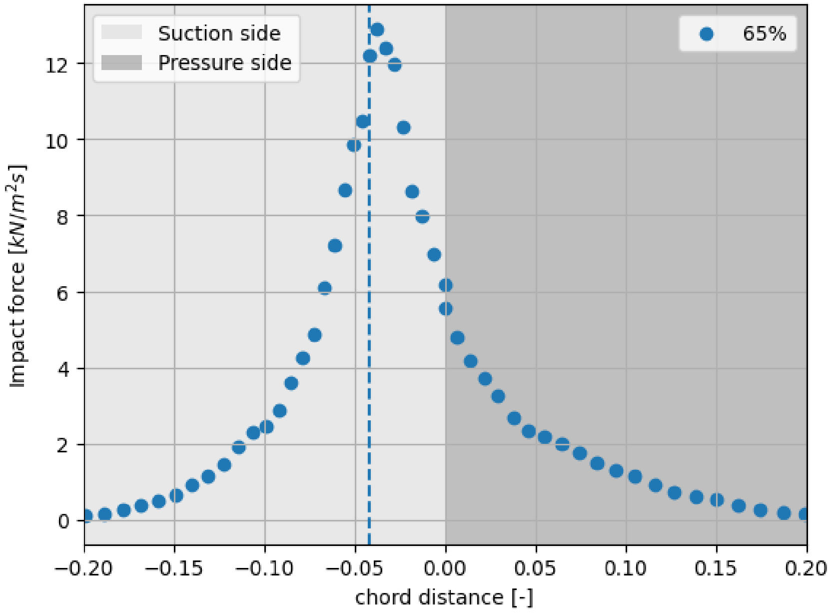




2D vs. 3D MRF - Comparison

- In 2D the rain cannot distribute freely along the blade span → particle impact condensed towards leading edge
- 3D allows for spanwise flow → higher distribution width
- Both cases show more impact on the suction side with similar max. impact force

