

Comparison of Jet Impingement Test CFD modeling using Ansys Fluent[®] and OpenFOAM[®]

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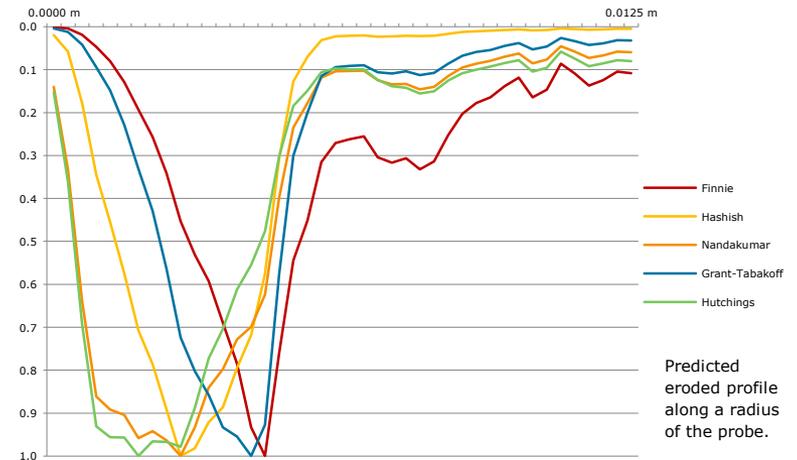
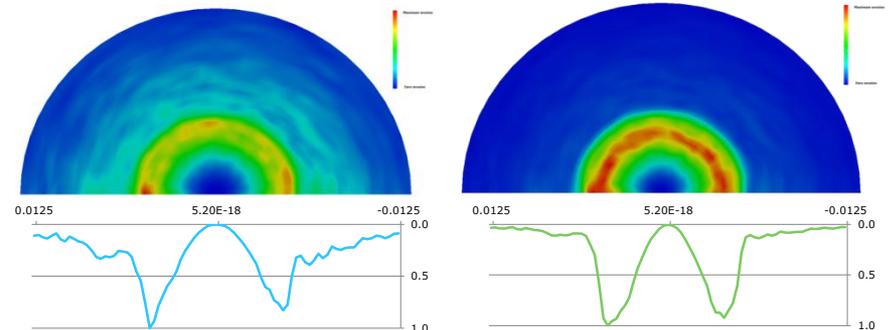
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Outline

- **Introduction**
- **Continuous phase steady-state**
- **Discrete phase Modelling**
- **Impingement conditions**
- **Conclusions**

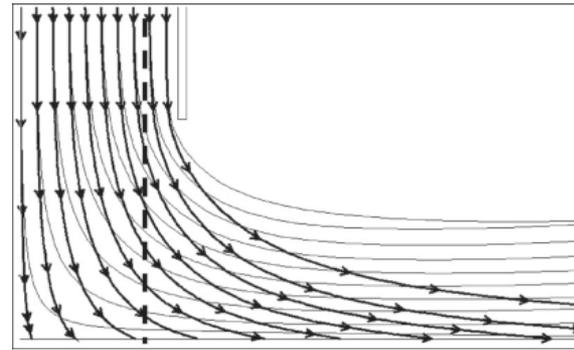
Introduction

- CFD of Erosion Processes
- Erosion
 - Angle of impingement
 - Particle rotation at impingement
 - Particle velocity at impingement
 - Particle size
 - Shape of the surface
 - Particle shape and strength
 - Particle concentration
- Meng and Ludema [Wear, Vol. 181-183 (1995), pp. 443-457]
 - Review of more than more than 5000 articles
 - 2000 empirical models
 - Each equation is the result of a very specific and individual approach
 - Models implemented and tested in OpenFOAM®

