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FACULTY OF ENGINEERING
AND ARCHITECTURE

DEPARTMENT OF ELECTROMECHANICAL, SYSTEMS AND METAL ENGINEERING
RESEARCH GROUP SUSTAINABLE THERMO-FLUID ENERGY SYSTEMS

SIMULATION OF ELASTOHYDRODYNAMIC LUBRICATION

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ERCOFTAC Autumn Festival 2023 – 12 October 2023

Supervisors: Prof. Joris Degroote and Prof. Dieter Fauconnier

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ELASTOHYDRODYNAMIC LUBRICATION

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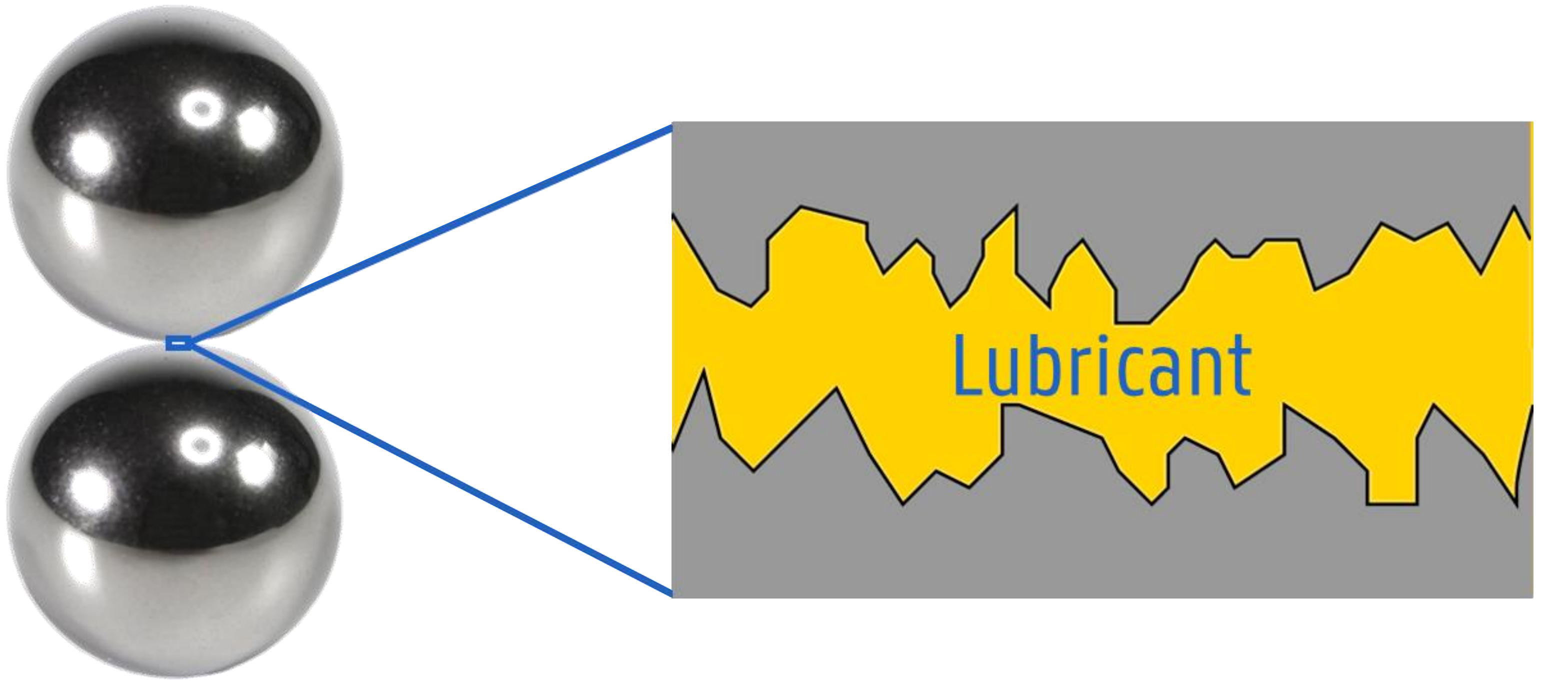
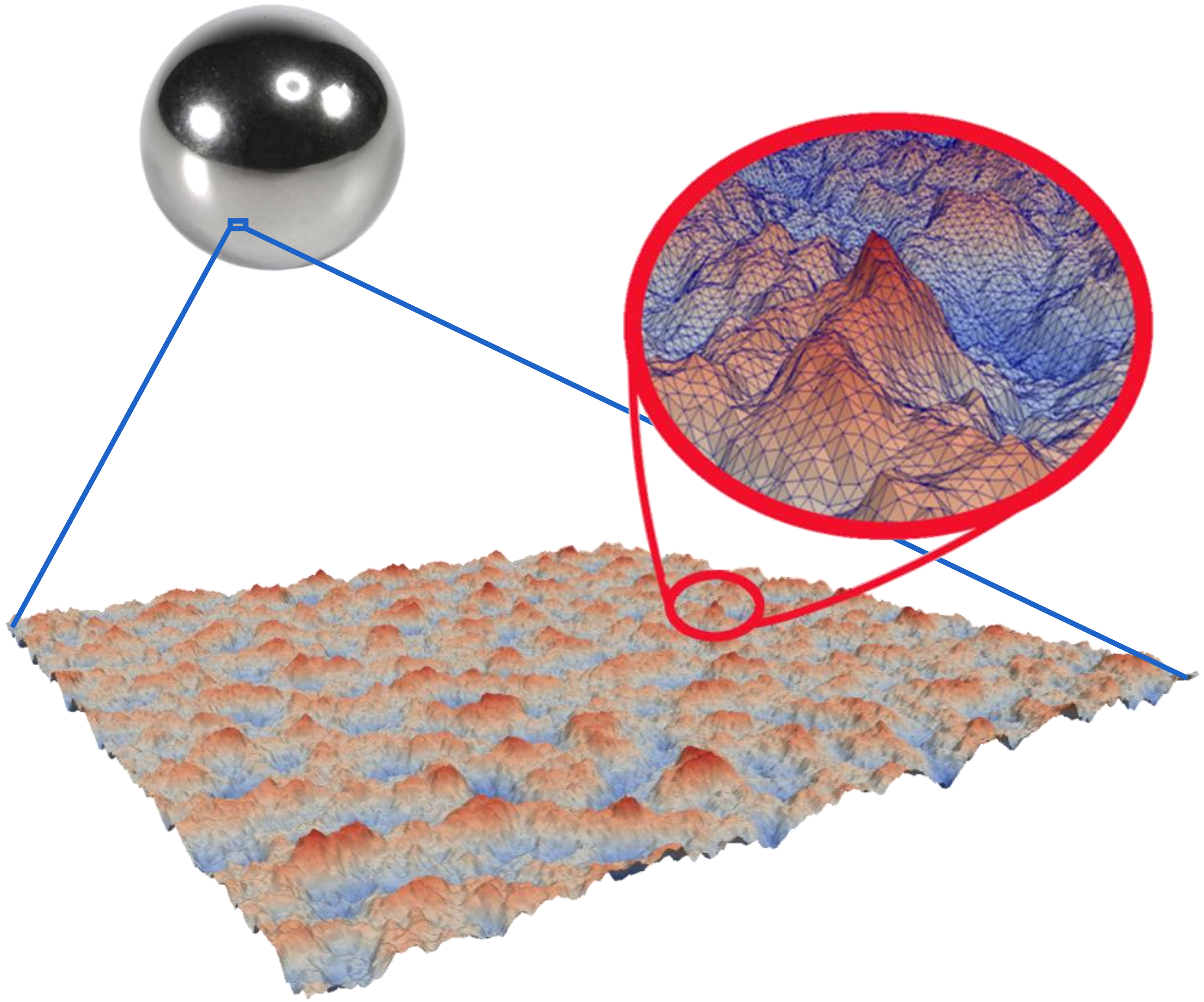
WHAT IS ELASTOHYDRODYNAMIC LUBRICATION?

— Why lubricate?

Keep surfaces separated





https://www.epfl.ch/labs/lsms/research/contact-mechanics-tribology/mesoscale-contact-friction-and-wear/

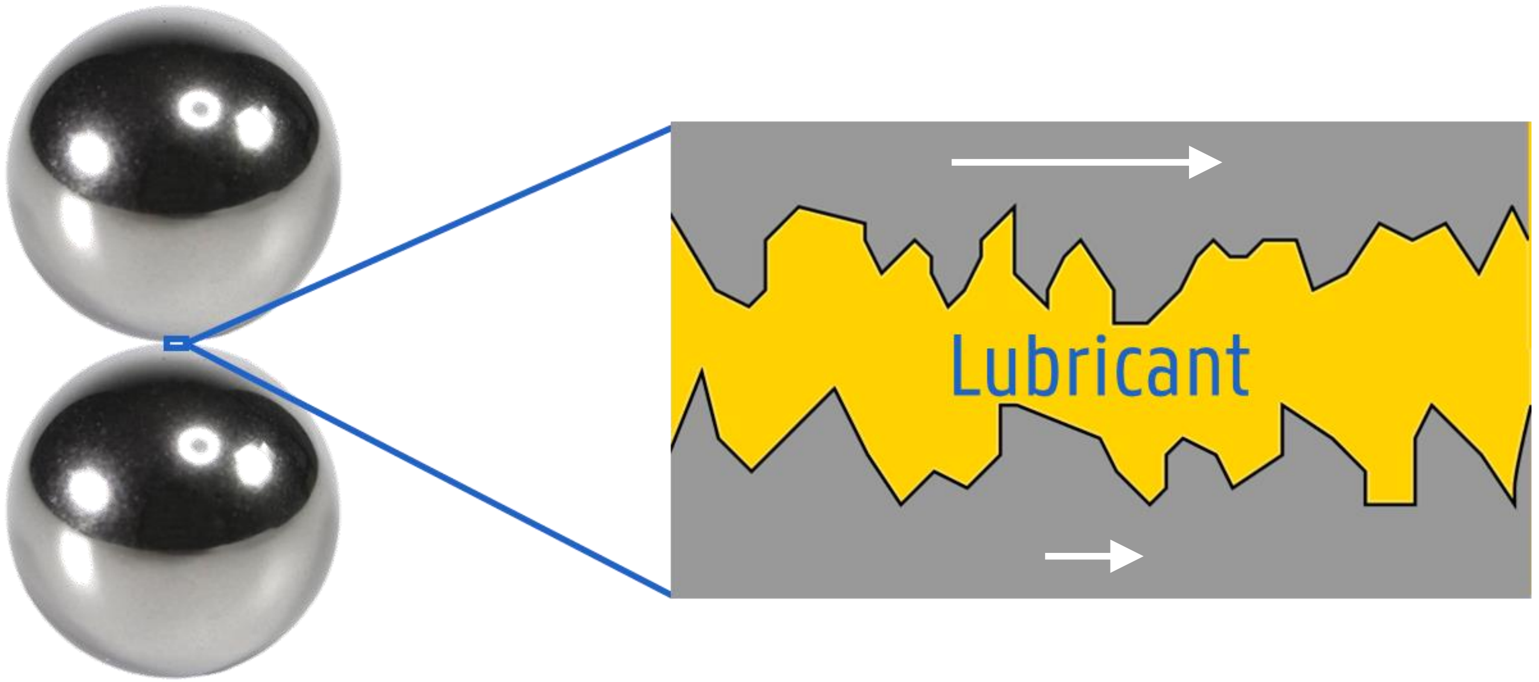
WHAT IS ELASTOHYDRODYNAMIC LUBRICATION?

- Why lubricate?