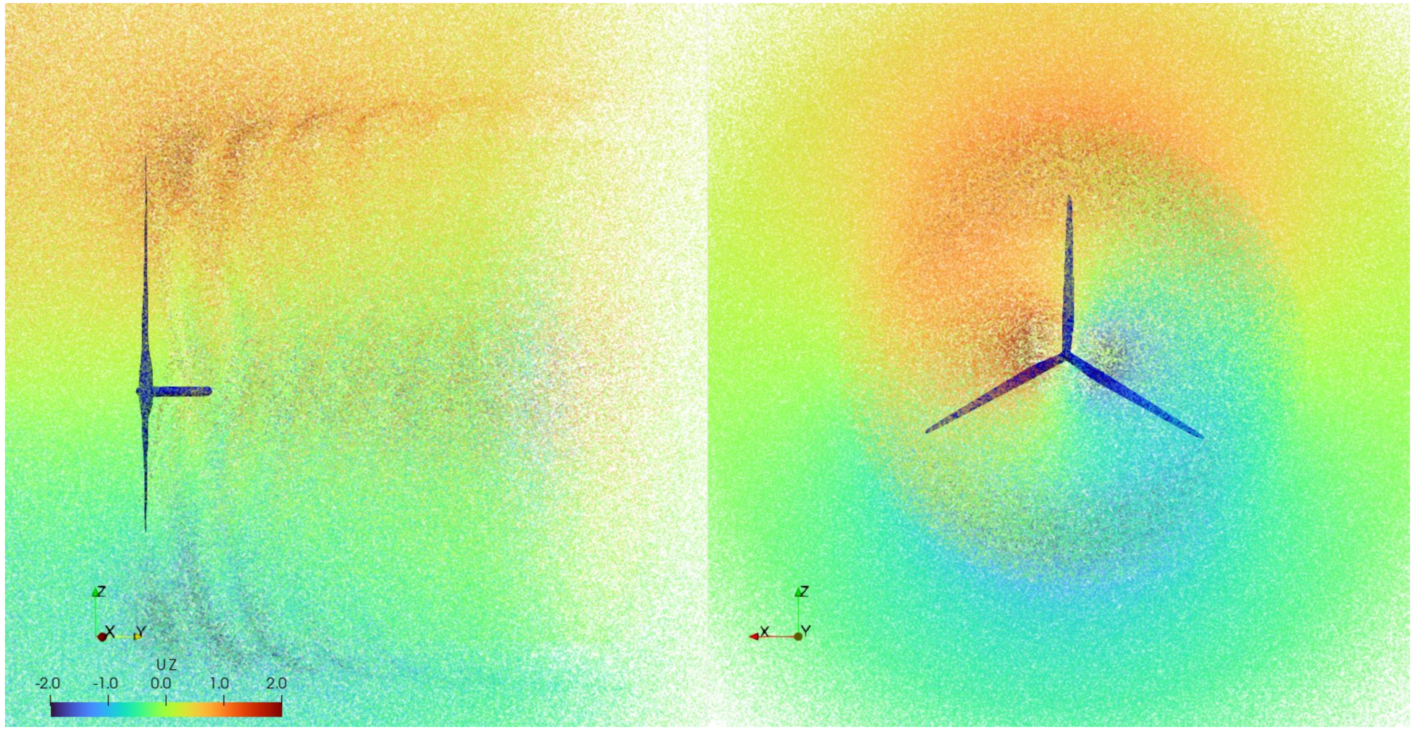




3D full IEA 15MW rotor

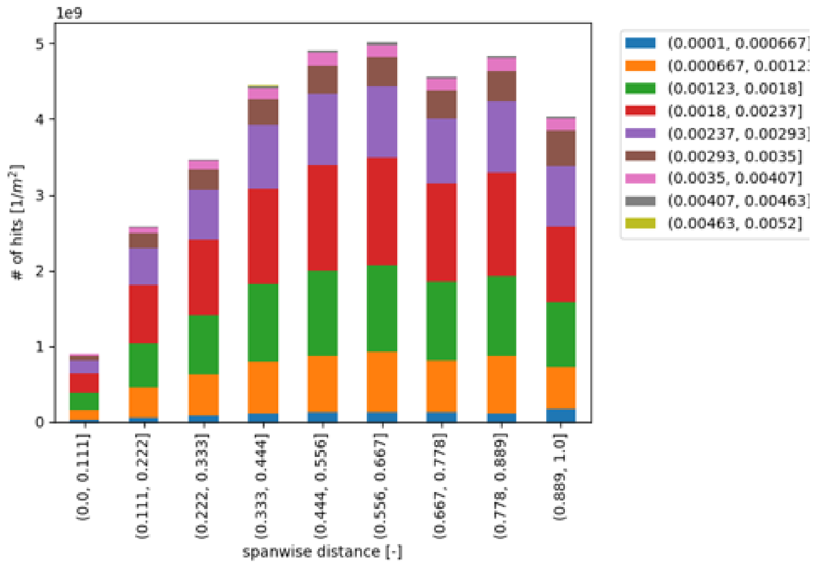
- 85 seconds simulated for the full rotor
- Both, particles and fluid domain are solved simultaneously
- Particles adjust trajectory towards flow field
- Wake rotation visible via normal velocity component

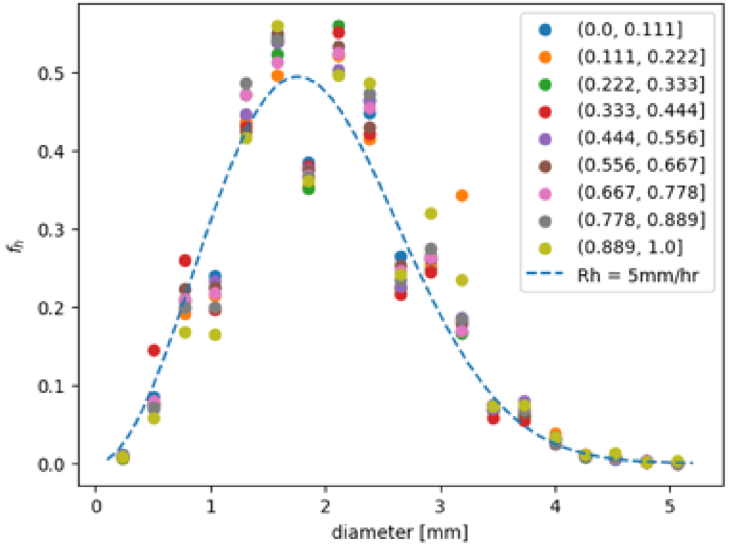
✓ Visual check confirmed

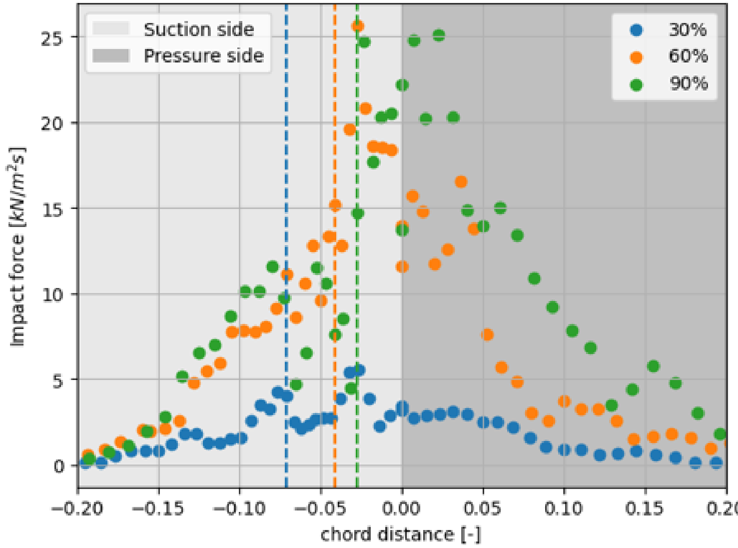


3D full rotor - Results

- Most hits mid-span
- Diameter distribution of particles hitting the blade roughly follow theoretical distribution within simulated time
- Impact force (source of erosion) higher towards the blade tip