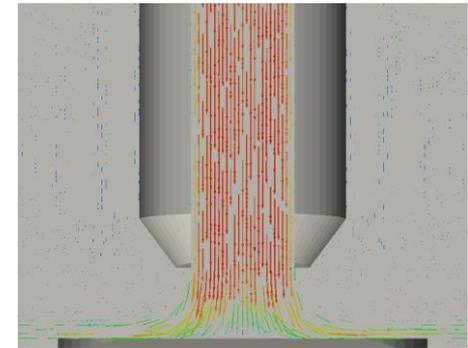


Introduction

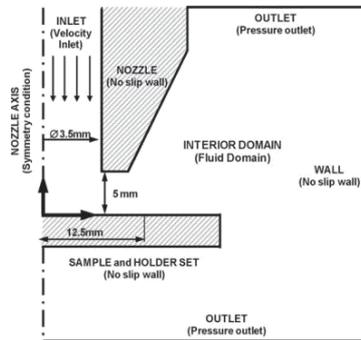
- Gnanavelu et al. [Wear, Vol. 267 (2009), pp. 1935–1944]
 - Jet Impingement Test
 - Wide range of impact angles and velocities
 - CFD
 - Monitor impingement conditions
 - Velocity and Impact angle
 - Obtain erosion equation
 - Wear Map



Particle trajectories of the 90 degrees JIT



Continuous phase velocity vectors



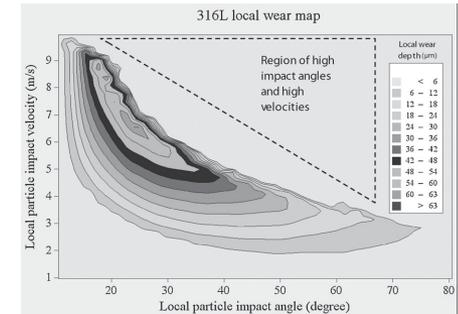
Configuration of JIT

Movement of particles inside a fluid

- Eulerian-Eulerian
- Eulerian-Lagrangian (Lagrangian Particle-Tracking)
 - One way coupling
 - Particle Mass loading $\beta = 0.003$
 - Stokes number $s_t = 26.29$
 - Negligible momentum transfer between phases

