Gear Splash Lubrication in OpenFOAM

Analysis of splash lubrication within a simple gearbox. Using the minimum working example of the fluid flow within a box containing a single rotating gear, the use of OpenFOAM is evaluated to analyse the fluid flow. The problem, meshing and set-up are discussed and results are compared with Particleworks, an MPS solution. Ideas for further research and extensions to the solution are considered.

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3rd Online International Meeting for OpenFOAM Users, April 2020

Motivation

- Inadequate lubrication can cause failure
- Experimental visualisation
- Moving particle simulation
  - Fast
  - Doesn’t capture all the physics
- Meshed methods
  - Advances in overset methods
  - Limited open source possibilities

Theory

- Incompressible
- Transient
- Turbulent
- Multiphase
- Isothermal

- Continuity

$$\nabla \cdot u = 0$$

- Momentum

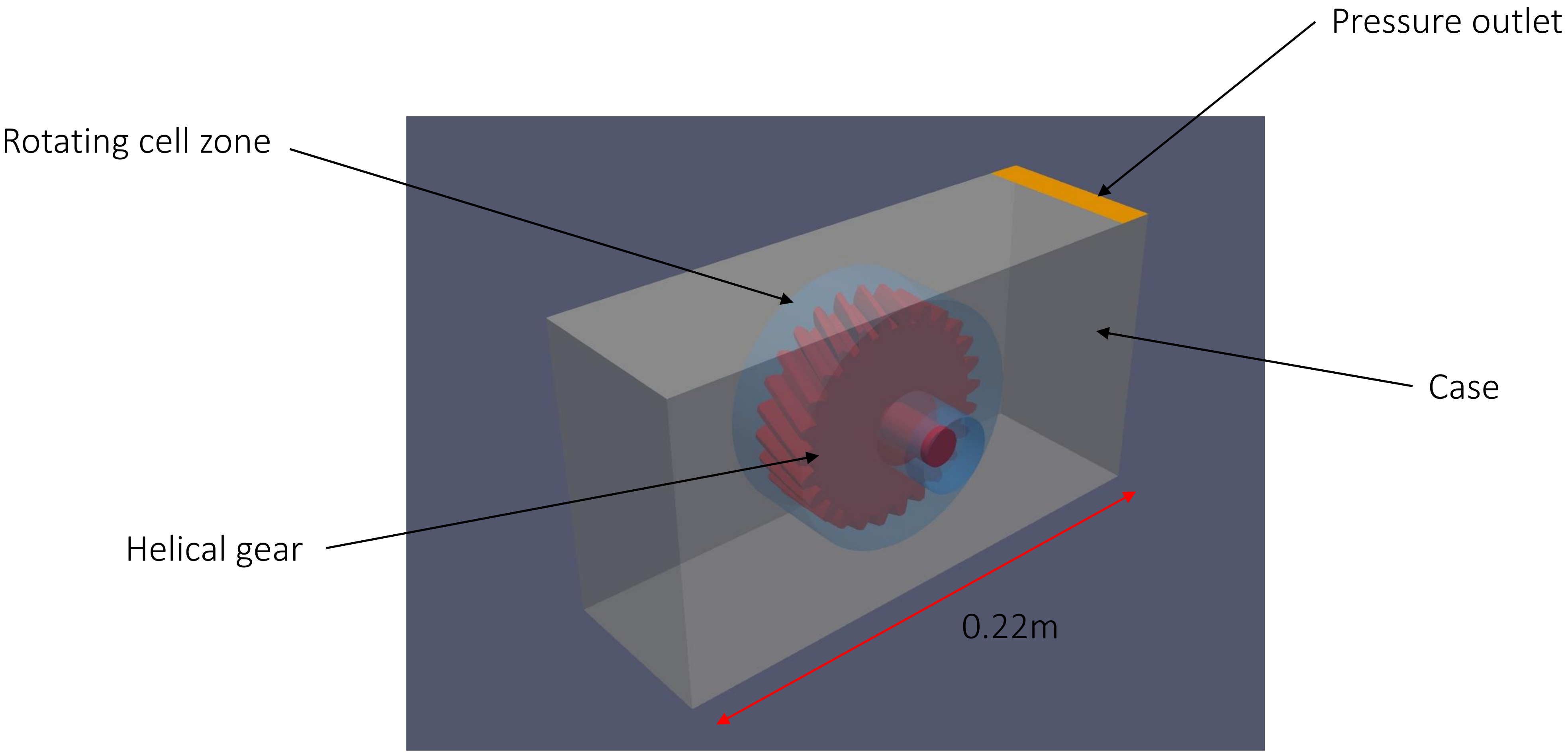
$$\frac{d\rho \boldsymbol{u}}{dt} + \nabla \cdot (p\boldsymbol{u}\boldsymbol{u}) = -\nabla \mathrm{p} + \vartheta \nabla^2 \boldsymbol{u} + \boldsymbol{f}$$

- Volume of fluid

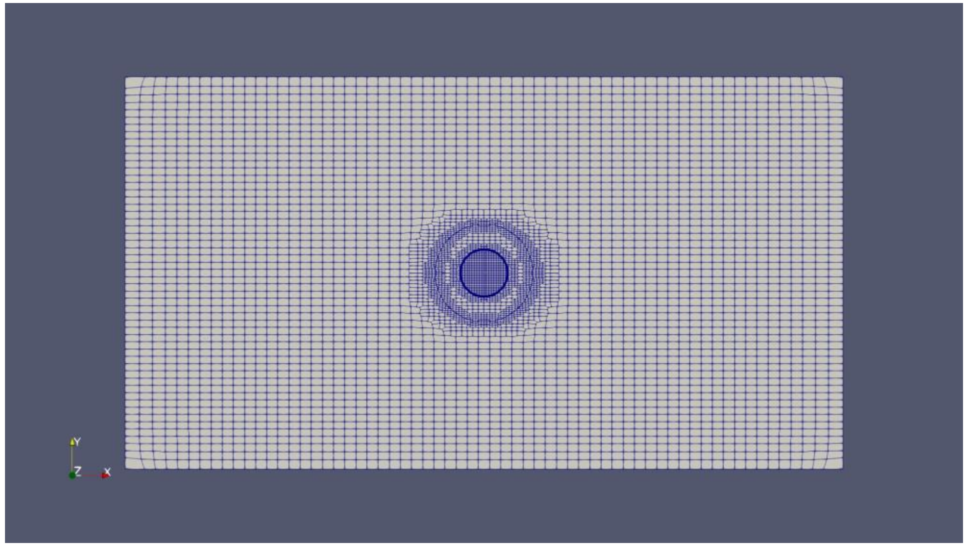
$$\rho = \alpha \rho_l + (1 - \alpha)\rho_g$$

$$\frac{d\alpha}{dt} + \nabla \cdot (\alpha \boldsymbol{u}) + \nabla \cdot (\alpha(1 - \alpha)\boldsymbol{u_r}) = 0$$