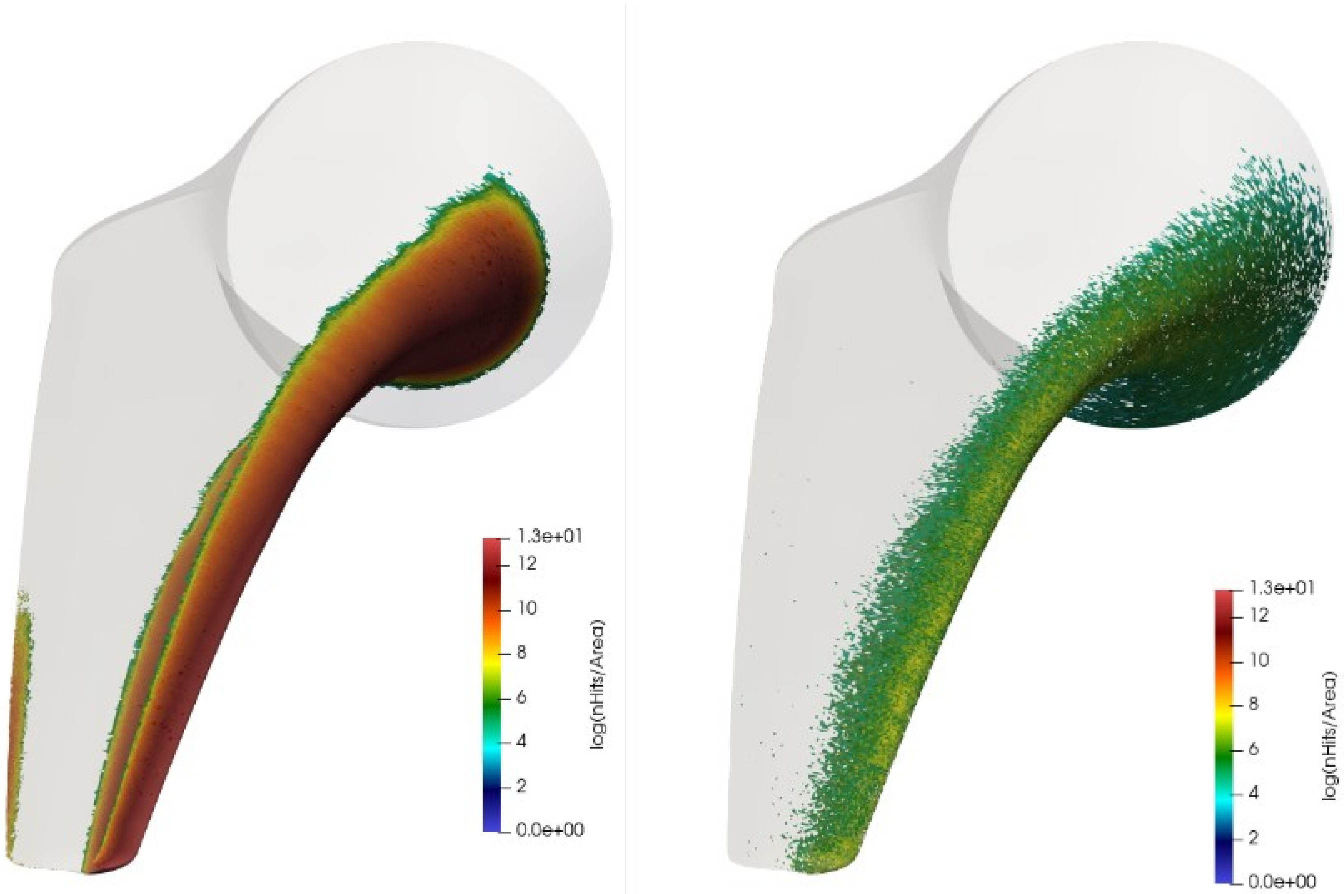






3D MRF vs. 3D full rotor

- Full rotor computationally way more expensive
- Both simulations show similar chordwise particle distributions
- Total amount of hits 2 magnitudes higher in MRF (due to longer simulation period)



Summary & conclusion

- 2D airfoil simulations of the local operation conditions similar to a mid-section of the IEA 15MW turbine
- Tools were developed on 2D and brought over to 3D simulations
- Rain impingement on rotor studied for a 5MW and a 15MW turbine showing similar trends
- ✓ The impact speed and force for different particle sizes (following the theoretical distribution) is computed
- ✓ Particle distribution spanwise and chordwise
- ✓ These simulations give detailed input for blade damage models

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Thank you.

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