  Keep surfaces separated

  - Avoid contact, peaks breaking off and contamination
  - Reduce friction and power consumption
  - Limit temperature and evacuate heat

Hydrodynamic lubrication

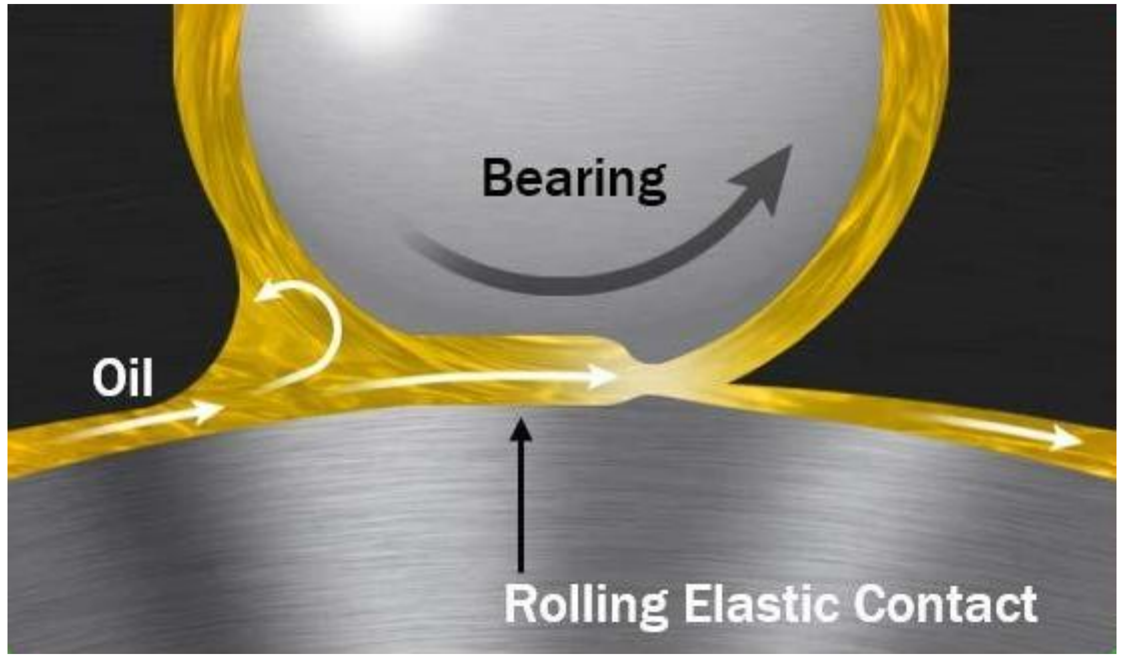


WHAT IS ELASTOHYDRODYNAMIC LUBRICATION?

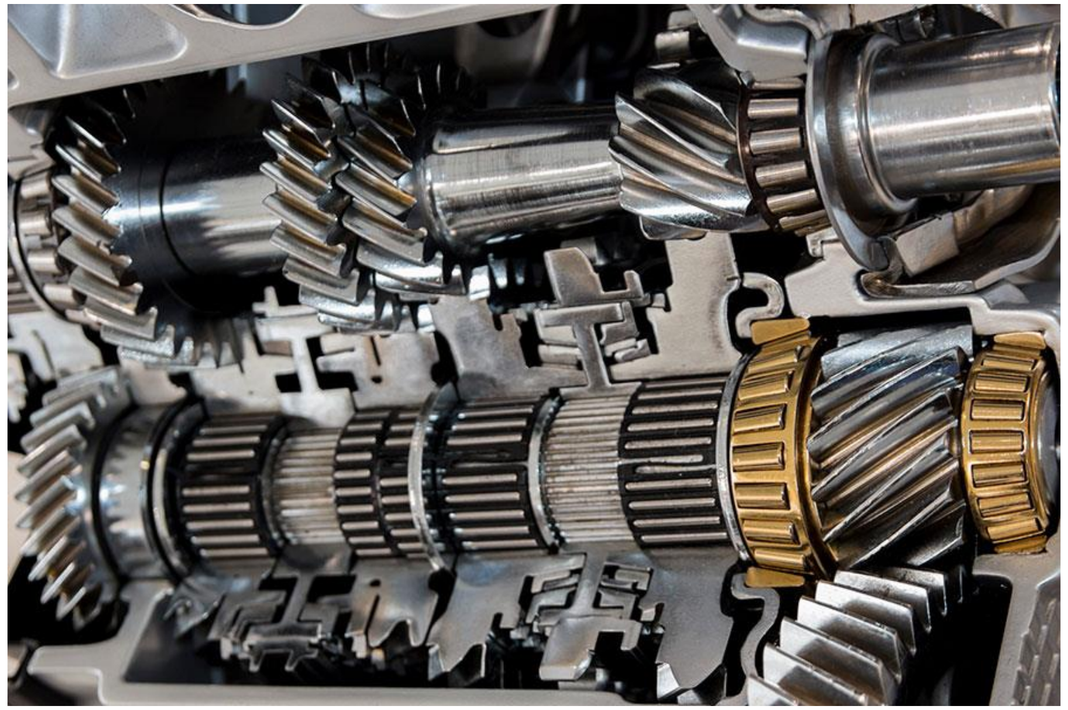
EHL

1. Deformation of the surfaces
2. Steep increase of viscosity with pressure

⇨ Support very high load without contact

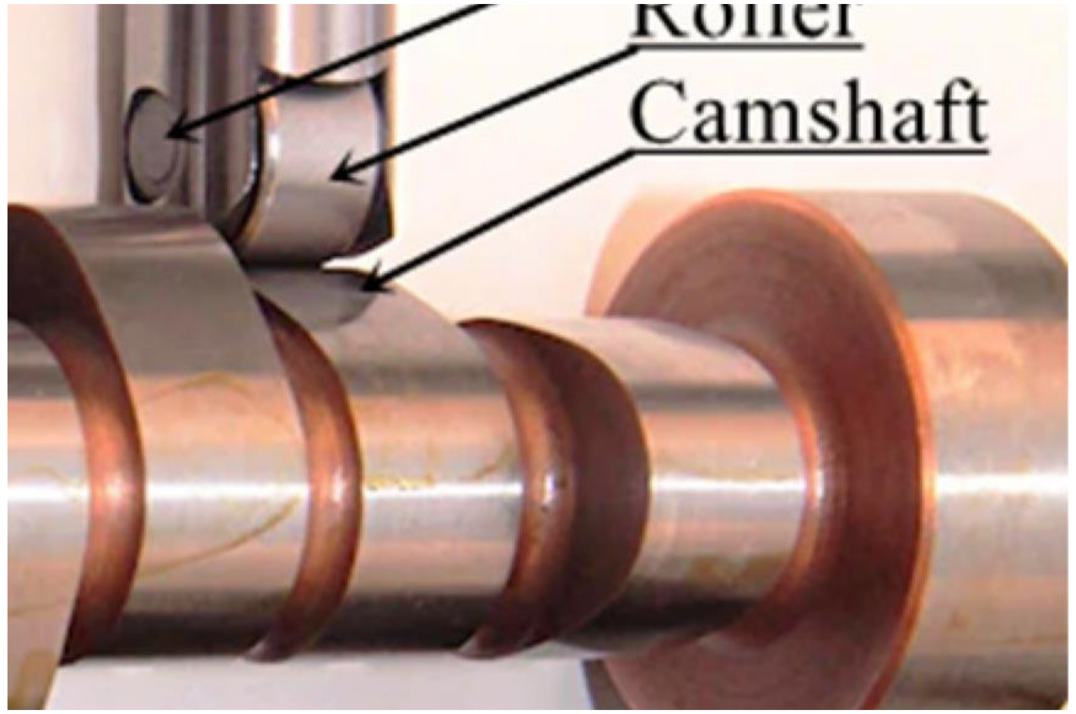


https://www.machinerylubrication.com/Read/30741/lubrication-regimes



https://www.powertransmission.com/articles/1353-the-efficient-evolving-technology-of-the-gearbox

https://www.machinerylubrication.com/Read/30741/lubrication-regimes



Li S, Guo F, Wong PL, Liang P, Huang J. Skidding Analysis of Exhaust Cam-Roller Unit in the Steady/Startup Operation of Internal Combustion Engine. Lubricants. 2023; 11(9):361.

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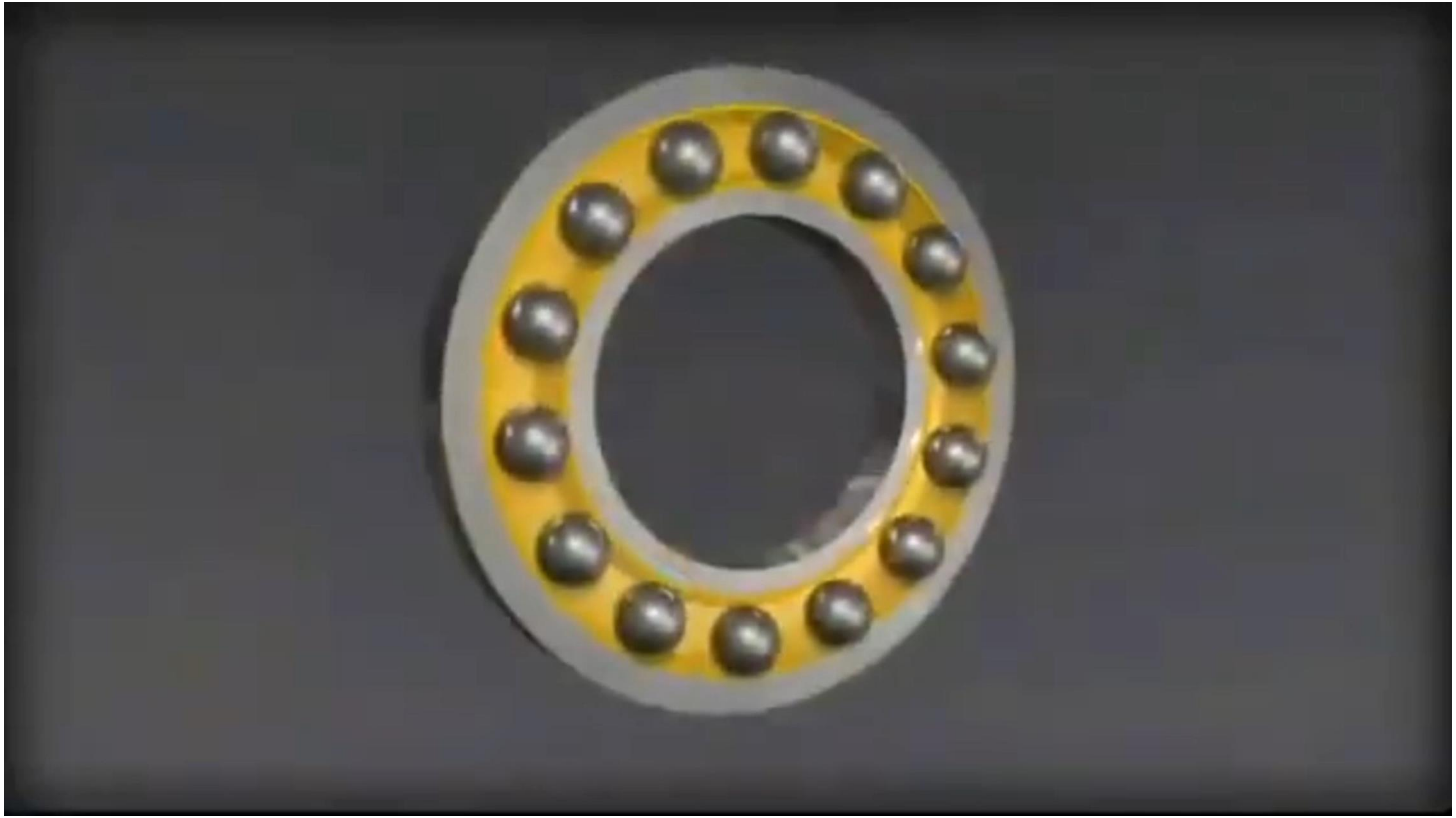
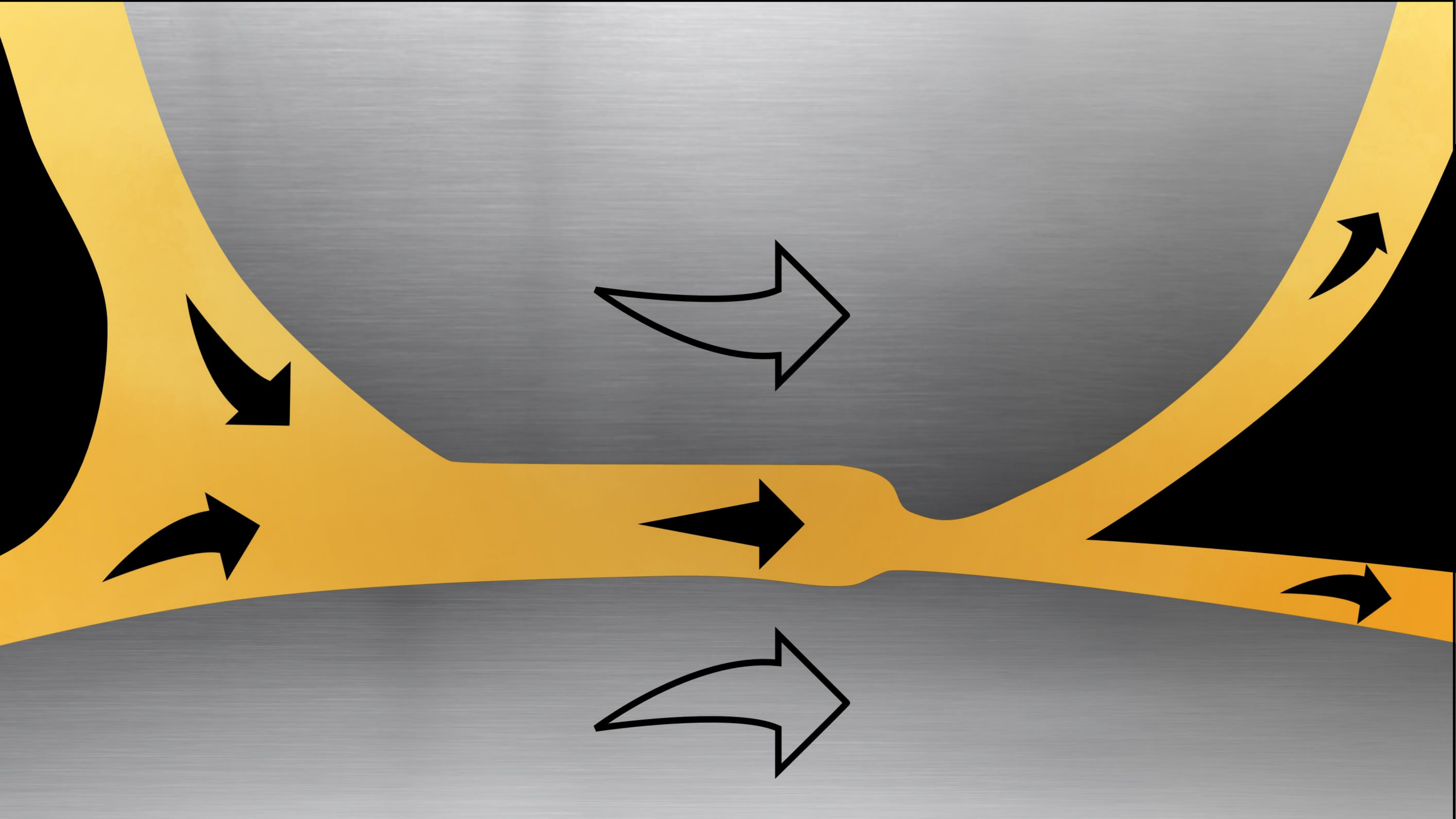
BEARINGS