Geometry



Mesh

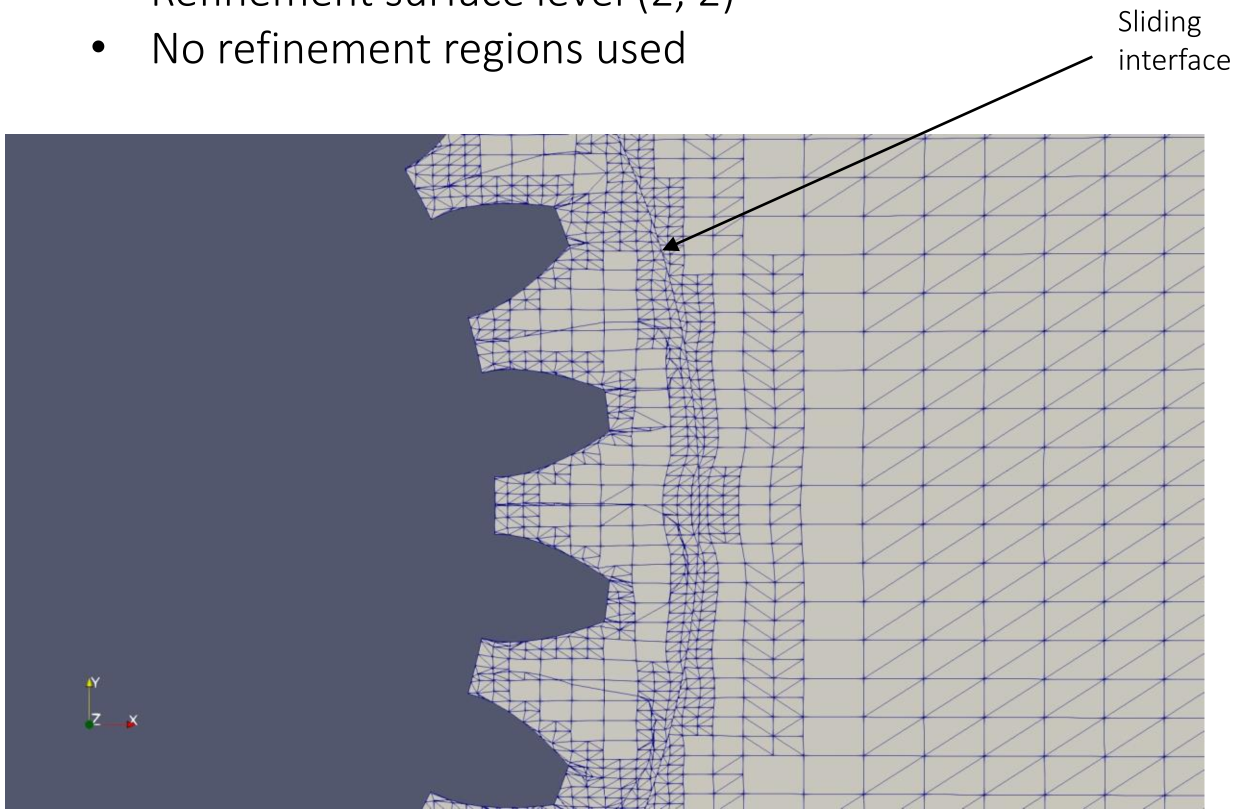


Coarse background mesh generated using BlockMesh

blocks
(
    hex (0 1 2 3 4 5 6 7) (65 55 30)
    simpleGrading (1 1 1)
);

Refined mesh around gear and AMI using SnappyHexMesh

- Feature levels 2
- Refinement surface level (2, 2)
- No refinement regions used



checkMesh

```
Checking geometry...
    Overall domain bounding box (-0.11 -0.06 -0.0225) (0.11 0.06 0.04750163)
    Mesh has 3 geometric (non-empty/wedge) directions (1 1 1)
    Mesh has 3 solution (non-empty) directions (1 1 1)
    Boundary openness (7.260829e-17 -5.185229e-17 -1.360128e-15) OK.
    Max cell openness = 4.375538e-16 OK.
    Max aspect ratio = 12.14043 OK.
    Minimum face area = 6.298877e-10. Maximum face area = 2.171783e-05.  Face area magnitudes OK.
    Min volume = 2.70283e-11. Max volume = 4.462817e-08.  Total volume = 0.001707158.  Cell volumes OK.
    Mesh non-orthogonality Max: 64.99828 average: 11.78549
    Non-orthogonality check OK.
    Face pyramids OK.
 ***Max skewness = 4.966894, 44 highly skew faces detected which may impair the quality of the results
  <<Writing 44 skew faces to set skewFaces
    Coupled point location match (average 0) OK.

Failed 1 mesh checks.

End
```

Simulation Set-Up

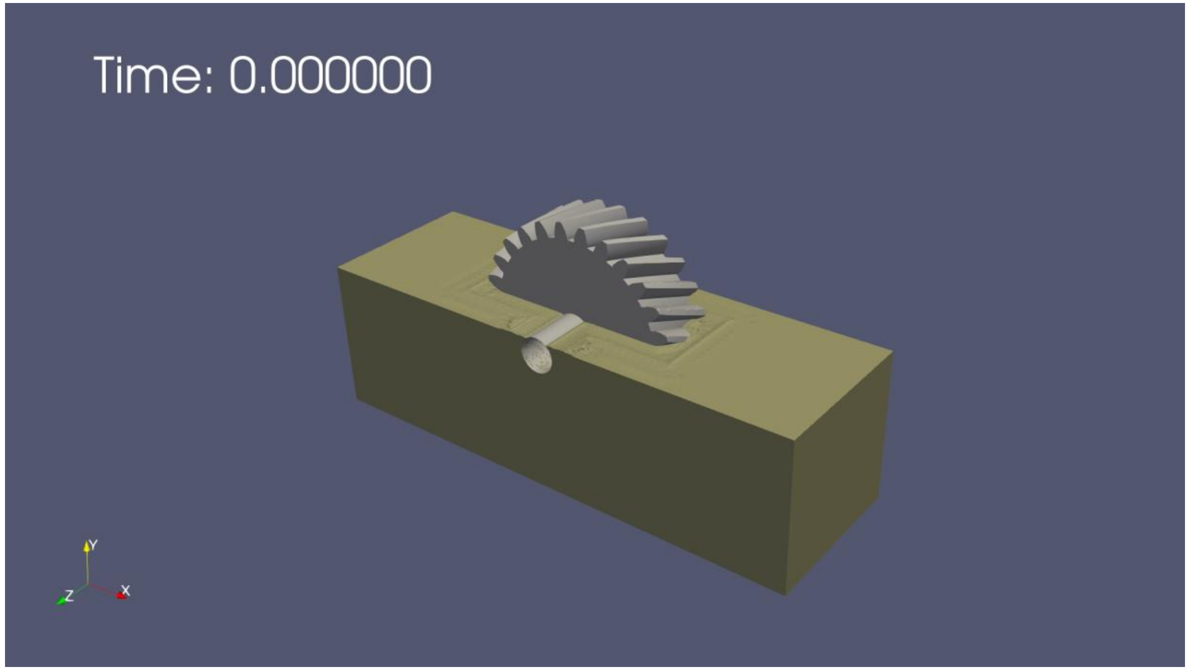
- Finish time – 0.13s
  - Approx. two full rotations
- Initial time step - 0.00002
- Write out every - 0.0006s
  - Approx. 1/100th of a full rotation, or ¼ of a gear tooth's rotation
- Max Courant - 0.5
- Max interface Co - 0.5
- k-Omega - SST