$$m_p \frac{du_p}{dt} = F_p$$

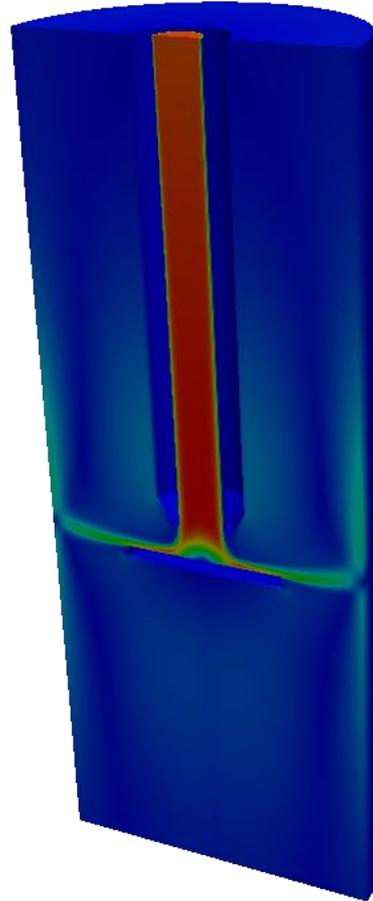
$$\frac{dx_p}{dt} = u_p$$



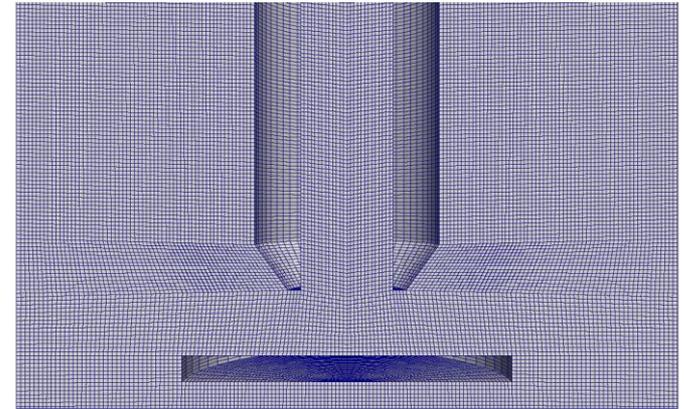
Example of the Wear Map Method

CFD Model

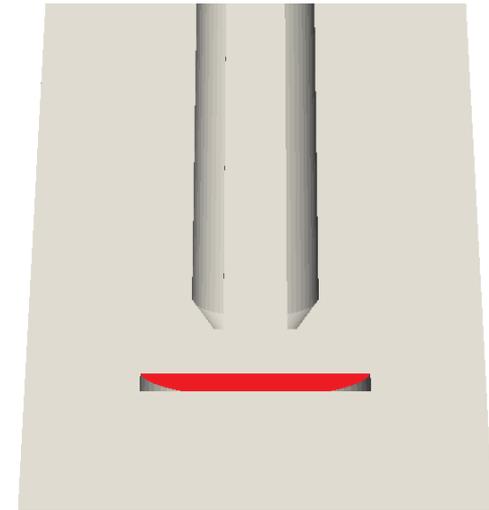
- Mesh size: 984960 cells
- Similar amount of iterations for both packages
- Adequate y^+ around the test probe for the k- ϵ model used.
- Relaxation factors
- The test probe is represented by a cylindrical hole below the pipe
- Impacts are recorded at the exact moment the particles reach the surface (red)



Velocity contours of the converged continuous phase



Detail of the mesh around the test probe



Test probe surface coloured in red

Continuous phase steady-state

Case set up

OpenFOAM 2.2.x[®]

Continuous Phase

- Incompressible solver – simpleFoam
- k- ϵ Turbulence model
- Reach Steady-state with first order schemes
- Upgrade to second order schemes for the momentum equation
- Convergence Criteria: Residuals below 1e-4
- Map results to second case for introduction of particles: mapFields

Fluent 14.0[®]

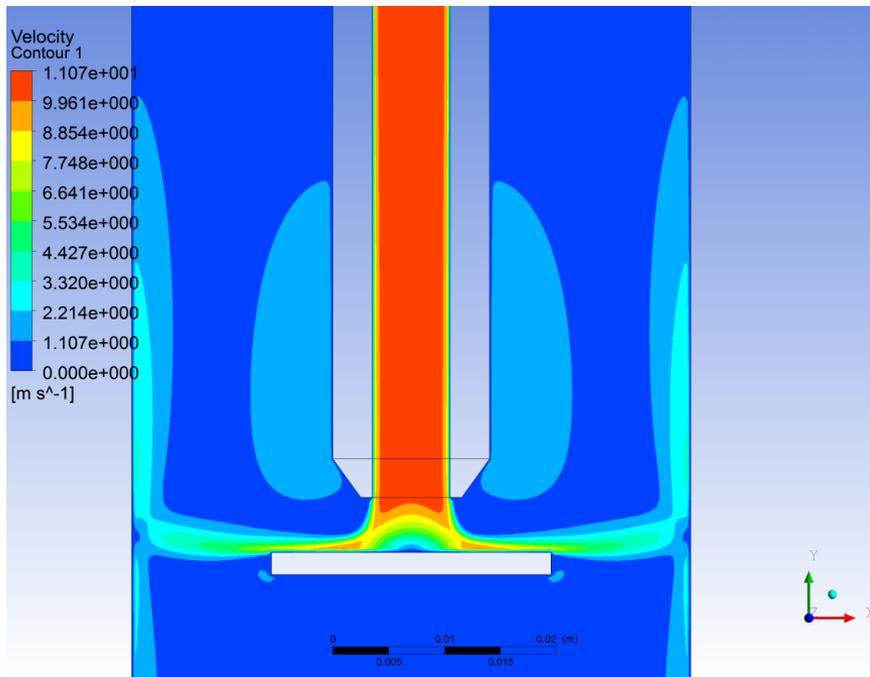
Continuous Phase

- Incompressible - SIMPLE algorithm
- k- ϵ Turbulence model
- Reach Steady-state with first order schemes
- Upgrade to second order schemes for the momentum equation
- Convergence Criteria: Residuals below 1e-4
- Introduce particles after case has converged and resume the simulation