Experimental measurements very difficult → simulation

- Improve reliability and durability
- Limiting noise, vibration and harshness
- Improving hydraulic performance



https://www.youtube.com/watch?v=WwvLvgwSpT4&t=468s&ab_channel=NanoEnergizerMalaysia



FLUID-STRUCTURE INTERACTION

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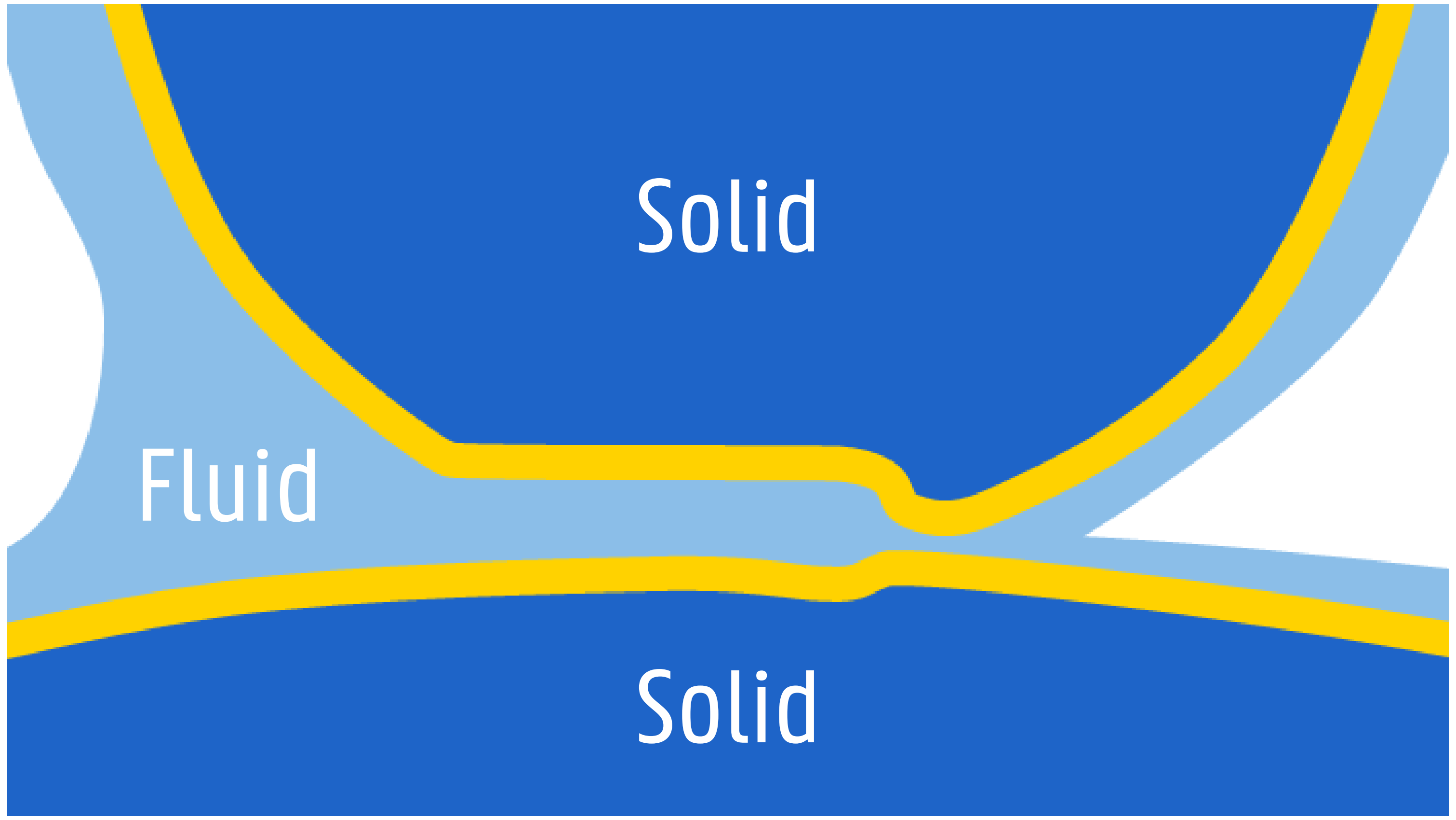
SOLVING AN FSI PROBLEM



Equilibrium conditions on interface

- Equal **displacement**
- Equal **force** magnitude, but opposite sign

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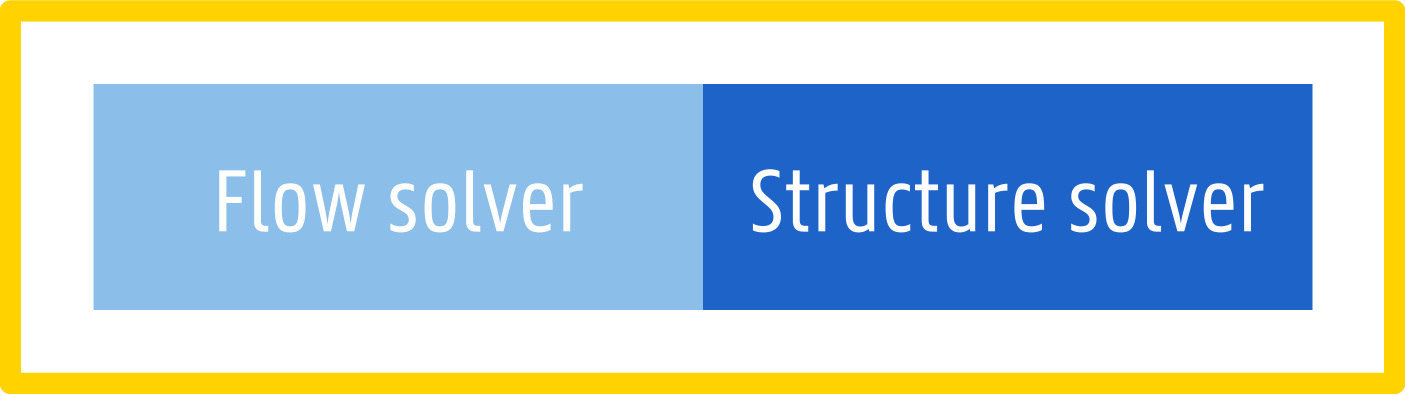
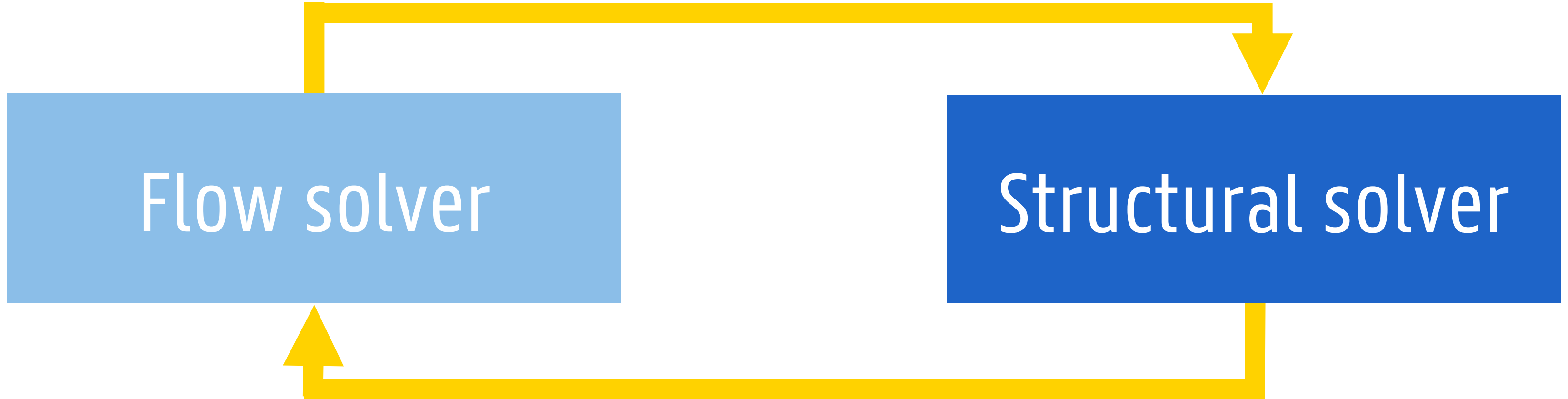
SOLVING AN FSI PROBLEM





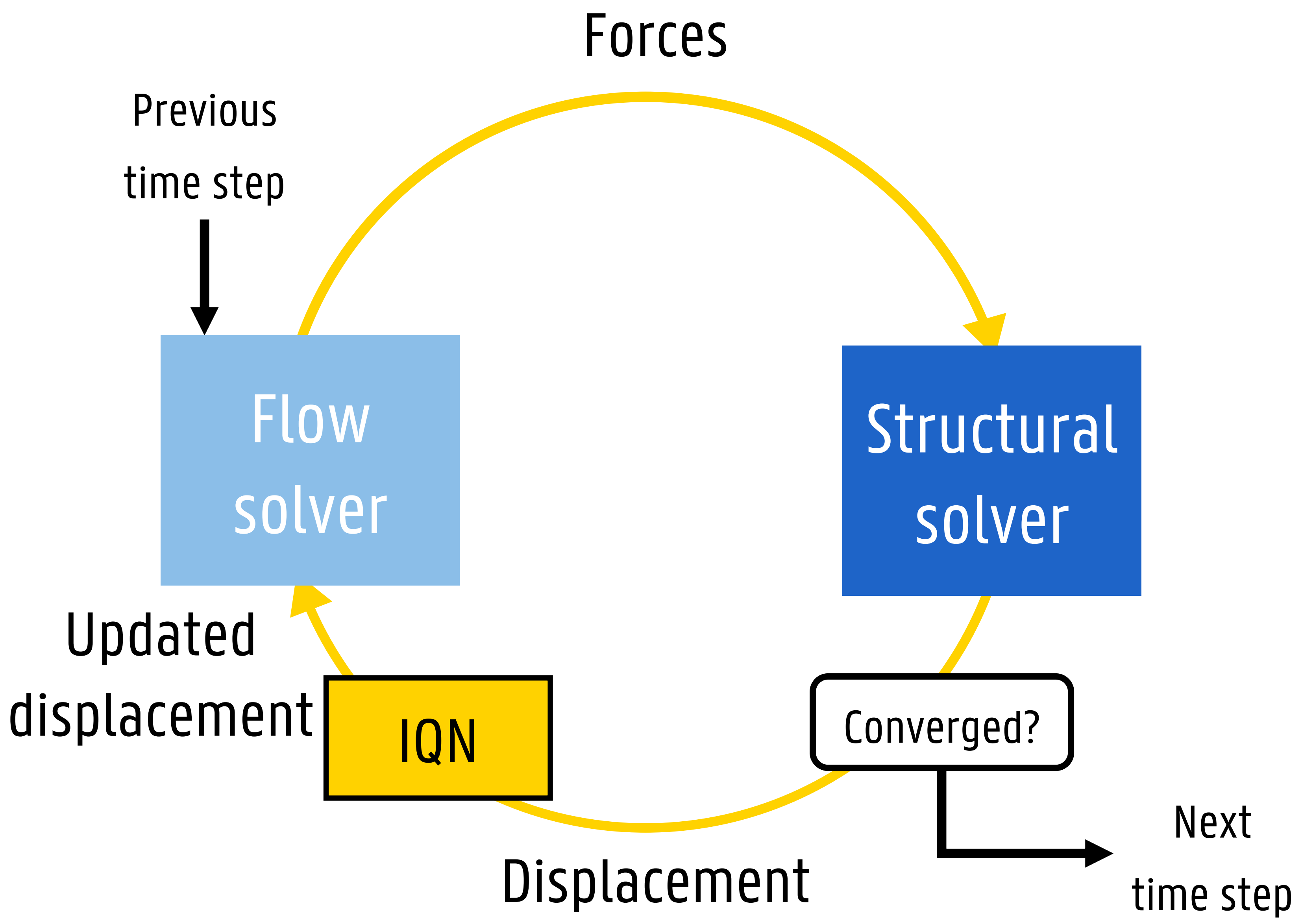
Monolithic approach

Partitioned approach

- ⊕ Mature and robust solvers
- ⊕ Application tailored solvers
- ⊖ Coupling iterations required