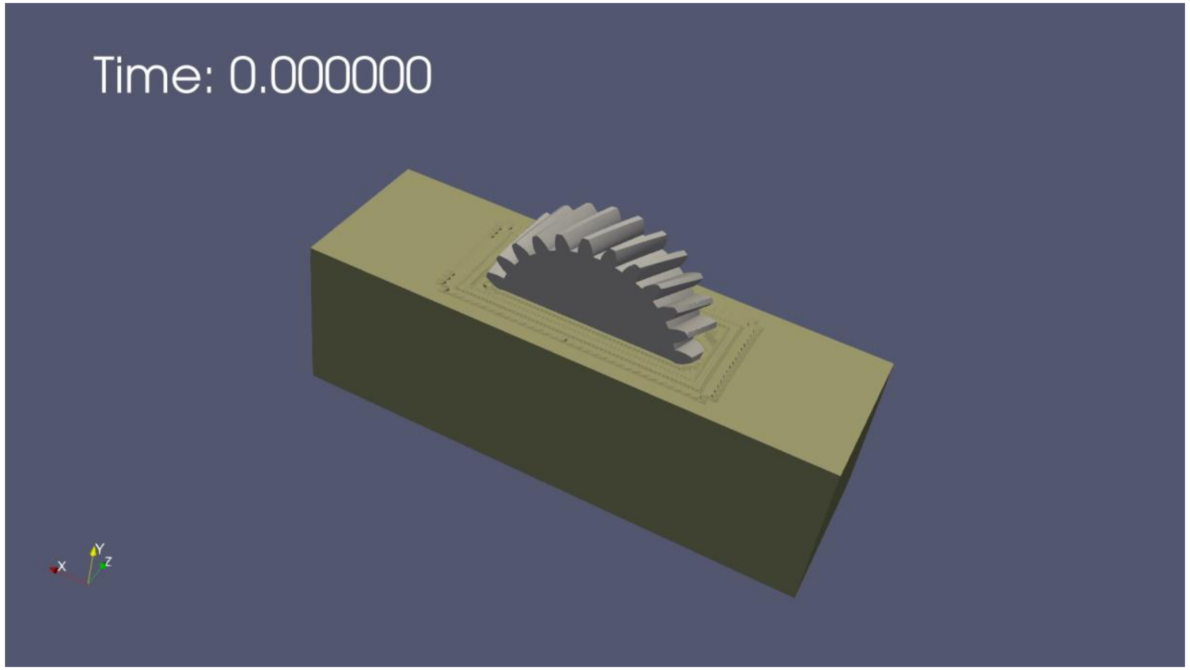
- Fluid properties
  - Density 800 kg/m^3
  - Viscosity 1e-5 m^2/s
  - Surface tension coefficient 0.025

- divSchemes
  - default none;
  - div(phi,k) Gauss linearUpwind grad(U);
  - div(phi,omega) Gauss linearUpwind grad(U);
  - div(rhoPhi,U) Gauss linearUpwind grad(U);
  - div(phi,alpha) Gauss vanLeer;
  - div(phirb,alpha) Gauss linear;
  - div(((rho*nuEff)*dev2(T(grad(U))))) Gauss linear;

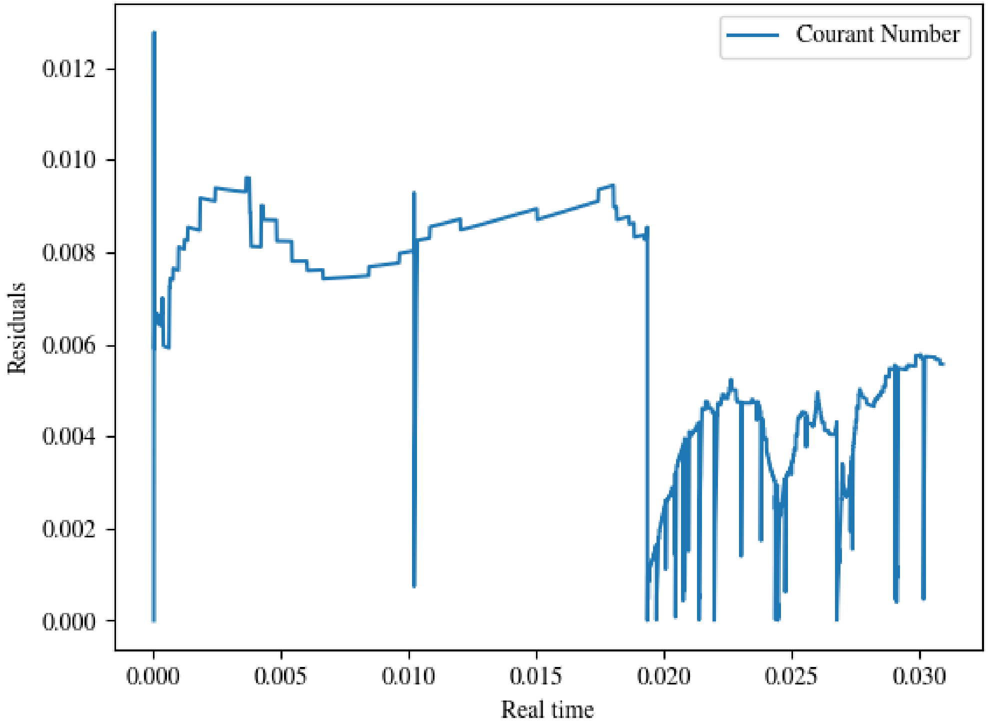
Validation, Results and Discussion

‘Colourful fluid dynamics’