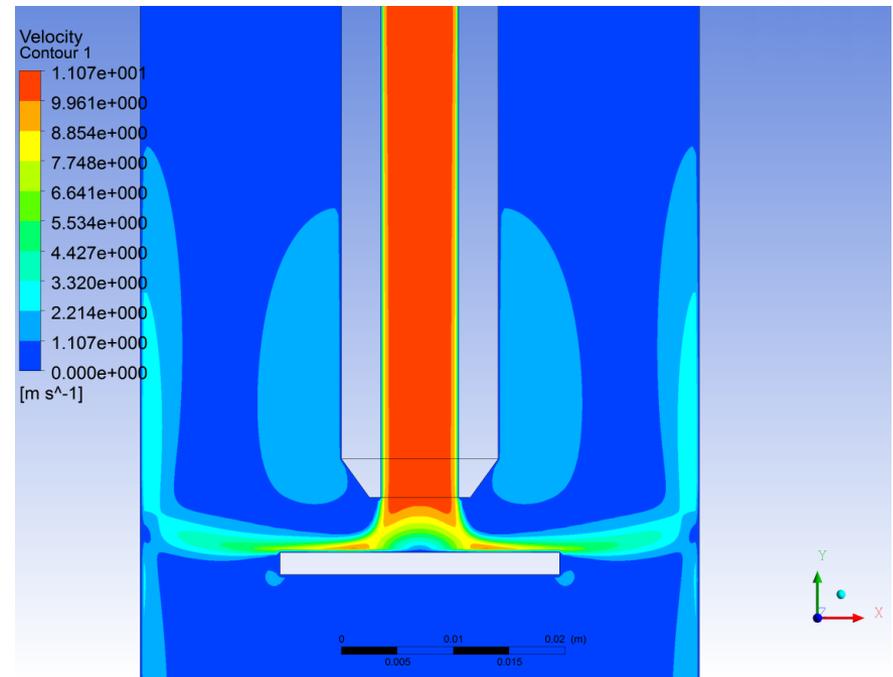
Continuous phase steady-state

Steady-state results in CFD-Post 14.0[®]

OpenFOAM 2.2.x[®]

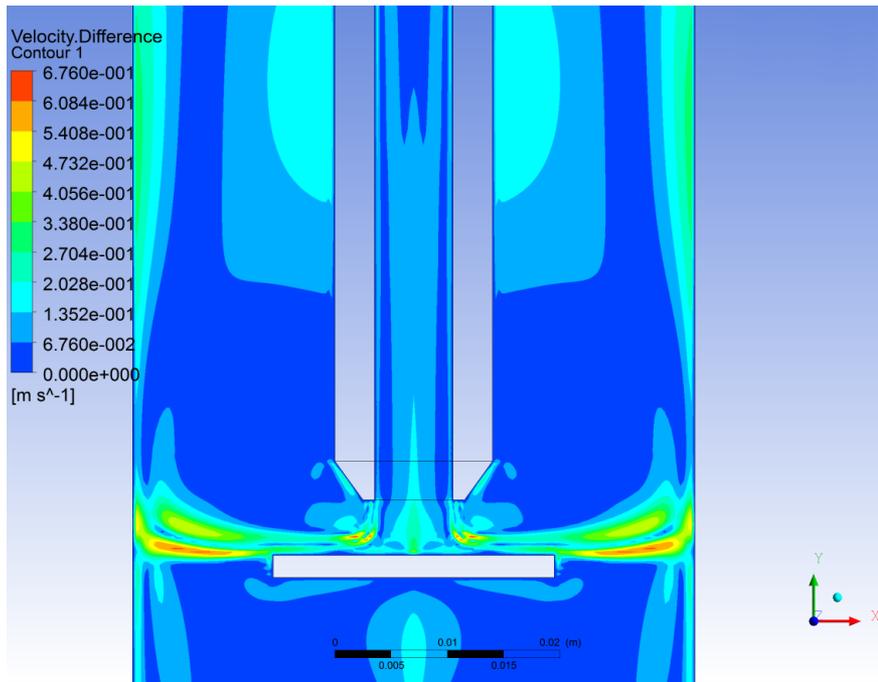


Fluent 14.0[®]