HOW TO SIMULATE FSI

- Loop until solution remains unchanged = converged
- One loop = coupling iteration
- Only exchange interface data
  ➔ black-box
- Strongly coupled problems with coupling algorithm
  ➔ interface quasi-Newton (IQN)



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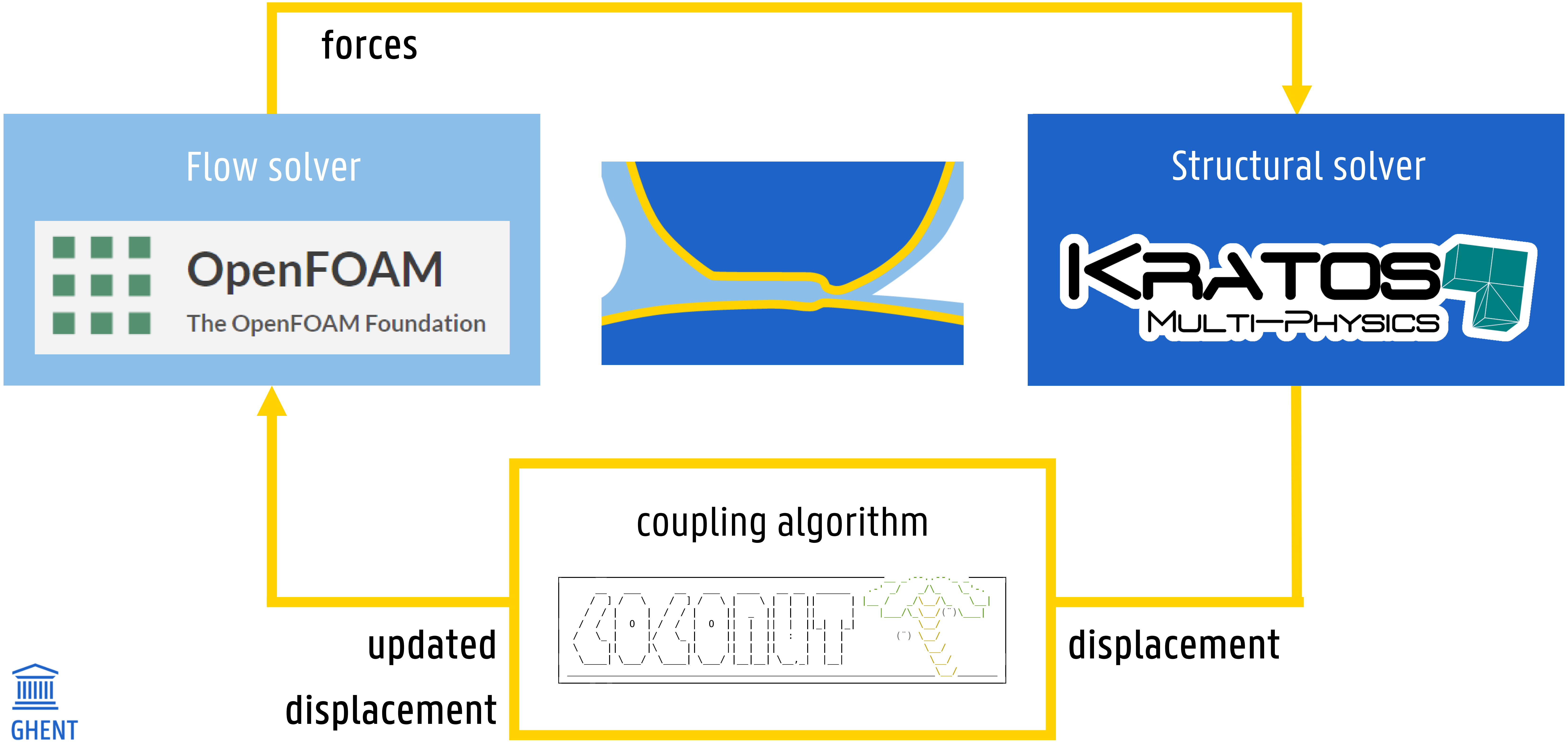
SOLVING AN FSI PROBLEM



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FSI SIMULATION OF EHL

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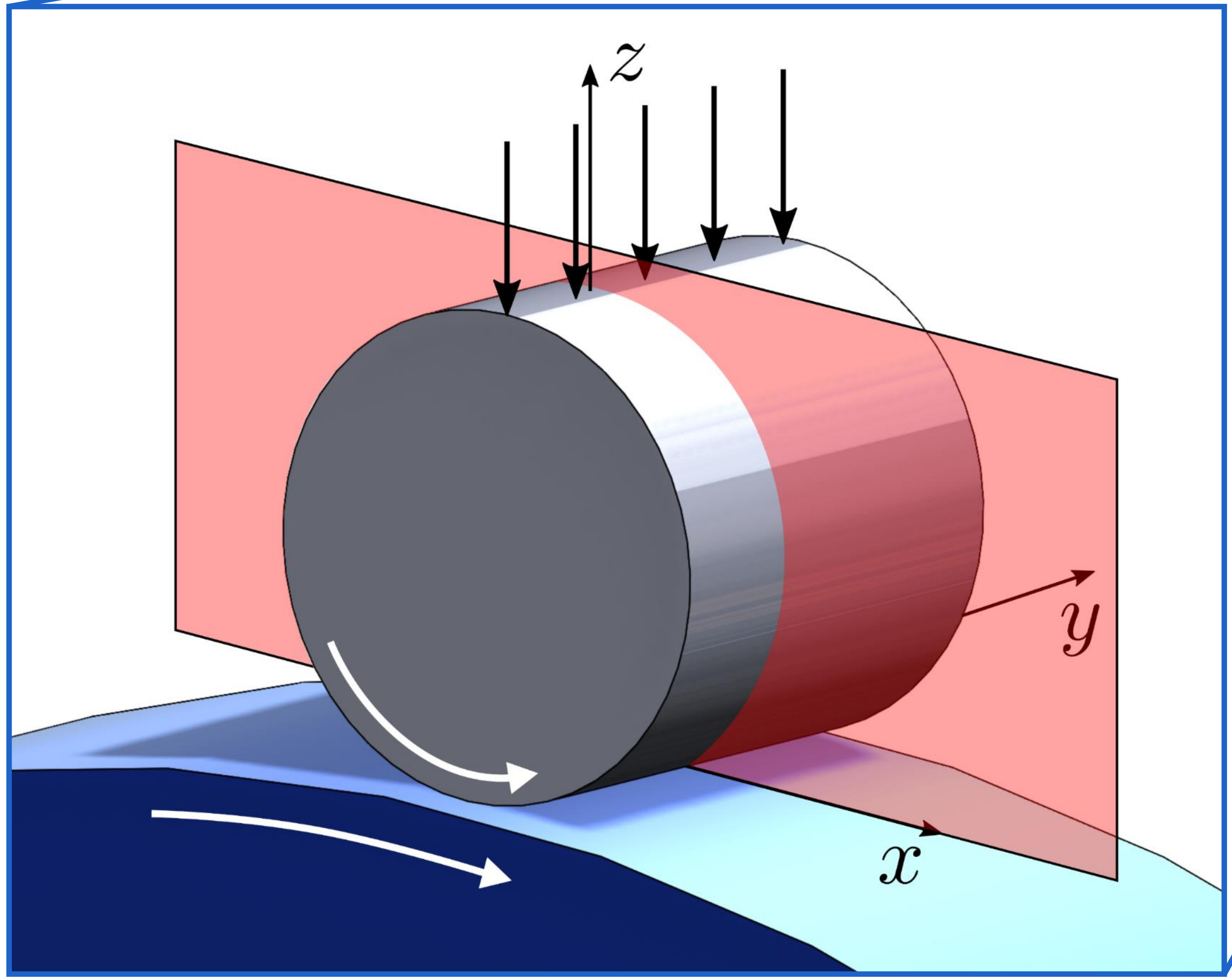
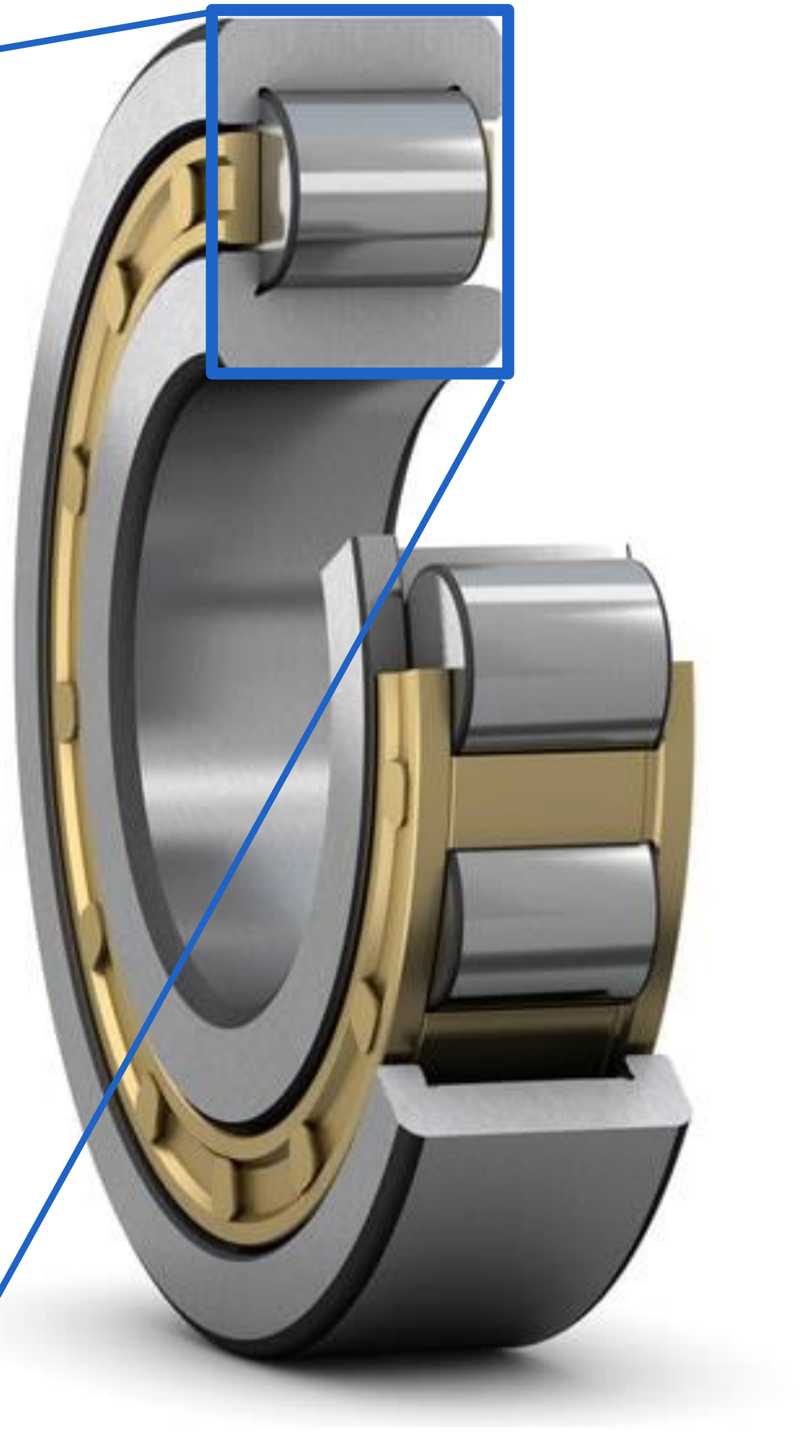
EHL SIMULATION