Courant number

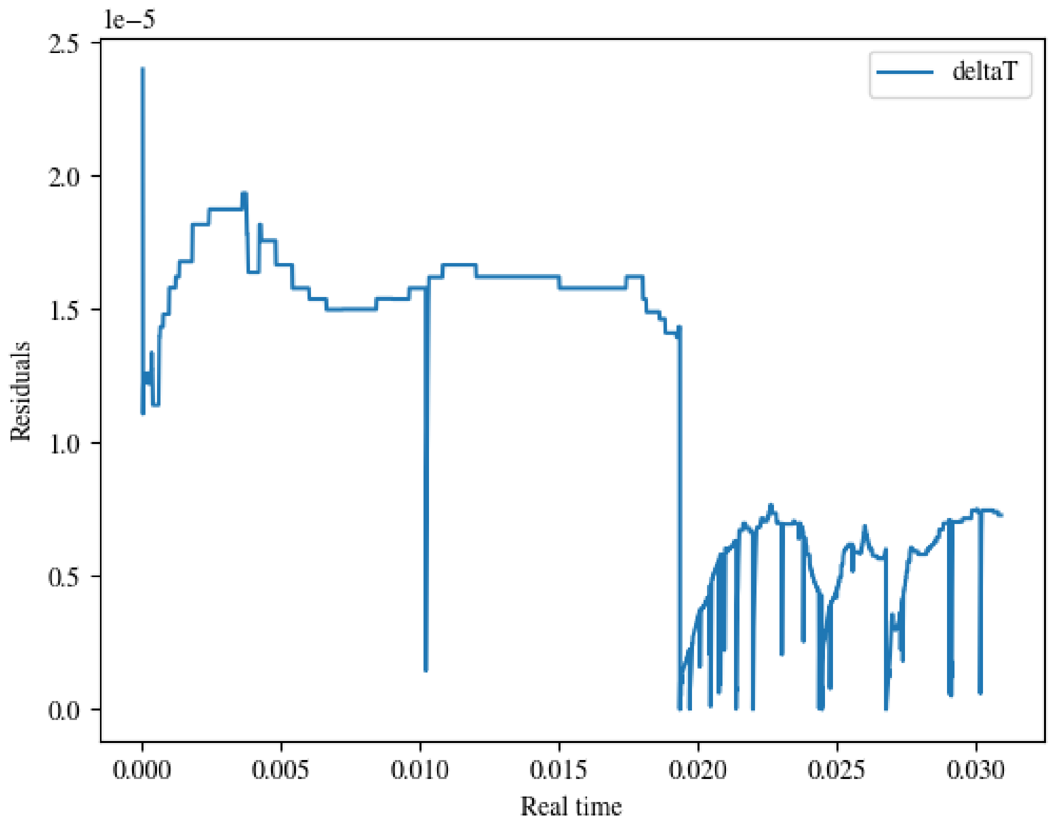


$$\text{Co} = U\frac{\Delta t}{\Delta x} < 0.5$$

$$3e-4 < \Delta x < 3.5e-3$$

$$3e-6 < \Delta t < 3.5e-4$$

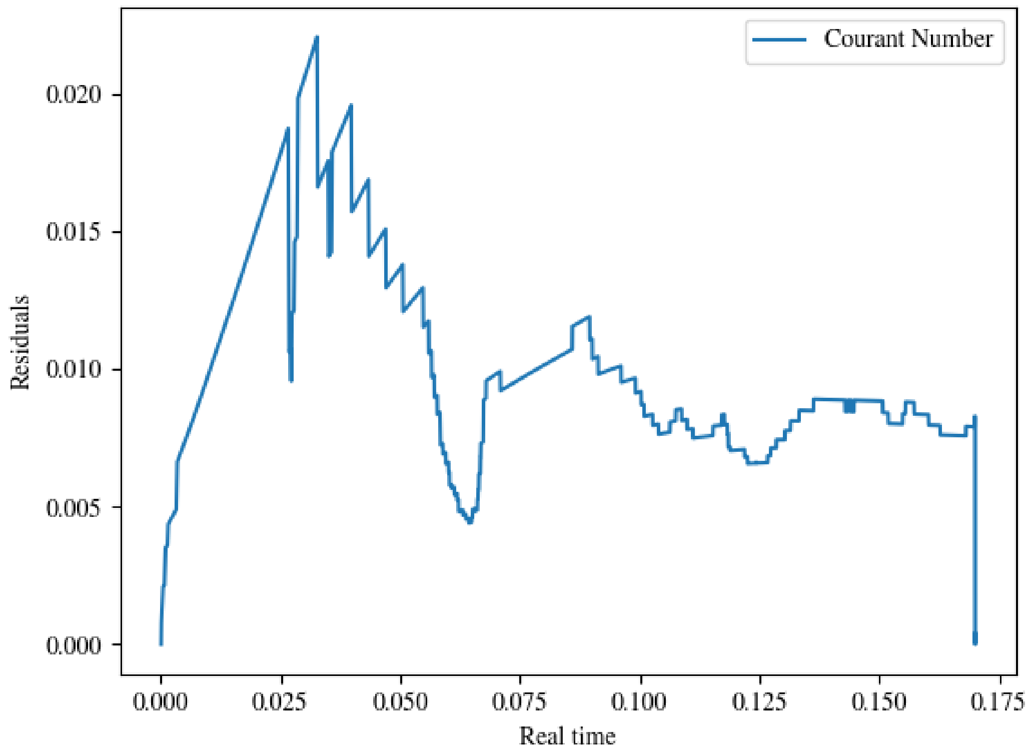
Timestep



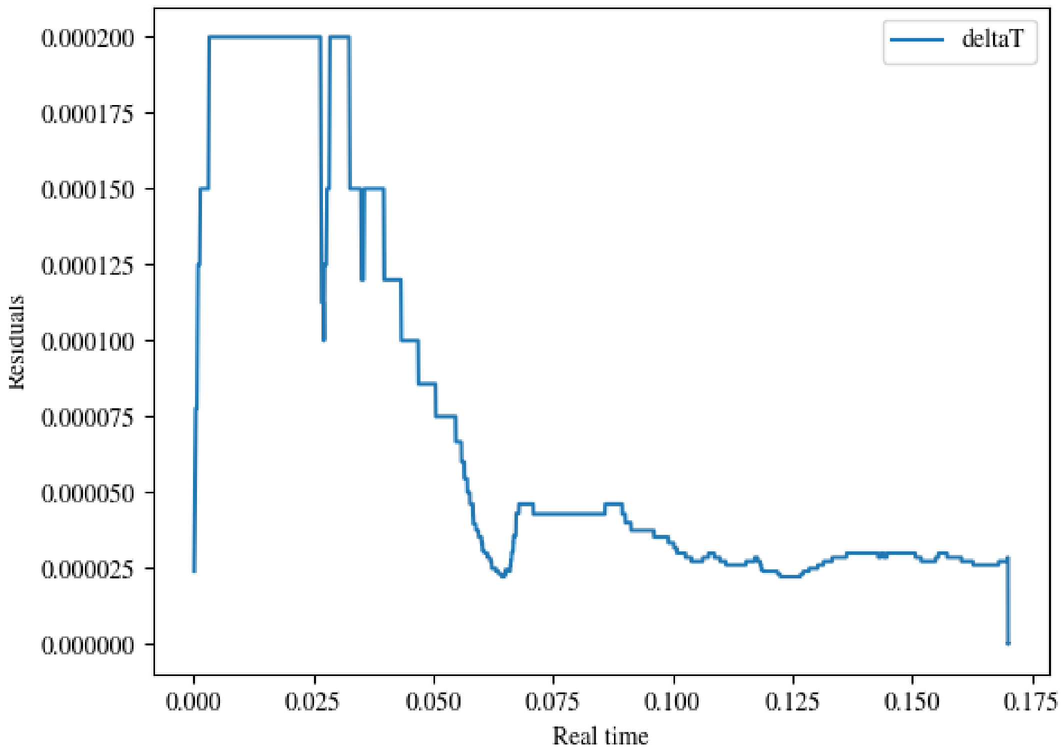
