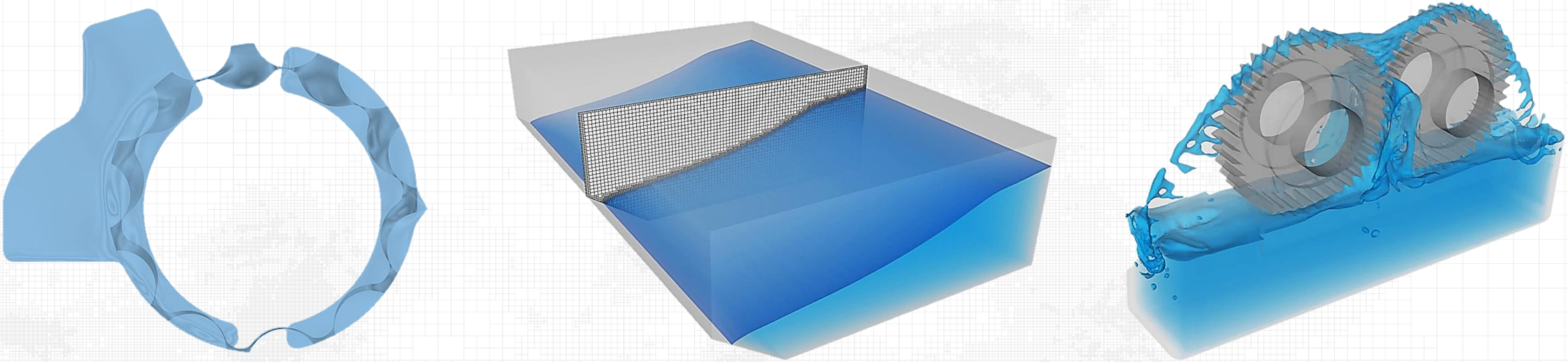

New Applications in Multi-phase Flow Modeling with CONVERGE: Gerotor Pumps, Fuel Tank Sloshing, and Gear Churning

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CONVERGE EUROPEAN USER CONFERENCE

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BOLOGNA, ITALY

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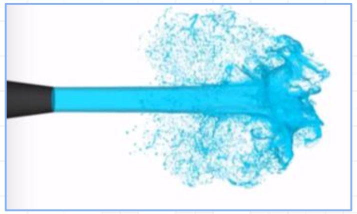
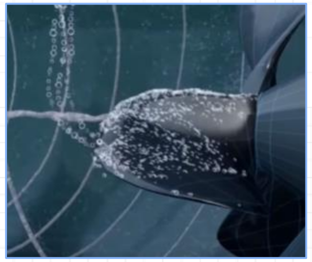
Outline

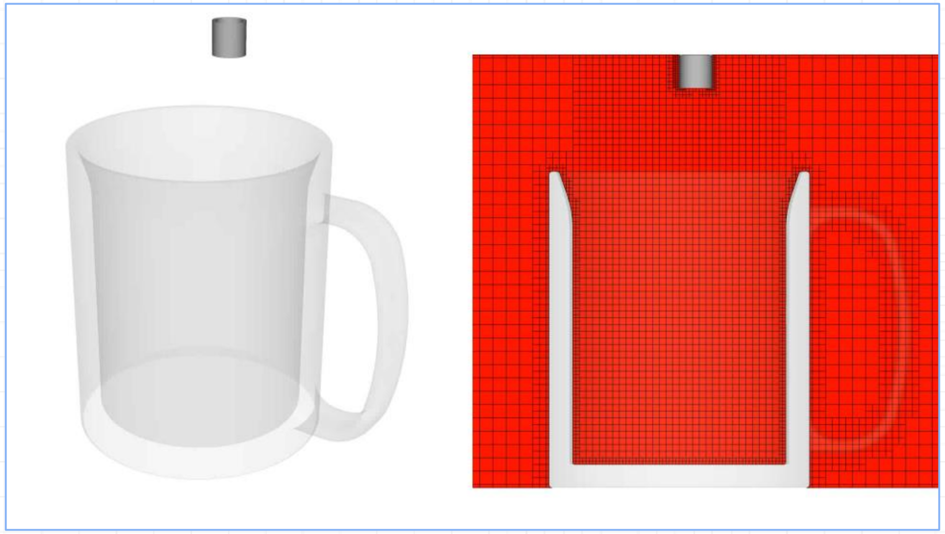
- Multiphase flow modeling in CONVERGE
- Case Study #1: Gerotor Oil Pump with Pressure-Relief Valve
- Case Study #2: Fuel Tank Sloshing
- Case Study #3: Gearbox Power Losses
- Conclusions and future work