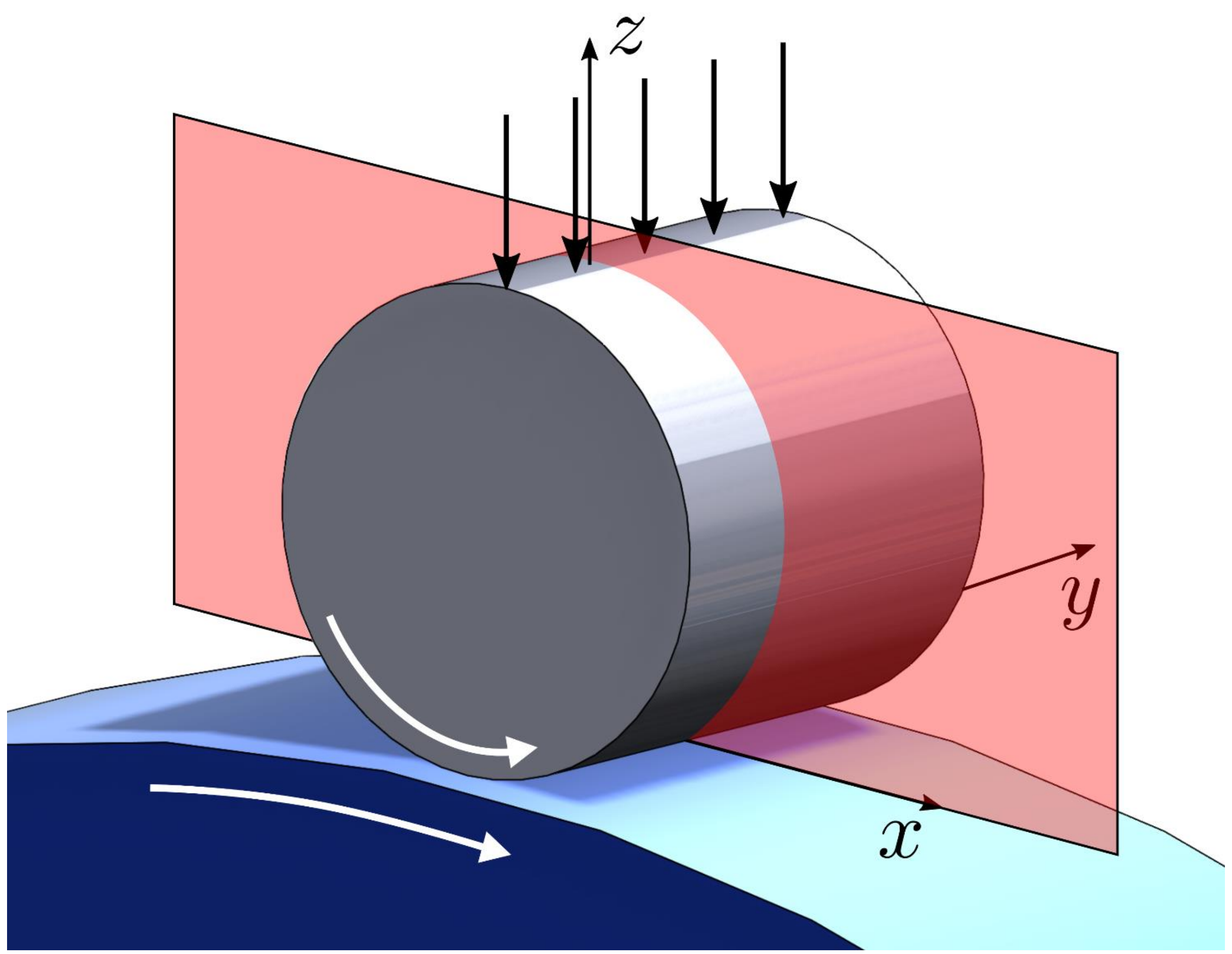
— Cylindrical roller bearing

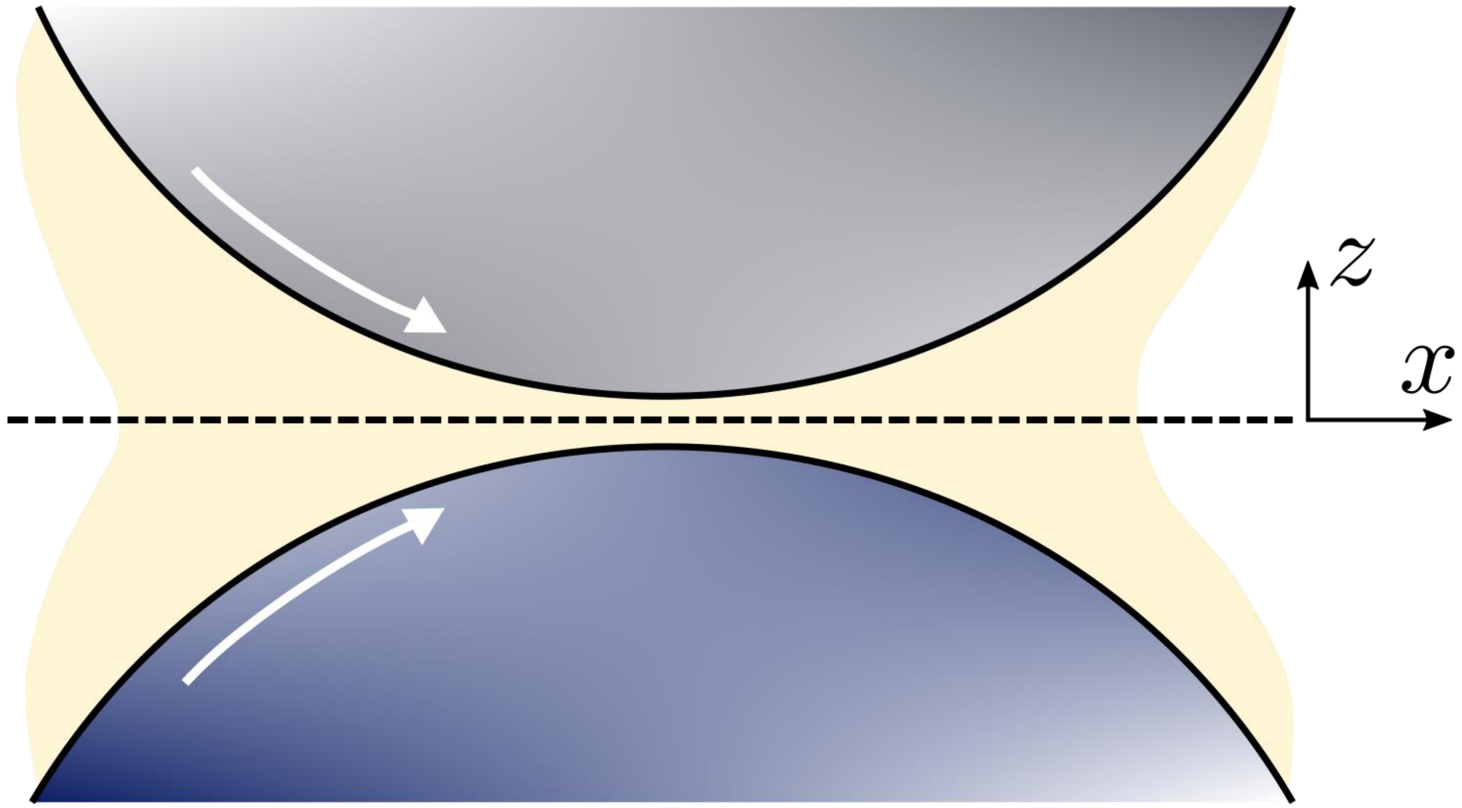




https://www.skf.com/uk/products/rolling-bearings/roller-bearings/cylindrical-roller-bearings