- Variable time step

- $\mathrm{Co} = U\,\frac{\Delta t}{\Delta x}$

Slow gear

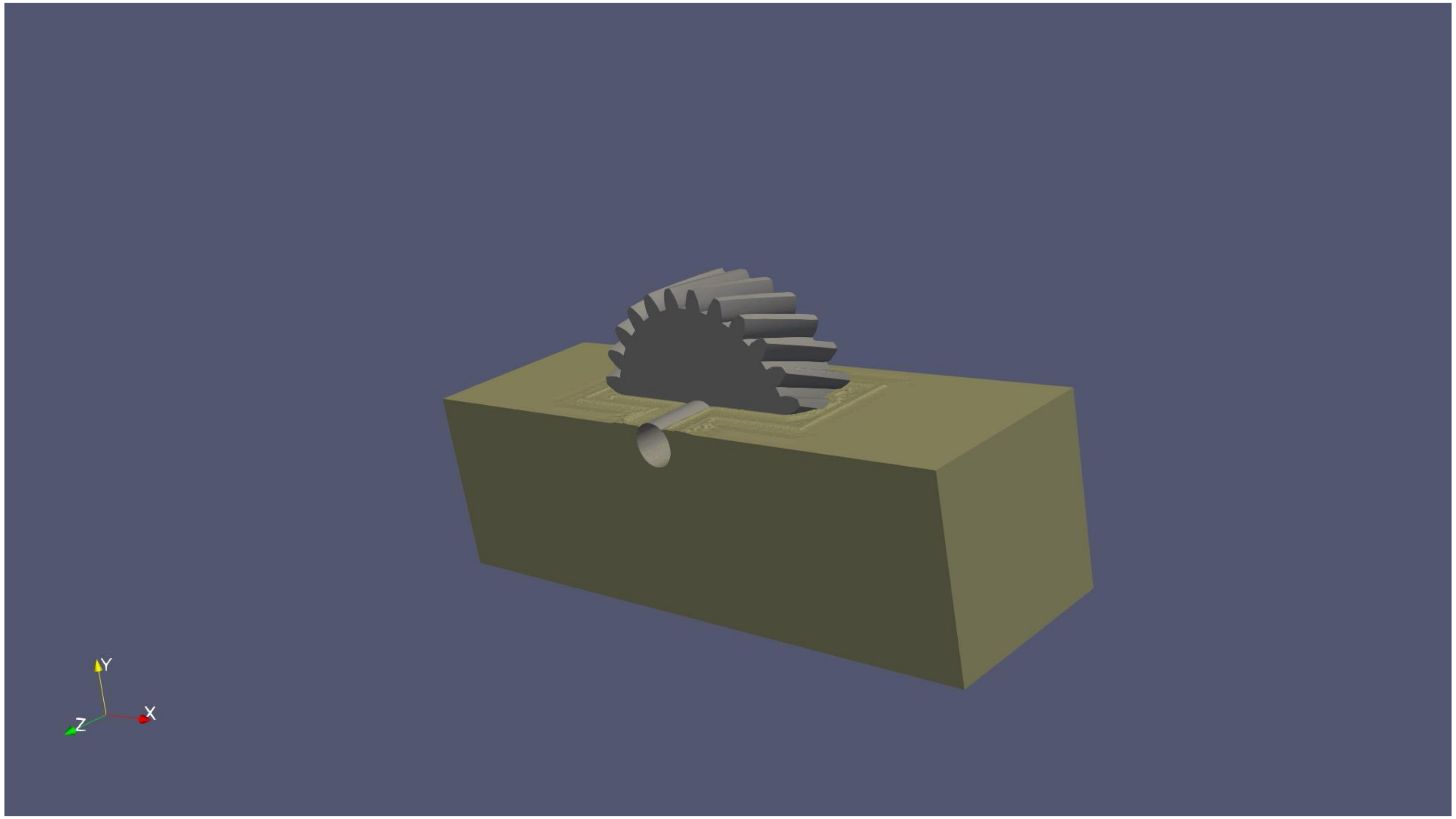


Courant Number
Residuals
0.000
0.005
0.010
0.015
0.020
0.000
0.025
0.050
0.075
0.100
0.125
0.150
0.175
Real time