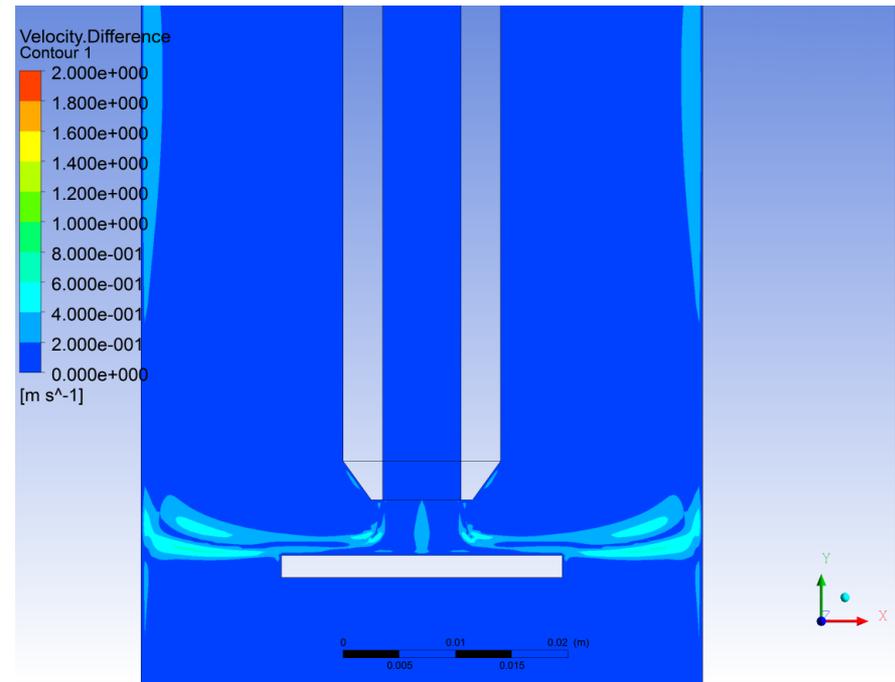


Continuous phase steady-state

Case comparison with CFD-Post 14.0[®]