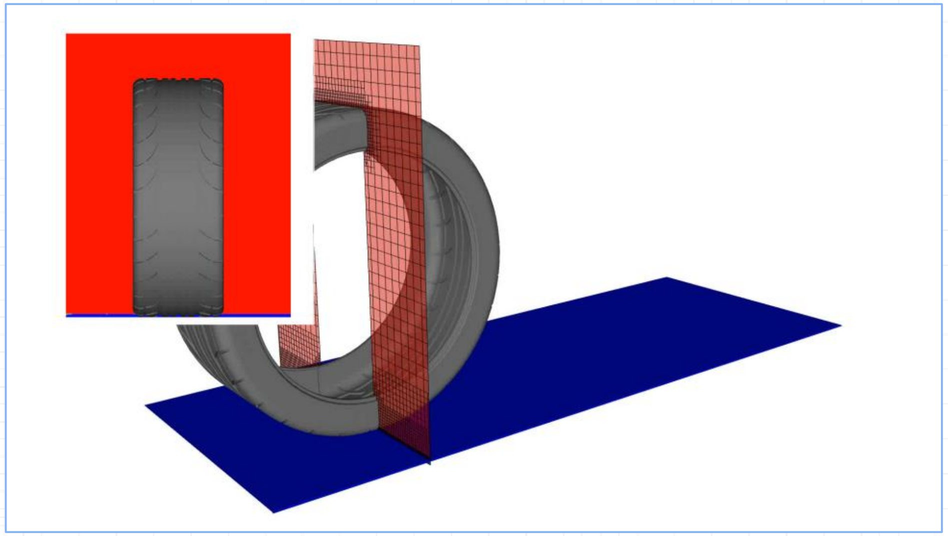
Multi-phase Flow Problems

- Many important engineering problems involve multi-phase flows:
  - Sprays: IC engines, gas turbines, burners, boilers, and furnaces
  - Phase change: evaporation, cavitation, condensation
  - Free surface flows: Environmental flows, marine applications, industrial mixing, chemical processing
- Multi-phase flows can be very challenging to model numerically, primarily due to the immense density differences that exist between the phases