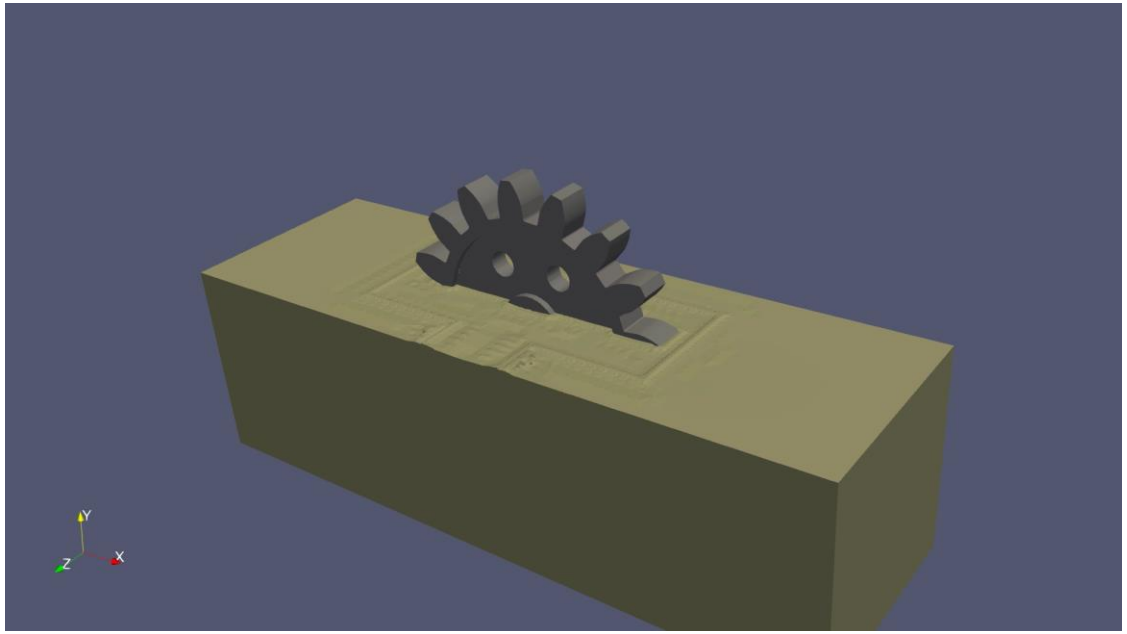


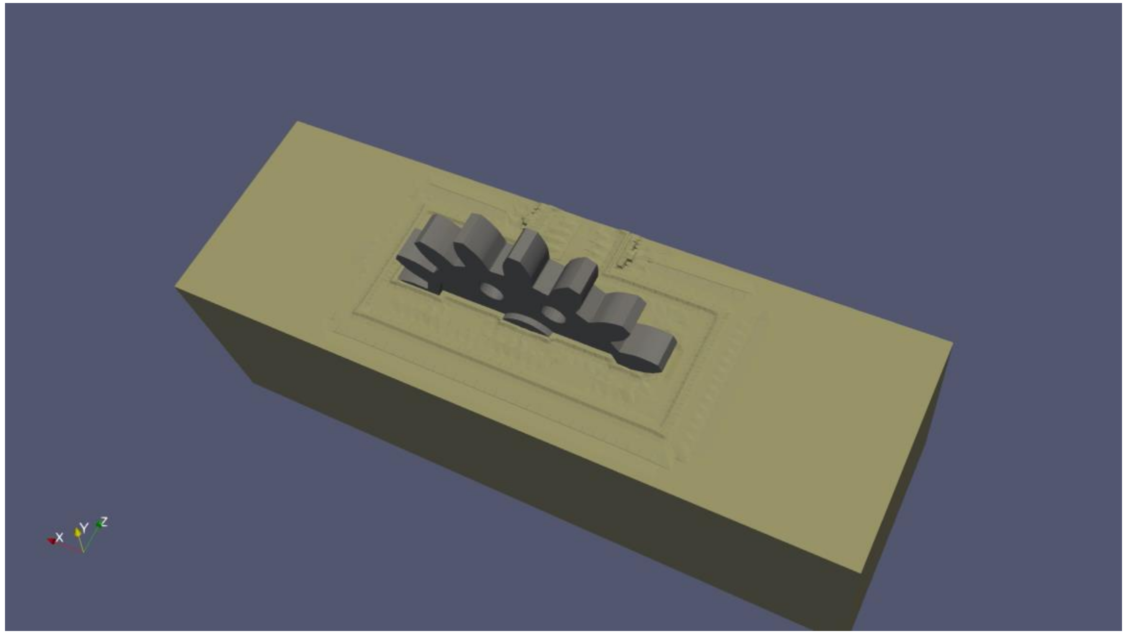
deltaT
Residuals
0.000000
0.000025
0.000050
0.000075
0.000100
0.000125
0.000150
0.000175
0.000200
0.000
0.025
0.050
0.075
0.100
0.125
0.150
0.175
Real time