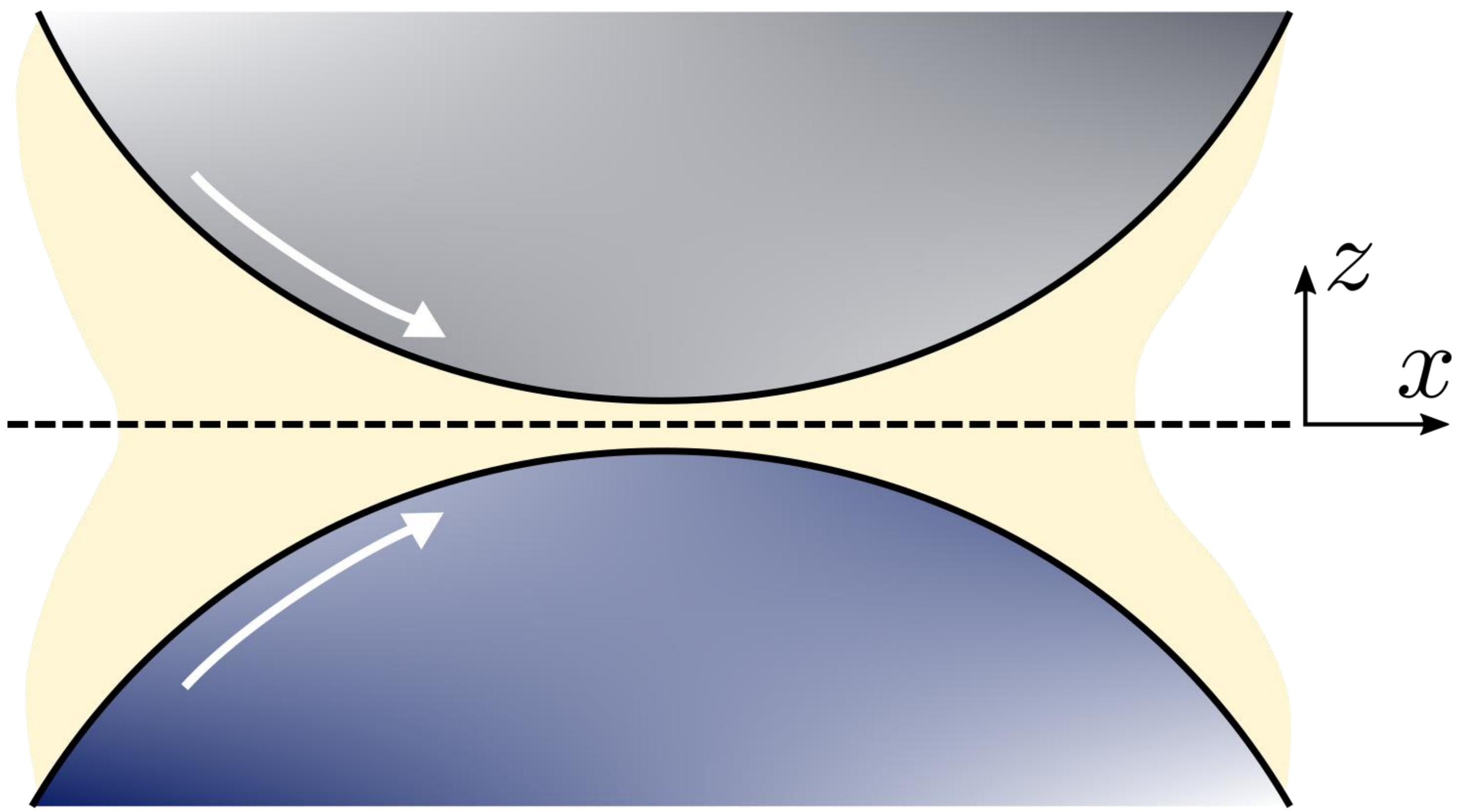
EHL SIMULATION



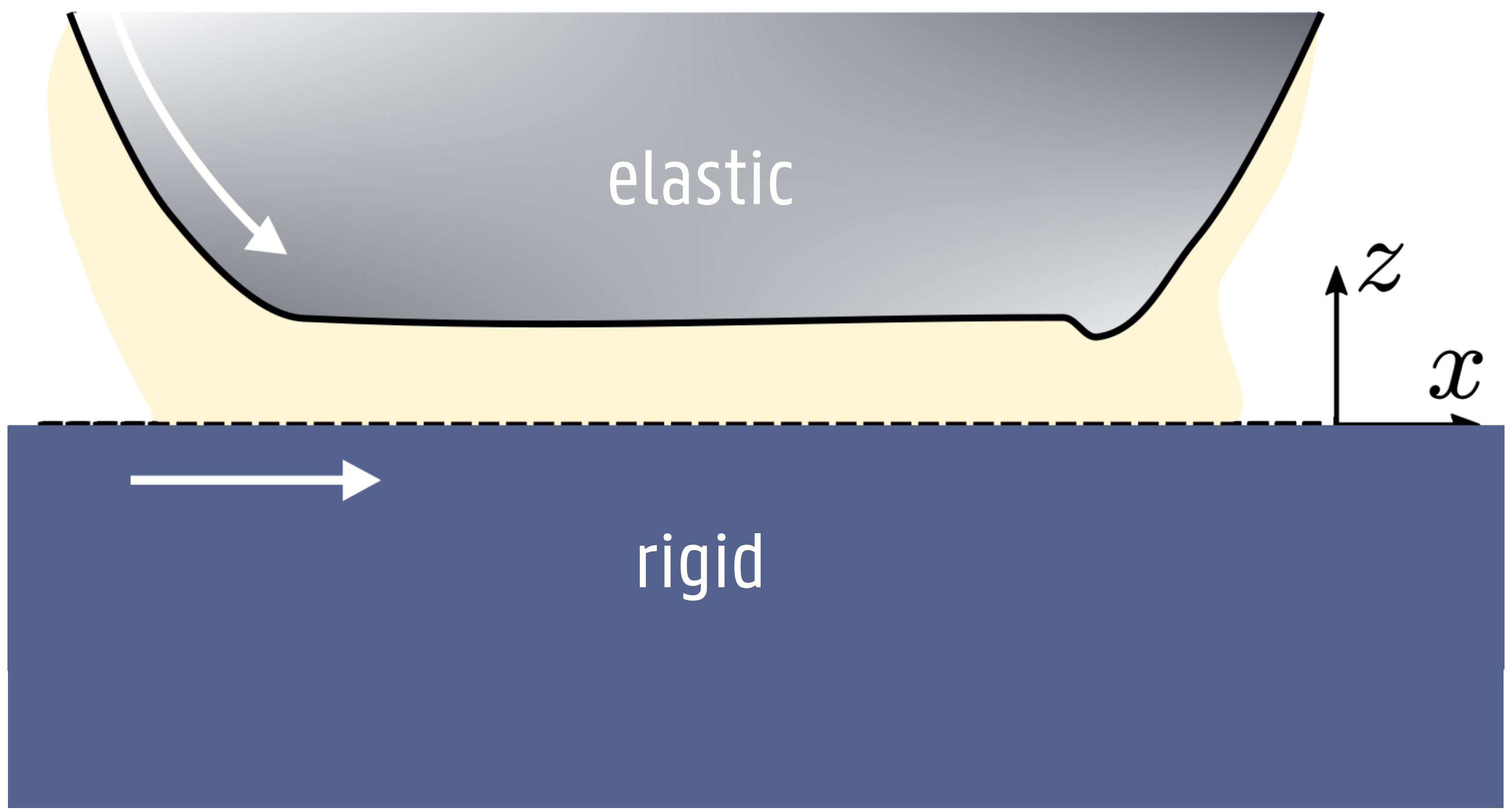


EHL SIMULATION

Actual geometry



Equivalent geometry



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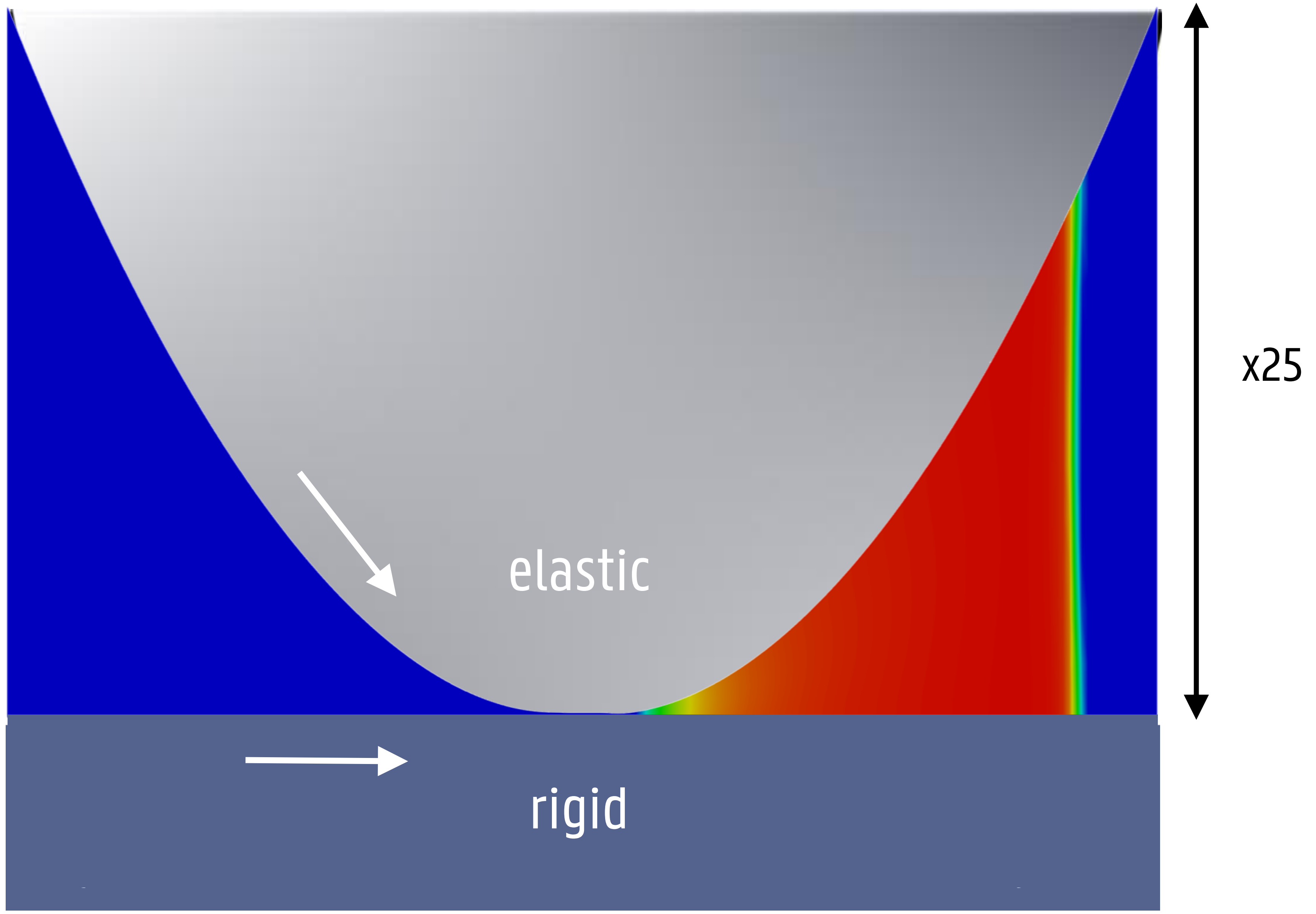
LUBRICANT MODELING

- Modeling the lubricant: squalane
  - Cavitation: homogeneous equilibrium model



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LUBRICANT MODELING

- Modeling the lubricant: squalane
  - Cavitation: homogeneous equilibrium model
  - Density: Tait equation
  - Viscosity: Doolittle equation
  - Shear-thinning: Carreau model
  - Thermal conductivity and heat capacity
- Flow solver → modification of solver in OpenFOAM

OpenFOAM
The OpenFOAM Foundation

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BOUNDARY CONDITIONS

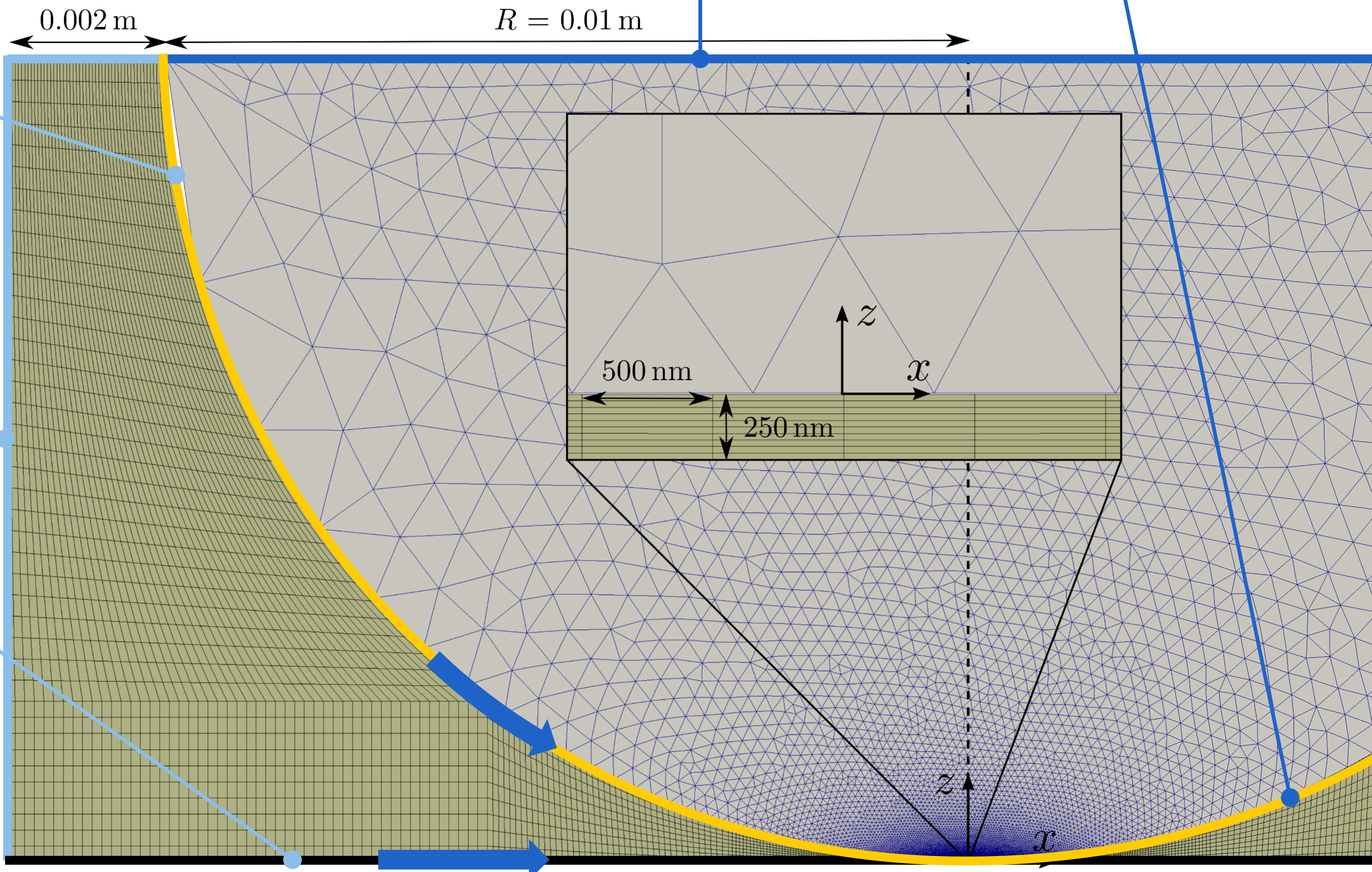
wall
rotating velocity
FSI displacement
fixed temperature