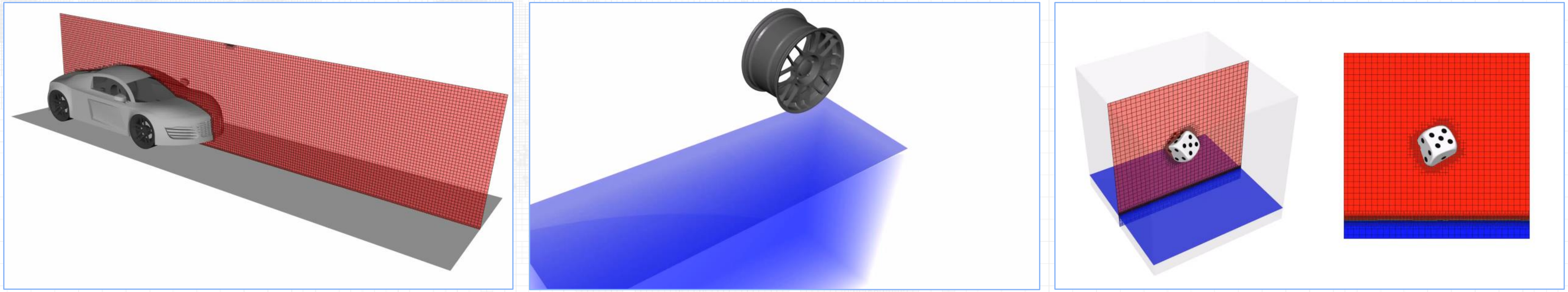




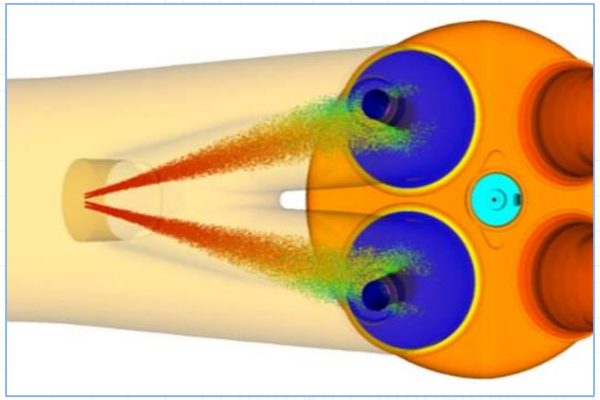


Multi-phase Flow Problems

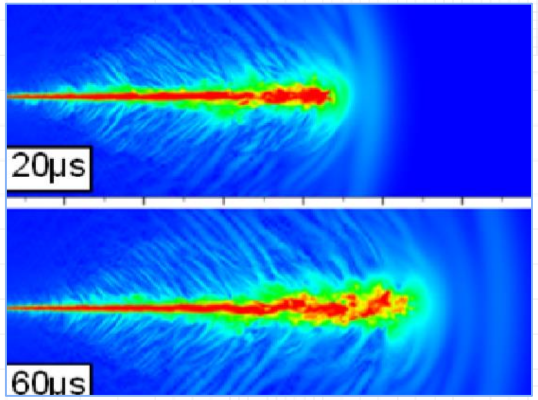
- Why CONVERGE™ for multi-phase flow problems?
  - Complex geometry, meshing, motion: no problem
  - Low numerical diffusion, high accuracy in surface tracking
  - Fast compressible and incompressible transient solvers
  - Variety of modeling techniques (Lagrangian, Eulerian: HRIC/PLIC)
  - Use of AMR to efficiently concentrate cells along interfaces



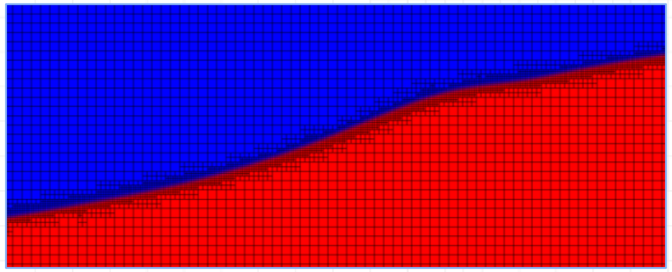
Multi-phase Flow Modeling in CONVERGE



- Three basic approaches for modeling multi-phase flows in CONVERGE
  - Lagrangian models: introduce parcels to represent droplets of liquid, statistically represent spray field
  - Eulerian models:
    - Species-based: solve transport equations for each species, compute void fraction field and interface
    - Interface tracking: solve for the interface, reconstruct species fields from interface location



- This presentation will feature three studies utilizing the Eulerian multi-phase models



Modeling a Gerotor Pump with a Pressure-Relief Valve

- Gerotor pumps are commonly used for pumping oil in automotive lubrication systems
- Inner rotor has *n* lobes, outer rotor has *n+1* lobes
- Co-rotation produces expanding pockets during suction, compressing pockets to high pressure delivery side

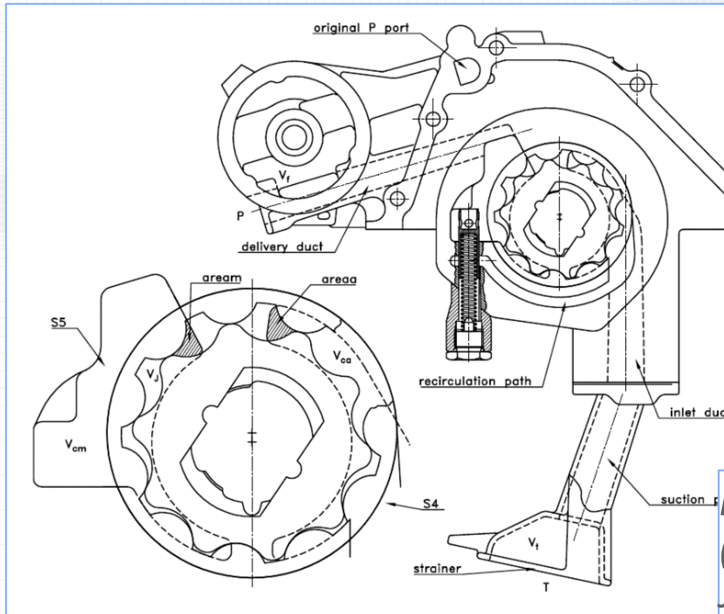


Figure 25: The complete system

- Pressure-relief valve (PRV) can open the high-pressure delivery side to the low-pressure suction side to ensure pressure at delivery is not too high