Slow gear

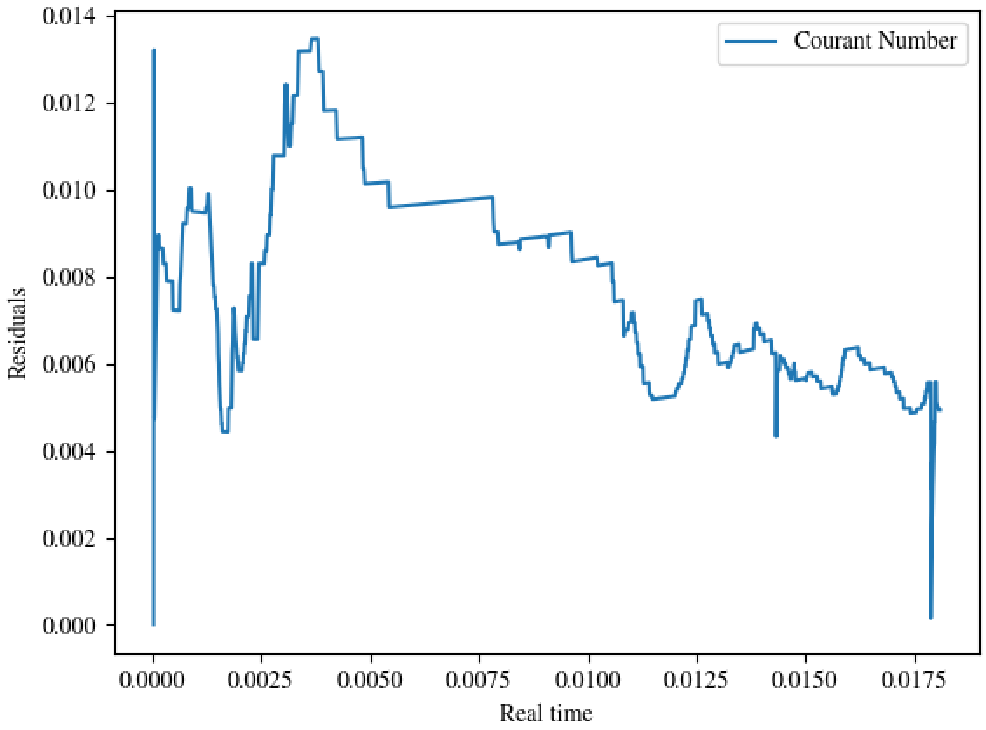


Spur gear

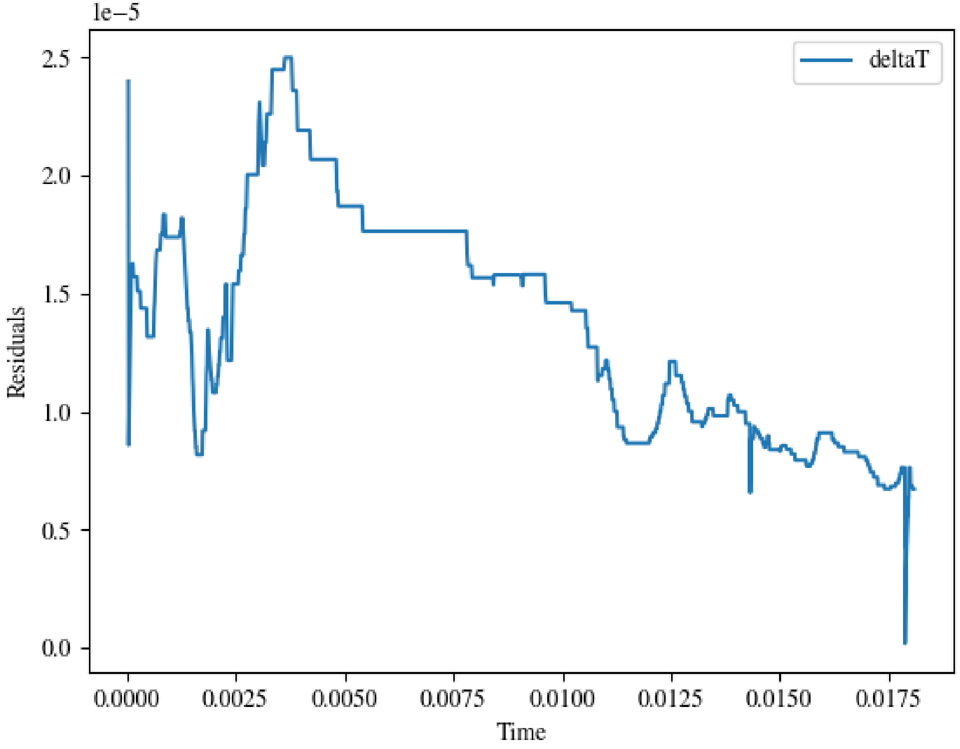




Spur gear



Courant Number
Residuals
Real time
0.014
0.012
0.010
0.008
0.006
0.004
0.002
0.000
0.0000
0.0025
0.0050
0.0075
0.0100
0.0125
0.0150
0.0175



1e−5
deltaT
Residuals
Time
2.5
2.0
1.5
1.0
0.5
0.0
0.0000
0.0025
0.0050
0.0075
0.0100
0.0125
0.0150
0.0175

fvSchemes

Original schemes

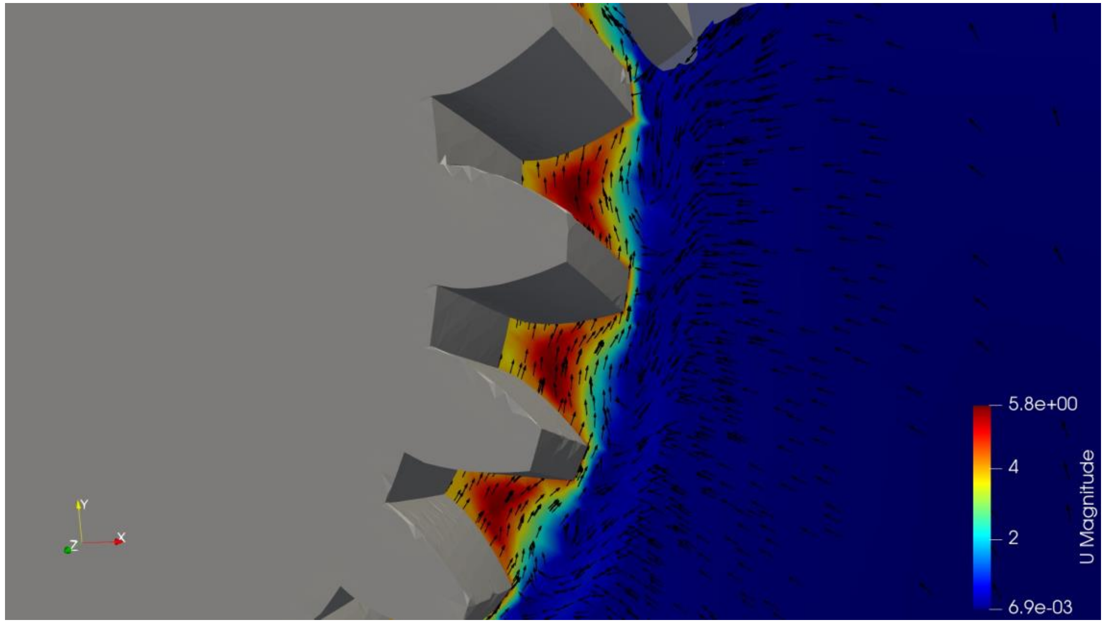
```
divSchemes
{
    default           none;
    div(phi,k)        Gauss linearUpwind grad(U);
    div(phi,omega)    Gauss linearUpwind grad(U);
    div(rhoPhi,U)   Gauss linearUpwind grad(U);
    div(phi,alpha)    Gauss vanLeer;
    div(phirb,alpha)  Gauss linear;
    div(((rho*nuEff)*dev2(T(grad(U))))) Gauss linear;
}
```

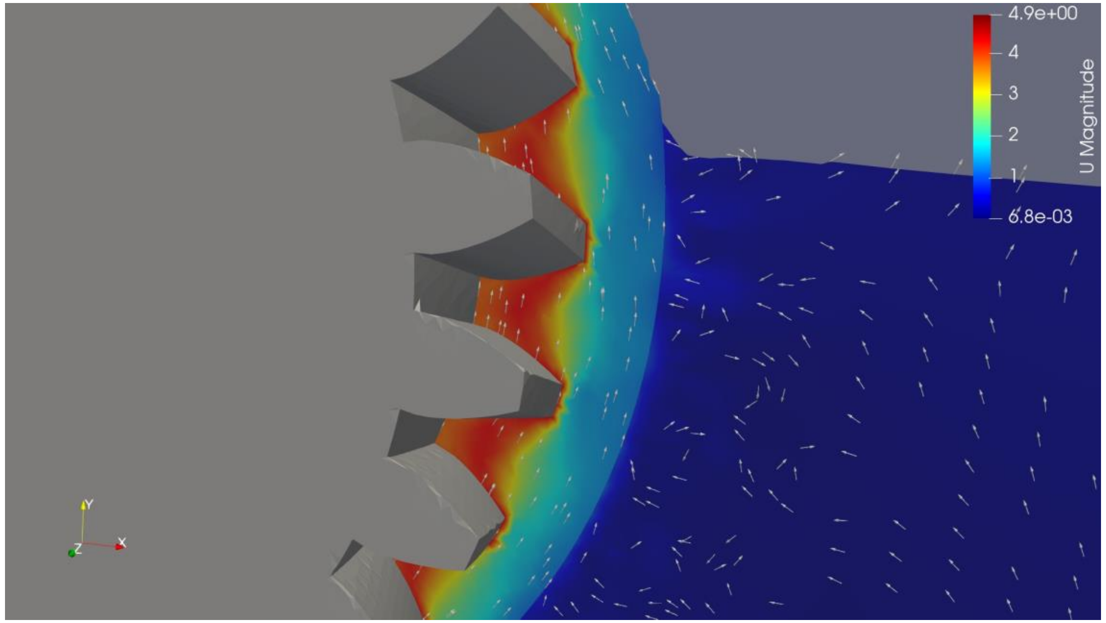
New schemes

```
divSchemes
{
    div(rhoPhi,U)   Gauss upwind;
    div(phi,k)        Gauss linearUpwind grad(U);
    div(phi,omega)    Gauss upwind;
    div(phi,alpha)    Gauss vanLeer;
    div(phirb,alpha)  Gauss linear;
    div(((rho*nuEff)*dev2(T(grad(U))))) Gauss linear;
}
```