fixed total pressure
zero gradient velocity
fixed temperature
fixed density

wall
translating velocity
fixed temperature

zero displacement

FSI pressure and traction



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DISCRETIZATION

Flow solver: OpenFOAM

- Time: first order backward Euler
- Convective terms: first order upwind

Structural solver: Kratos Multiphysics Structural Mechanics

- Time: second order Bossak
- First-order plane strain elements

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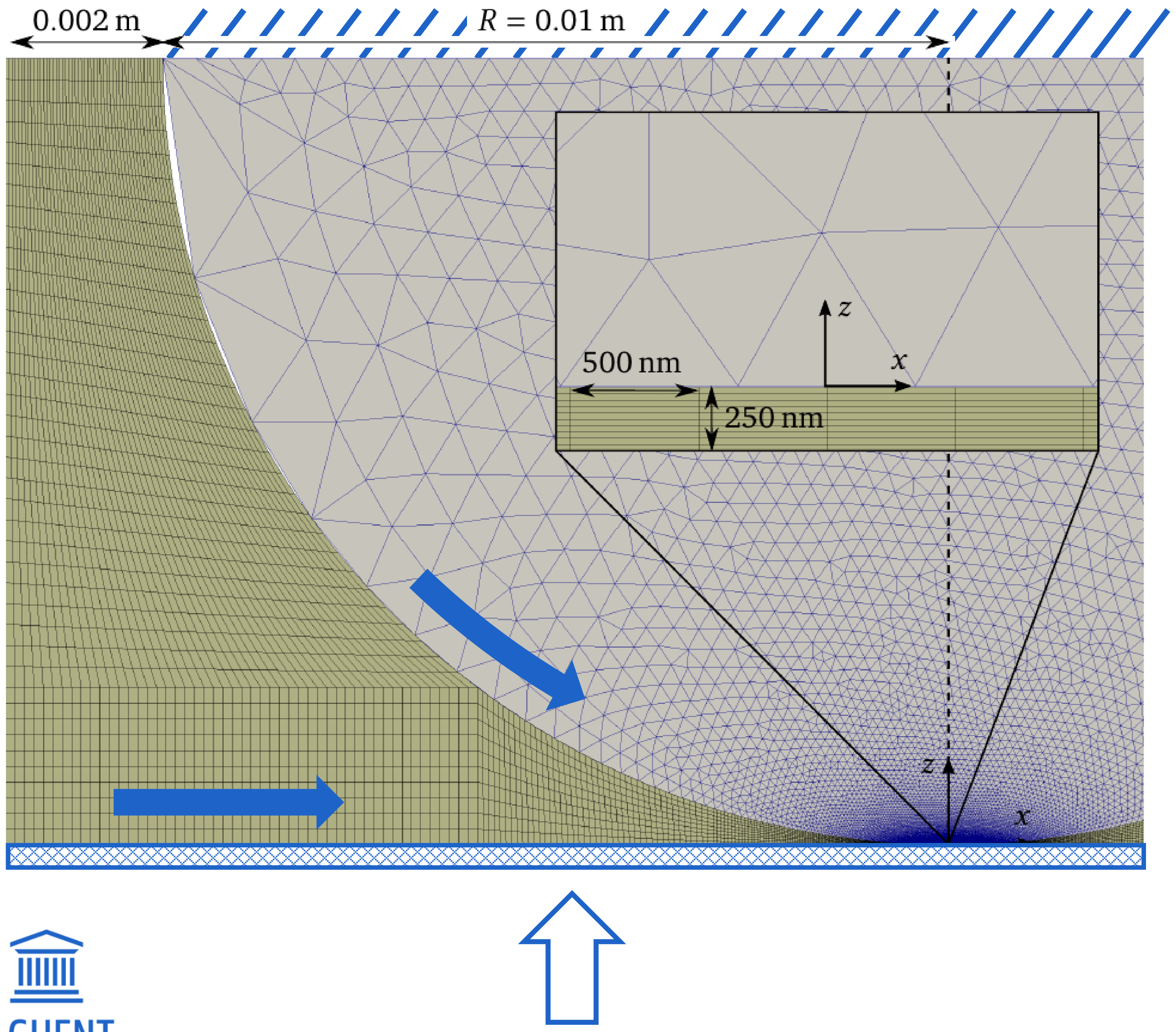
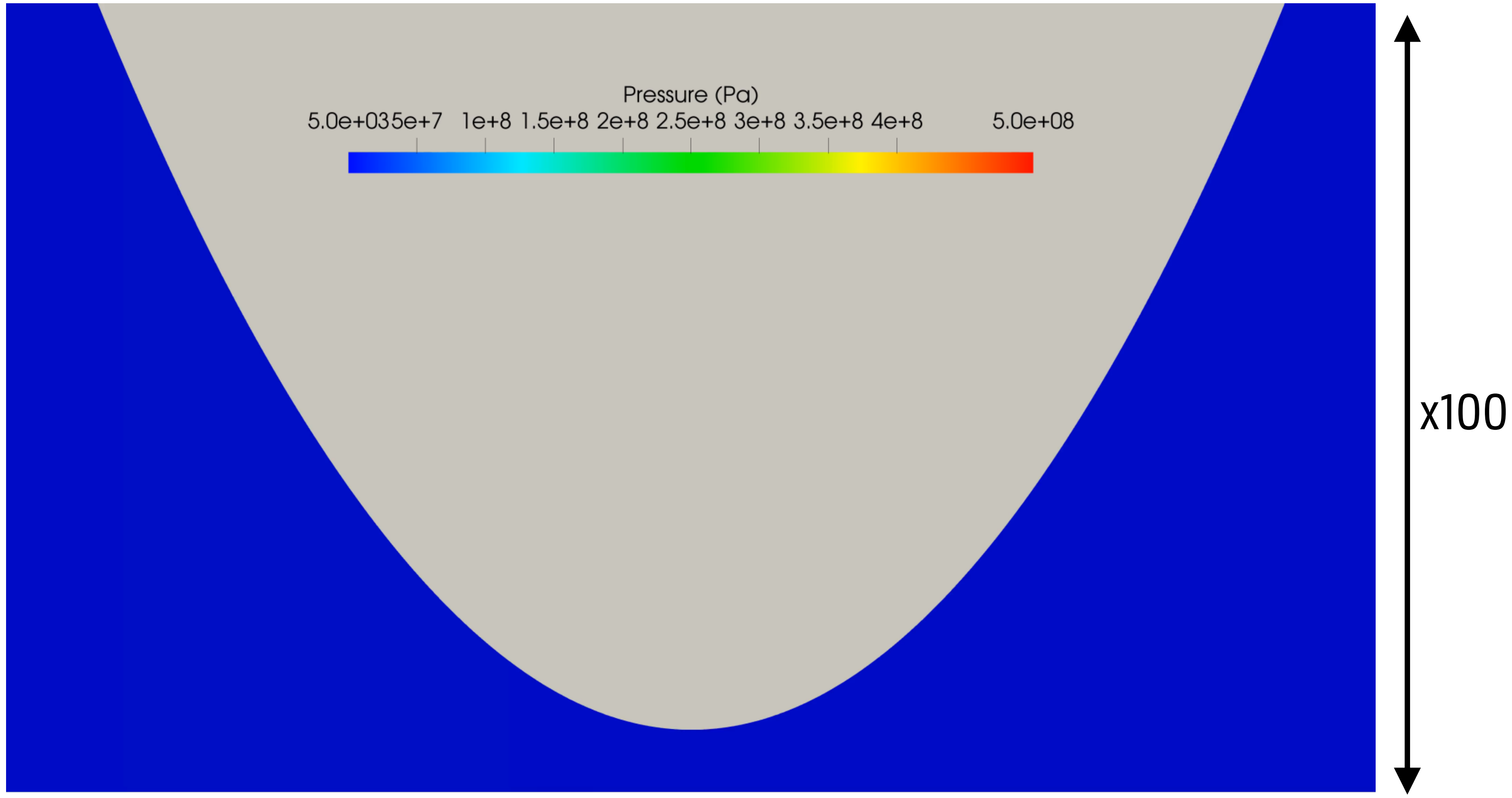
EHL SIMULATION

- Time step size 10 ns





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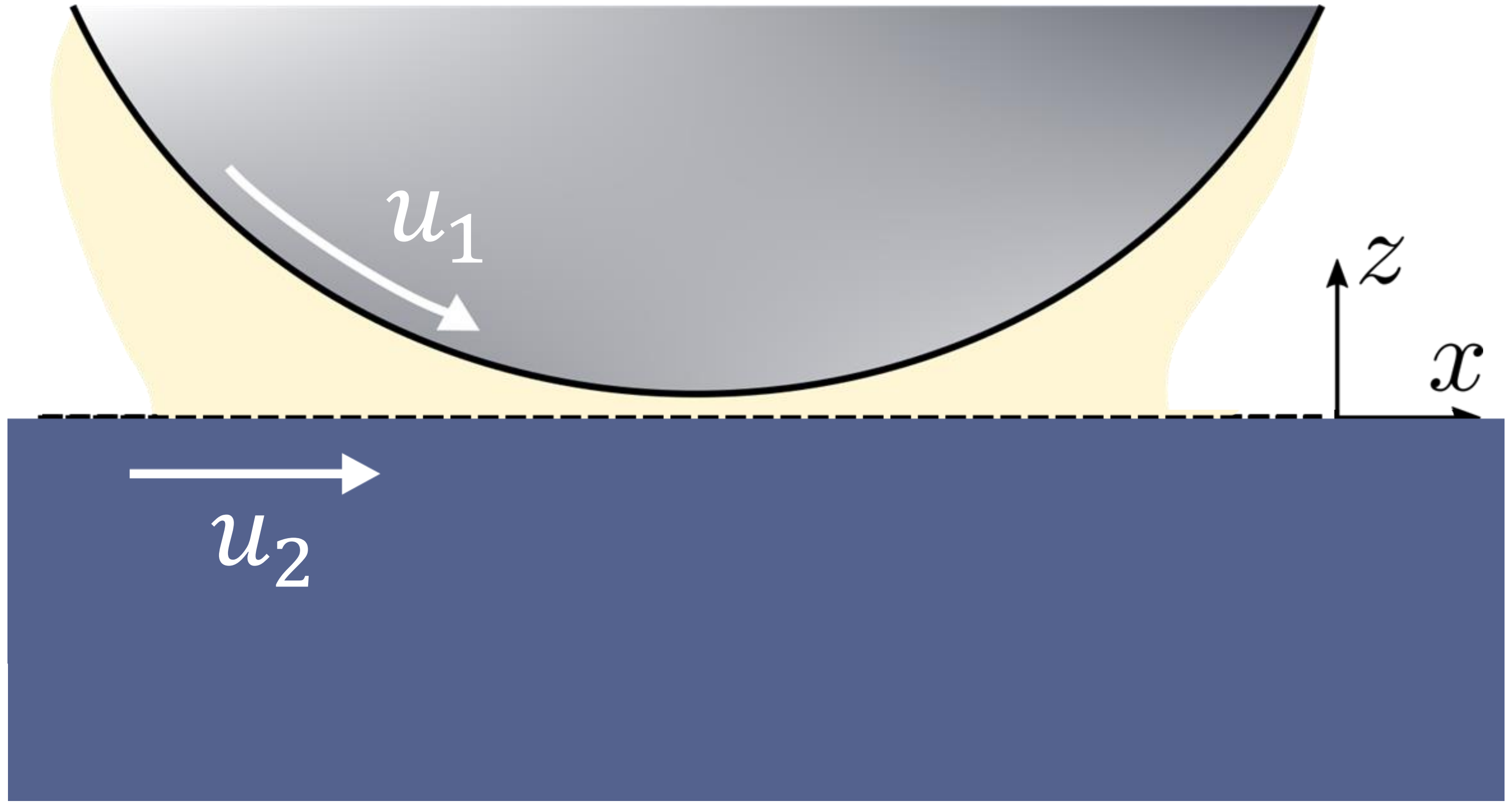
EHL SIMULATION

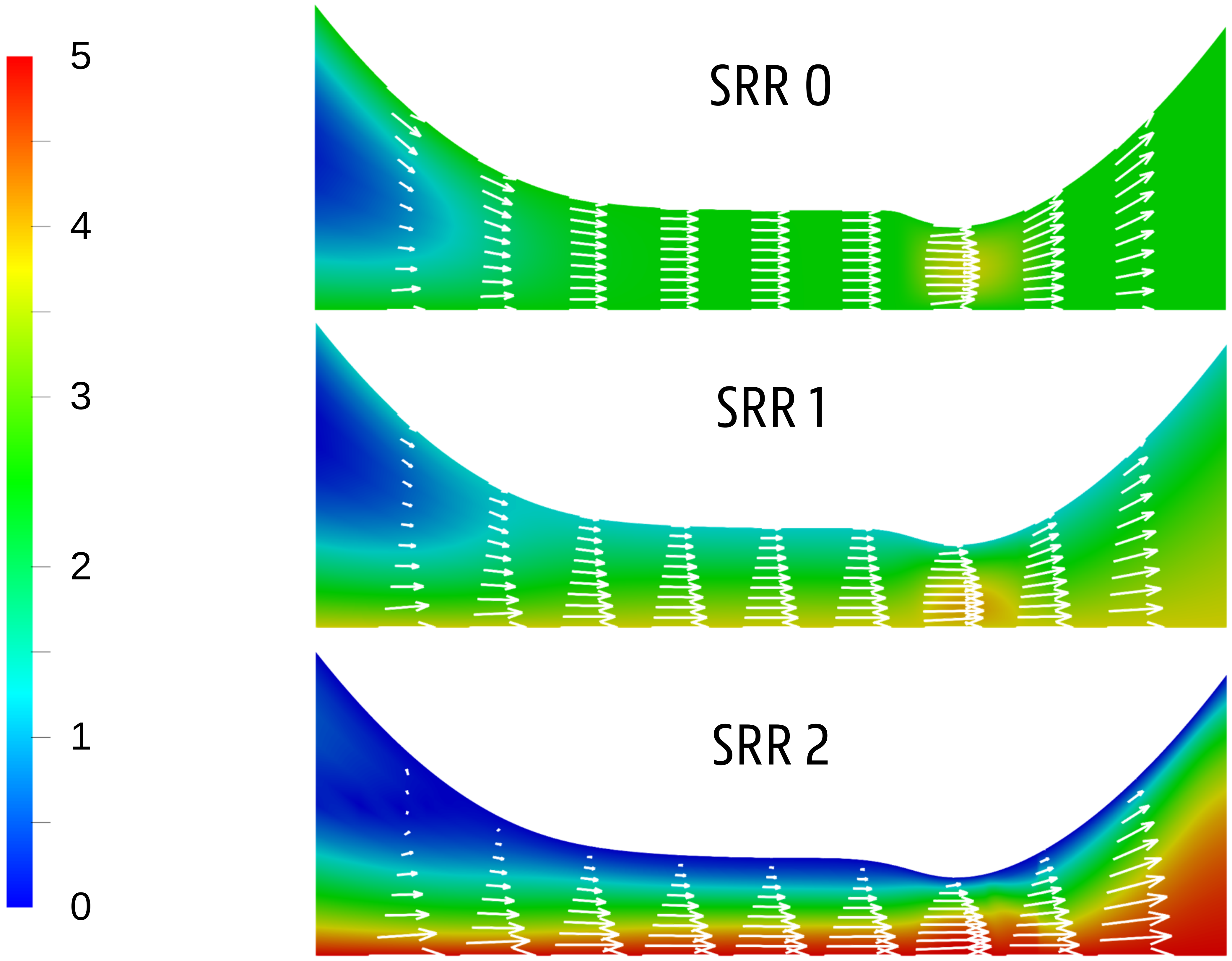
- Entrainment speed = $\frac{u_1+u_2}{2}$
- Sliding speed = $|u_1 - u_2|$
- Slip-to-roll ratio (SRR) = $\frac{2|u_1-u_2|}{u_1+u_2}$