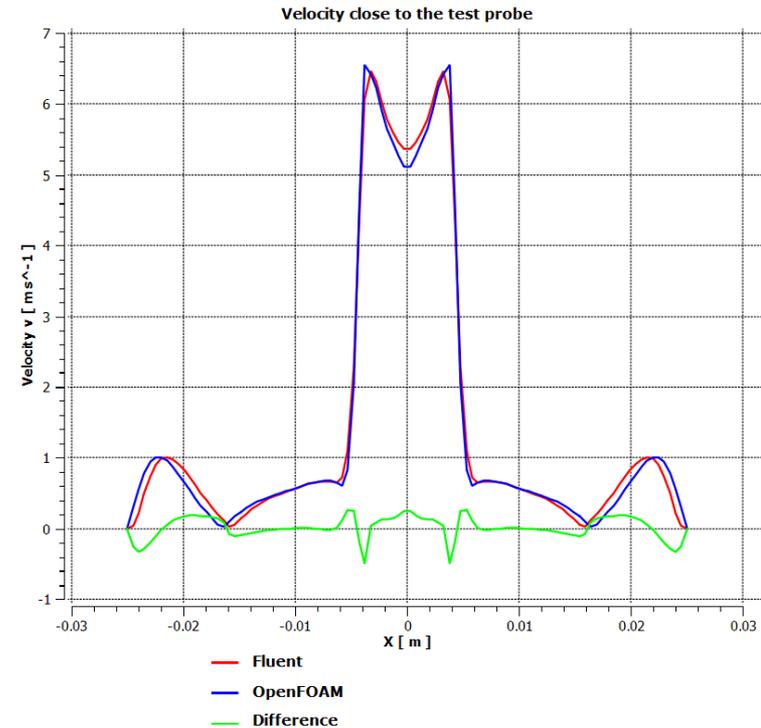
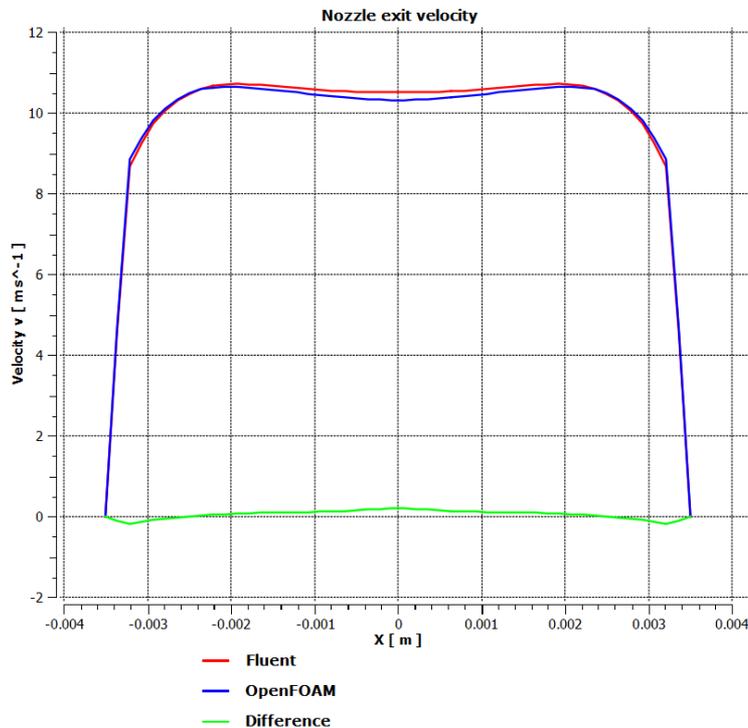
- Maximum difference of 6.1 %



- Overall difference of less than 2 %

Continuous phase steady-state

Case comparison with CFD-Post 14.0[®]



- Velocity profile at nozzle exit

- Velocity profile close to the test surface

- None of them shows important differences

Discrete Phase Modelling



- Discrete Phase Model
 - Linkage with Lagrangian Intermediate library
- Implemented changes
 - Implementation of additional erosion models
 - Simple additional code for patchPostProcessing cloudFunctionObject: angle of impingement, velocity magnitude, impinging mass ...
 - Morsi and Alexander Drag Force additional model
- Common features for both DPM
 - Transient simulation
 - 0 velocity at inlet patch injection
 - 250 μm diameter particles
 - Uniform distribution
 - One way coupling – Particles have no effect on the fluid phase
 - Stochastic dispersion
 - Drag Force
 - No gravity
 - Particle variables are gathered as they impact the surface

- Other common features

Variable	Units	Value
Time-Step	s	1.8759E-05
Number of Time Steps	-	53307
Particle Material	-	Carbon
Particle diameter distribution	-	Uniform
Particle Diameter value	m	2.50E-04
Coupling between phases	-	One way
Forces	-	Drag
Drag Coefficient Calculation	-	Sphere Drag

- For this particular case, comparisons between, sphere drag, NonSphere Drag ($\phi = 1$) and Morsi and Alexander formulae yielded the same results.

Discrete Phase Modelling

Monitoring the impacts on the test surface:

OpenFOAM[®]

- Injection Model: patchInjection
- Uniform distribution of 250 μm particles
- patchPostProcessing
cloudFunctionObject and some additional code for angle of impingement and magnitude of the velocity
- Particle trajectory terminates at test surface. Condition met via the kinematicCloudProperties dictionary, defining an “escape” type for the probe’s boundary
- StochasticDispersionRAS included to account for lack of impact randomness

Ansys Fluent 14.0[®]

- Single injections at each time-step in order to have a similar amount of impacts on the surface
- User Defined Function (UDF). Code that gathers the particle velocity, the angle of impingement and impact location relative to the radius along the probe
- In addition, the UDF also terminates the particle trajectory once they impact the surface
- Added dispersion to account for the lack of randomness