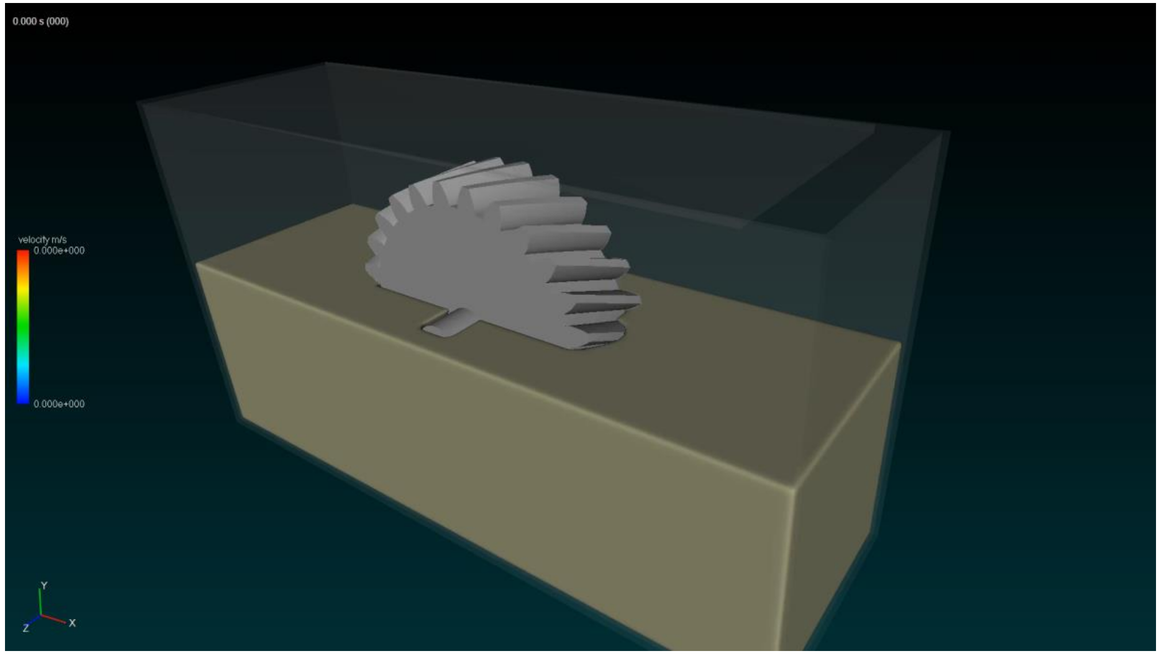
Fluid velocity

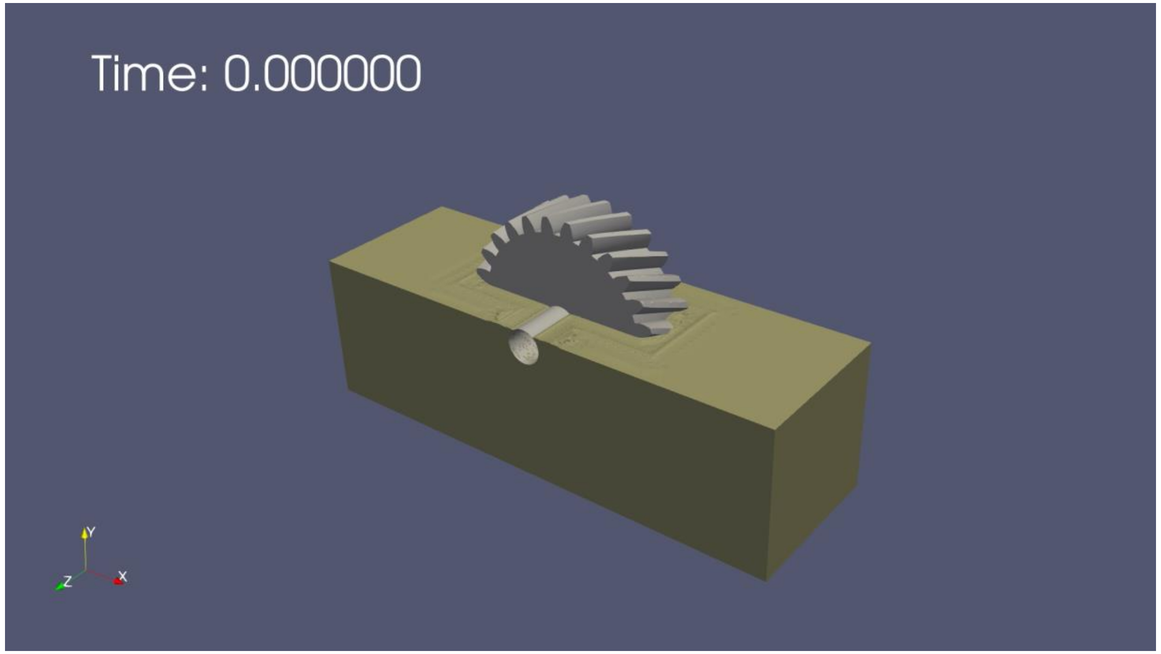
Velocity vectors in the place of the slice: U_X*iHat + U_Y*jHat





Comparison with Particleworks





Comparison with Particleworks

- interFoam
  - 4 cores @ 4.8GHz
  - 24 hrs for 0.306s real time

- Particleworks
  - 1mm particle size
  - 4 cores @ 2.8GHz
  - 3 hrs for 0.306s real time
  - Optimised for GPU

Summary

- What have we done
  - Sliding mesh, multi phase & transient simulation
  - Gear splash lubrication
- What next?
  - Robustness of simulation
    - Reduction in timestep
    - fvSolution settings
    - Turbulence model
    - Mesh quality
  - Multiple gears
    - Remeshing?
    - Overset?
  - Full gearbox