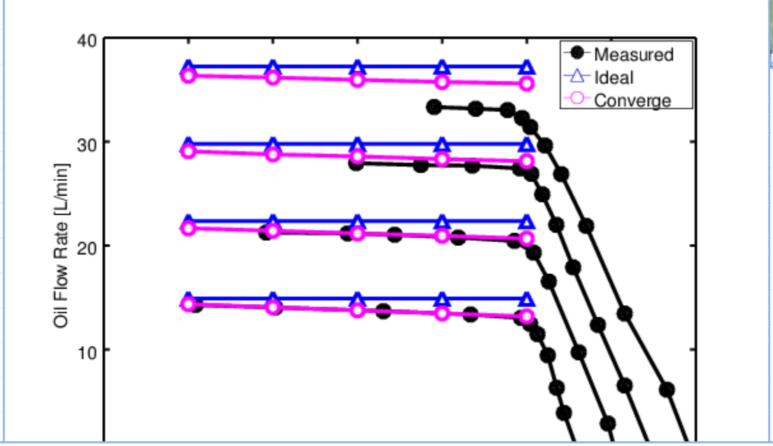
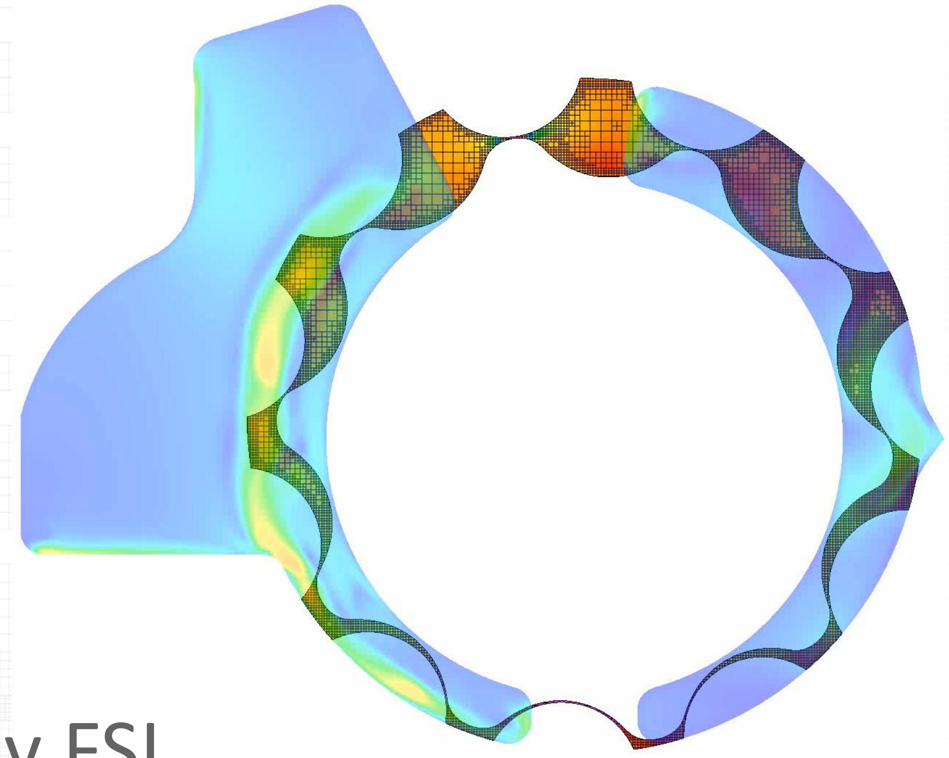


Diagram and image from: Rundo, Massimo & Fabiani, Marco & Mancò, Salvatore & Nervegna, Nicola. (1999). Modelling and Simulation of Gerotor Gearing in Lubricating Oil Pumps. SAE Transaction - Journal of Engines. 108. 989-1003. 10.4271/1999-01-0626.