- Pure rolling: SRR 0
- Pure slip: SRR 2

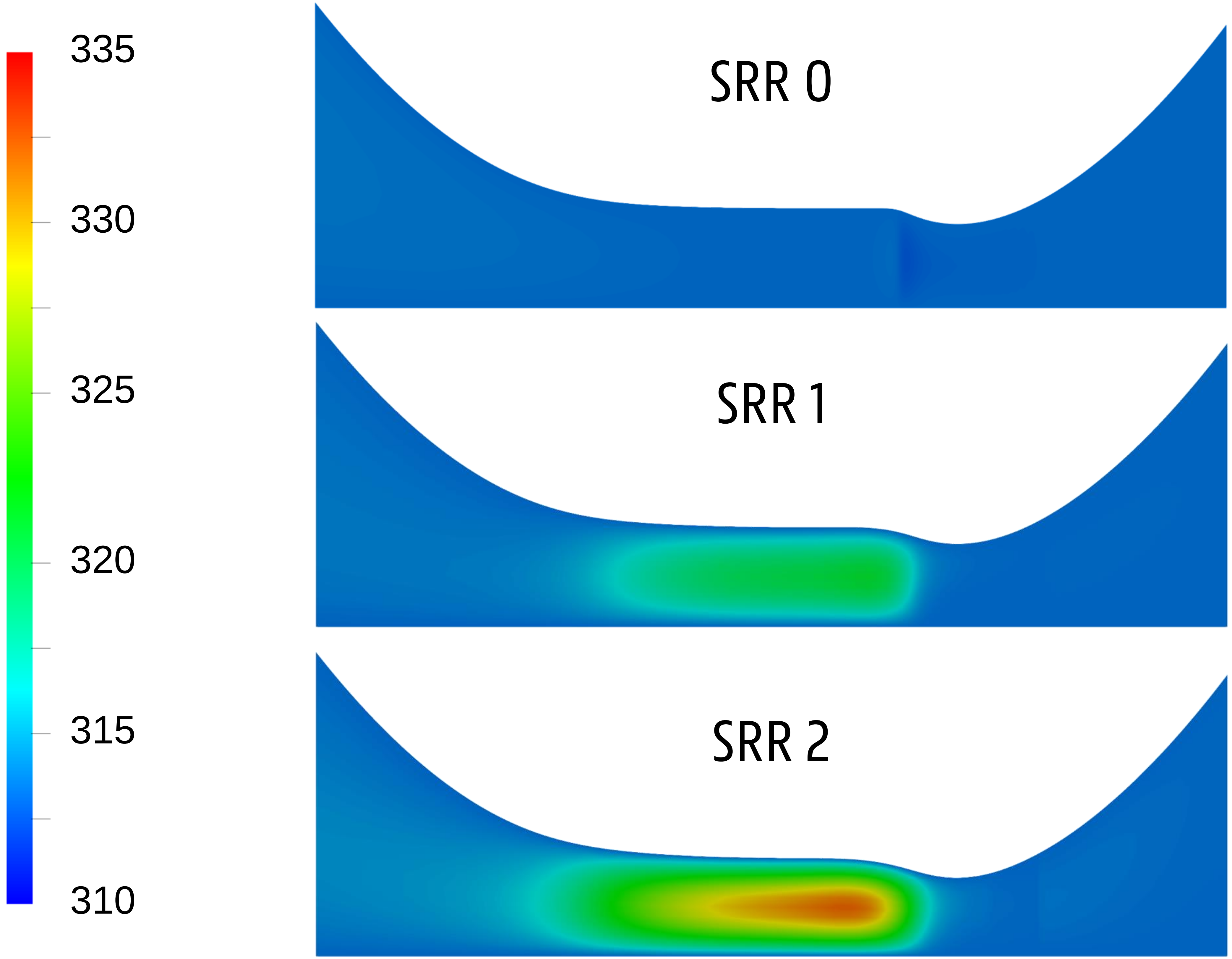


EHL SIMULATION: VELOCITY (m/s)

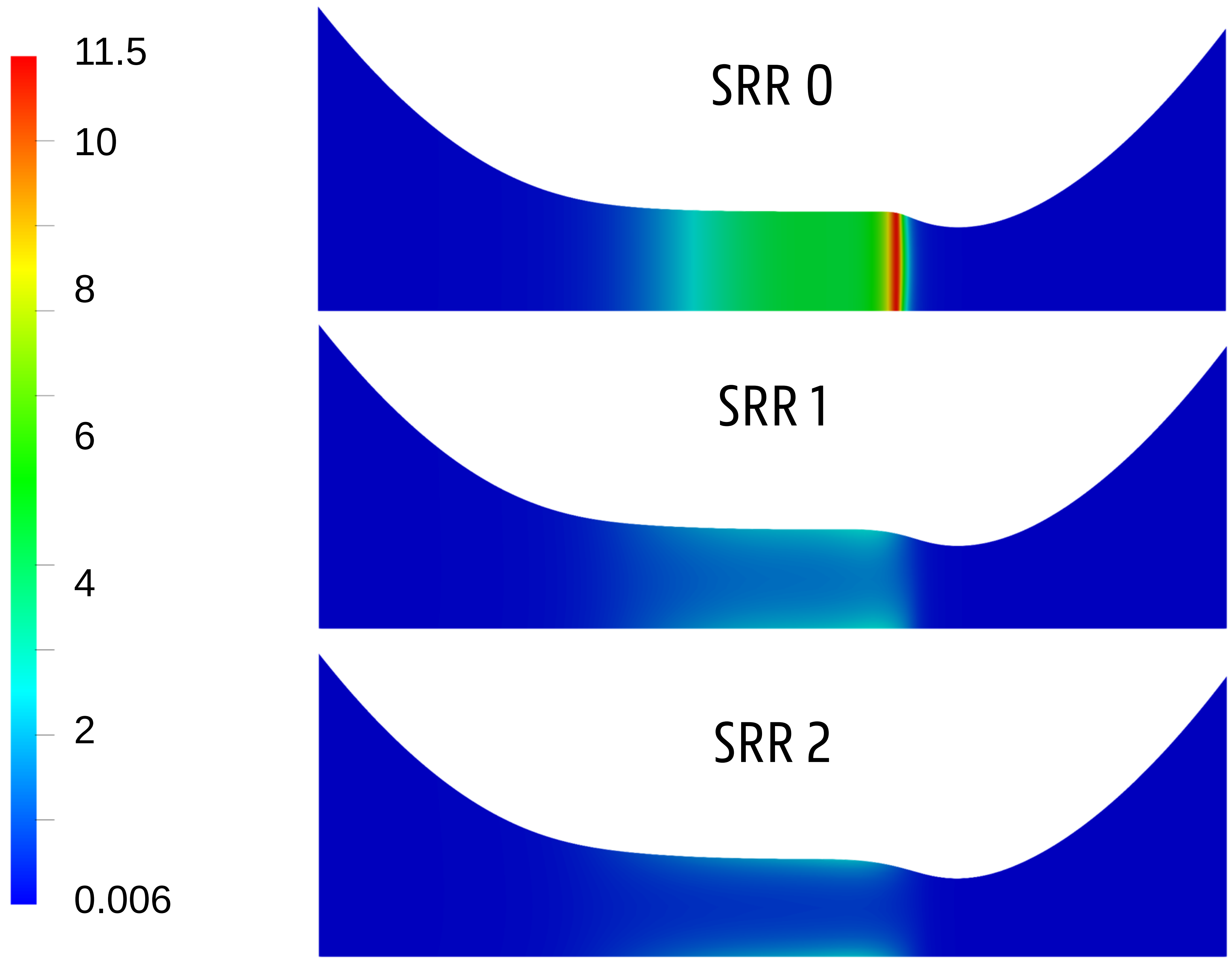
Entrainment speed 2.5 m/s



EHL SIMULATION: TEMPERATURE (K)

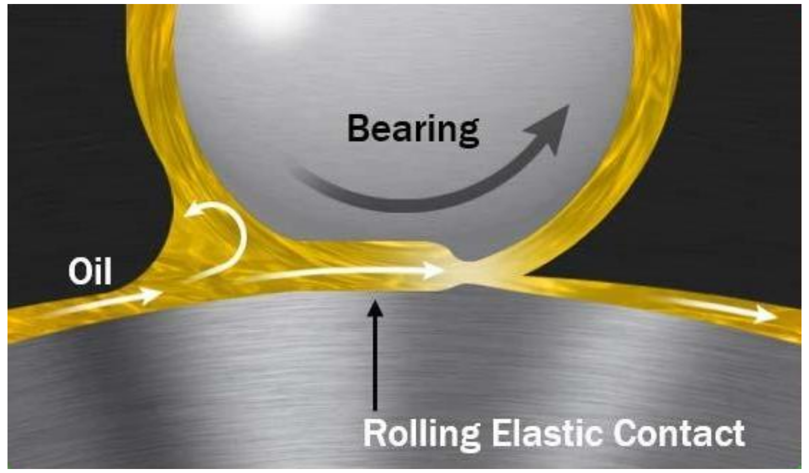


EHL SIMULATION: DYNAMIC VISCOSITY (Pa s)

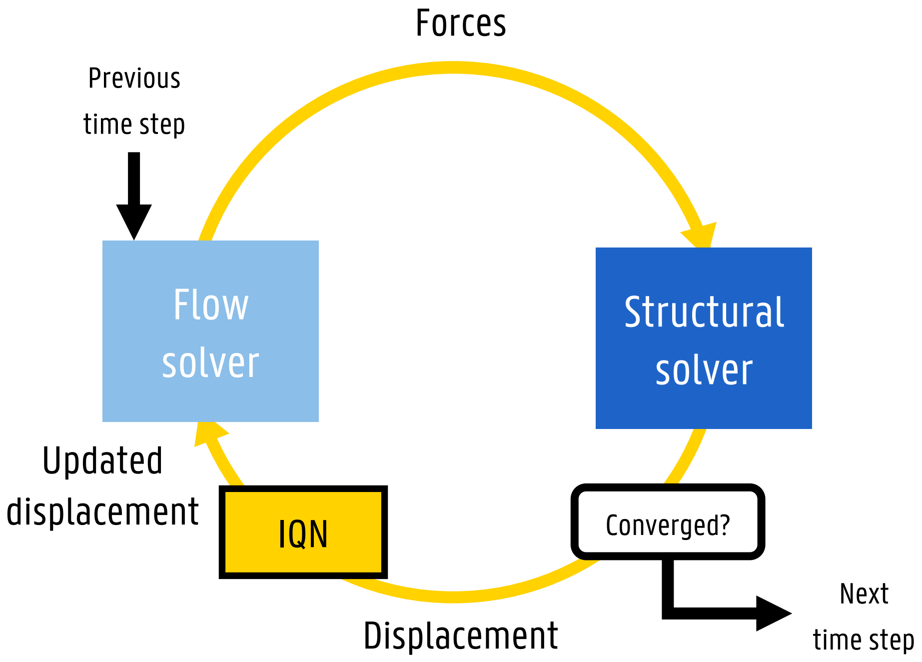


CONCLUSION

– Elastohydrodynamic lubrication:
  flattening of surfaces + increase of viscosity



– Partitioned FSI:
  reuse existing solvers



– Opensource high-fidelity solvers

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