AWJC Nozzle simulation
by 6-way coupling of DEM+CFD+FEM
using preCICE coupling library

ECCOMAS Coupled Problems 2021

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Problem Statement

- Abrasive WaterJet Cutting Nozzle
- AWJC Nozzle the first target of abrasive particles
- Erosion difficult to capture through experimentation
Previous Work

- DEM+CFD coupling used to identify erosion zones[1]
- Particle impact velocity and angle of attack ignored

Challenges and Goals

- Evaluation of erosion in AWJC Nozzle by DEM+CFD+FEM coupling
- Using out of the box resources
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Methodology

Discrete Element Method


6-way DEM+CFD+FEM coupling

- OpenFOAM: Solves for Fluid
- CalculiX: Solves for Solid
- preCICE: Exchanges Displacements and Forces
6-way DEM+CFD+FEM coupling

OpenFOAM

CalculiX

preCICE

Solves for Fluid

Solves for Solid

Displacements

Forces

Solves for Particles

XDEM
6-way DEM+CFD+FEM coupling

OpenFOAM
- Solves for Fluid
- Displacements

CalculiX
- Solves for Solid
- Forces

preCICE
- Surface forces
- Displacements

XDEM
- Solves for Particles
6-way DEM+CFD+FEM coupling

- Add momentum source with fvOptions

- Compute Drag & Buoyancy force on particles
- Compute source terms[6]

OpenFOAM

CalculiX

preCICE

XDEM

Test-case setup

Fluid flowing through a channel
10 m/s

heavy particles
1 m/s (50p/s)

light particles
1 m/s (50p/s)

DEM with XDEM

CFD with OF

FEM with CCX

Deformable flap
6way coupling OF + CCX +XDEM results: rhoPimpleFoam

Fluid flowing through a channel 10 m/s

heavy particles 1 m/s (50p/s)

light particles 1 m/s (50p/s)

Compressible Transient turbulent flow (LES)
dt OF = 1e-04
dt CCX = 1e-04
dt XDEM = 1e-05
preCICE coupling dt = 1e-04
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Nozzle case setup
Nozzle coupled simulation set-up

Fluid Part\(^1\)
Nozzle coupled simulation set-up

Water Jet
Inlet = 300 m/s
Nozzle coupled simulation set-up

Particle inlet

Fluid Part

Water Jet
Inlet = 300 m/s
Nozzle coupled simulation set-up

Nozzle Solid part

Particle inlet

Fluid Part \[^{[1]}\]

Water Jet
Inlet = 300 m/s
Nozzle

CFD results
Nozzle CFD results

Incompressible
Transient
multiphase: 2 immiscible phases
isothermal
turbulent flow (LES)
dt OF = 1e-08
dt CCX = 1e-07
preCICE coupling
dt = 1e-07
Nozzle CFD results (waterjet)

Incompressible
Transient
multiphase: 2
immiscible
phases
Isothermal
turbulent flow
(LES)
dt OF = 1e-08
dt CCX = 1e-07
preCICE coupling
dt = 1e-07
Nozzle CFD results (waterjet)

Incompressible
Transient
multiphase: 2
immiscible
phases
isothermal
turbulent flow
(LES)
dt OF = 1e-08
dt CCX = 1e-07
preCICE coupling
dt = 1e-07
Nozzle 2way
CFD+XDEM results
2way CFD+XDEM Nozzle test case

Water inlet 100m/s Steel particles

Air

Outlet
2way CFD+XDEM Nozzle test results

Time: 0.002476(s)
2way CFD+XDEM particle drop test results

- **Air**: $\rho = 1 \text{ kg/m}^3$
- **“Bubble” particle**: $\rho = 0.5 \text{ kg/m}^3$
- **Styrofoam particle**: $\rho = 50 \text{ kg/m}^3$
- **Steel particle**: $\rho = 7850 \text{ kg/m}^3$
- **Water**: $\rho = 1000 \text{ kg/m}^3$
2way CFD+XDEM particle drop test results

Incompressible Transient multiphase: 2 immiscible phases isothermal turbulent flow (LES) 

\[ dt \text{ OF} = 1e-04 \]
\[ dt \text{ XDEM} = 1e-04 \]
preCICE coupling \[ dt = 1e-04 \]
2way CFD+XDEM particle drop test results

Air
ρ=1 kg/m³

Steel particle
Initial velocity 30m/s

Water
ρ=1000 kg/m³
2way CFD+XDEM particle drop test results

- Incompressible
- Transient
- Multiphase: 2 immiscible phases
- Isothermal
- Turbulent flow (LES)
- \( \Delta t_{\text{OF}} = 1\times10^{-4} \)
- \( \Delta t_{\text{XDEM}} = 1\times10^{-4} \)
- preCICE coupling
- \( \Delta t = 1\times10^{-4} \)
Nozzle 2way
XDEM+FEM results
Nozzle XDEM + CCX results
Nozzle XDEM + CCX results

Particles: 10 m/s
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Conclusions

• General 6-way coupling achieved
• Strong CFD to DEM coupling
• Weak DEM to CFD coupling
• Particle interaction with Air-Water interface incomplete
• DEM+FEM coupling working as expected
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Next Steps

- Particle effects in Transport and pressure equations
- Particle volume in CFD
- Validation of CFD+XDEM coupling
- Erosion predictions and calculations inside Nozzle
- Vibrational analysis of Nozzle through FEM
Thank you for your attention!

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References


[4] https://openfoam.org/ (Online; accessed 01 April 2020)