Impingement Conditions

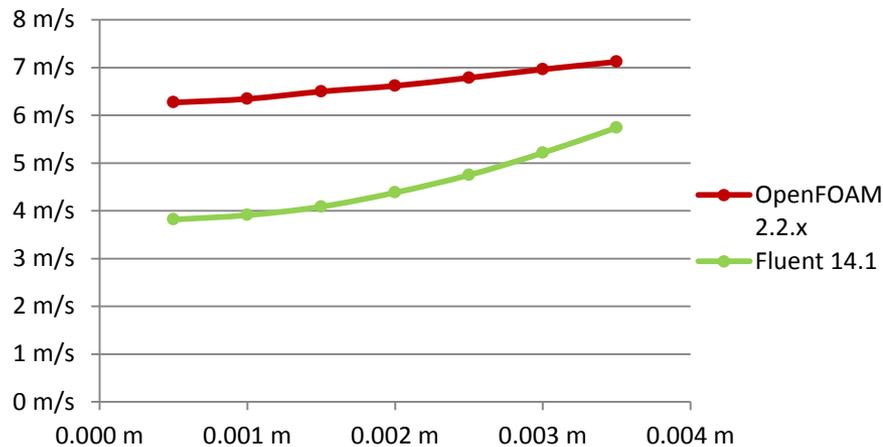
- ❑ Number of impacts
 - OpenFOAM: 52864
 - Fluent 14.0: 52833
- ❑ The impacts are summed up every 0.5 millimetres and averaged for that radius range.
- ❑ Only the inner part of the surface is taken into account due to the higher impact density.



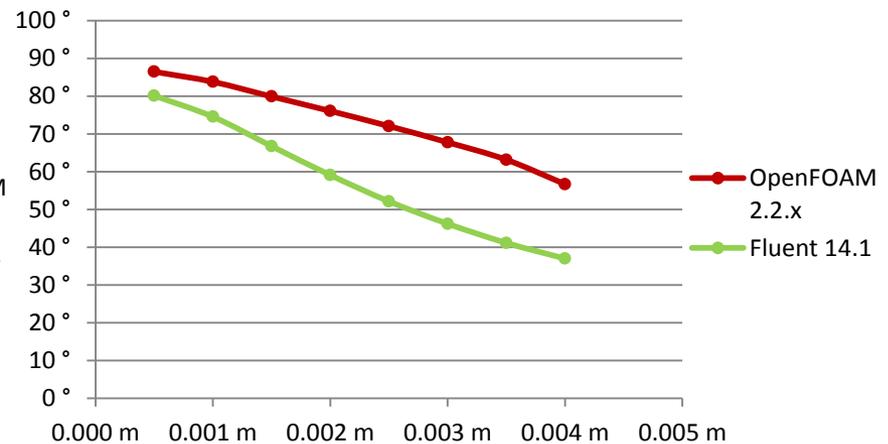
- ❑ The amount of impacts on the outer part of the disc is very small. High value of the standard deviation for this region. Thus, only impacts within the 0-4 mm region are considered.

Impingement Conditions

- Mean velocity versus distance from the centre



- Mean angle of impingement versus distance from the centre



- No gravity term is included in either of the discrete phase models
- The differences in the steady-state calculations do not account for such a difference in the impact velocities of the discrete phase
- Results do not vary significantly by decreasing the continuous phase residuals in further iterations
- Average of the velocities is unaffected by the selected drag model.

Conclusions and Future Work

- Both packages agree to a high level of accuracy in the continuous phase solution
- OpenFOAM and Fluent 14.0 also seem to agree to a certain extent in the angle of impingement
- However significant discrepancies can be observed between averaged impact velocities in both packages
- Further investigation of the velocity calculation is required and is currently being carried out
- The aim is to validate OpenFOAM's kinematic intermediate library for DPM and erosion calculations
- A test rig is being designed at the moment for validation of the model, which will also allow the implementation of better models and, potentially, more accurate algorithms for the discrete phase
- Implementation of particle rotation and inclusion of this term into the erosion formulae

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Questions ?



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