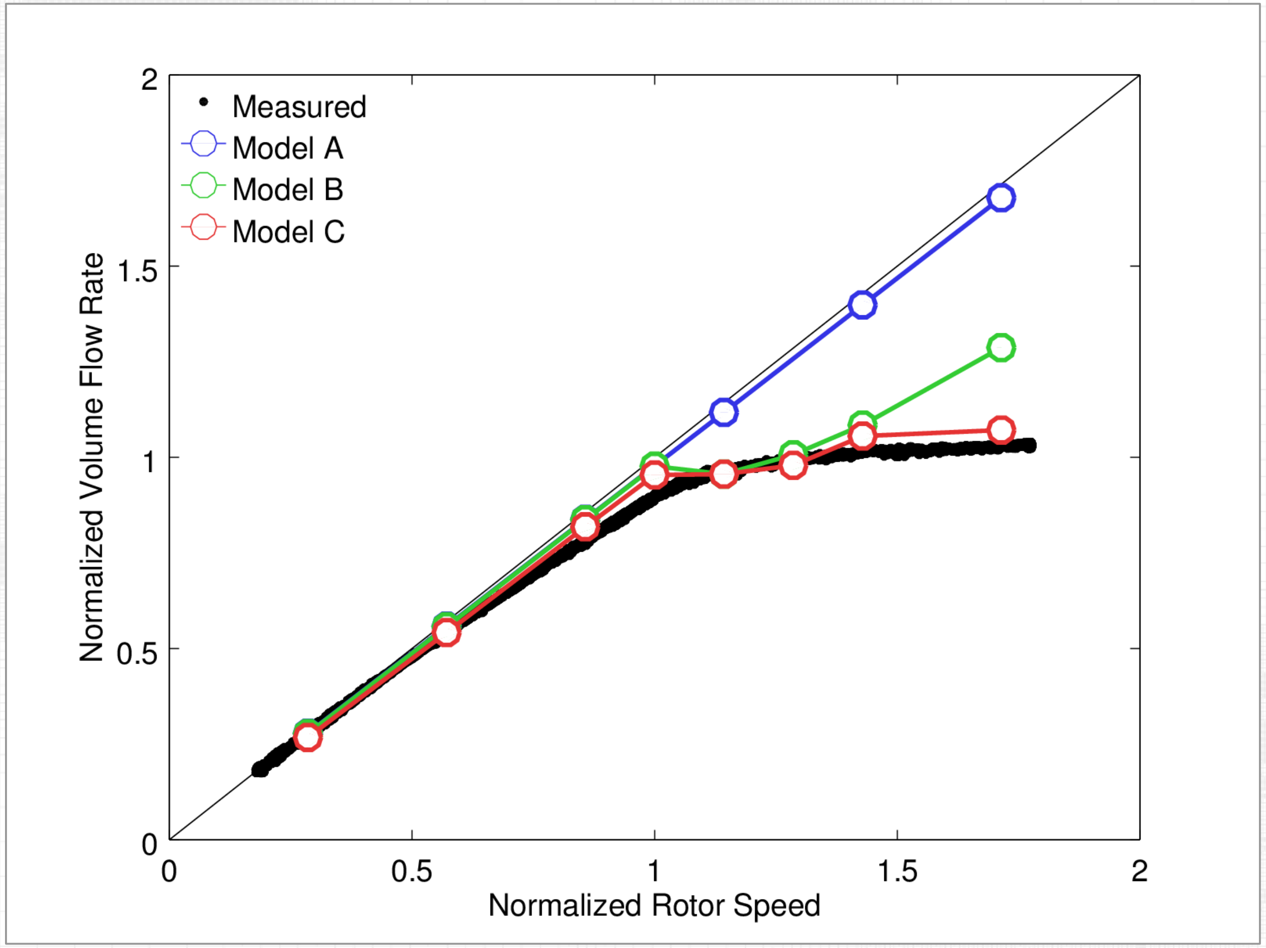
Modeling a Gerotor Pump with a Pressure-Relief Valve

CONVERGE case setup:

- Compressible fluid, SAE 10W-30
- Aeration of 0-10% by volume
- Cavitation through HRM
- Both full sealing and leakage of gaps
- Pressure relief valve through rigid body FSI



Modeling a Gerotor Pump with a Pressure-Relief Valve: Results



The main objective of the model is to predict the flow rate as a function of the gerotor speed. To the left is plotted the measured flow rate (black) compared to the modeled flow rate for three models:

Model A: Port-only setup (no PRV)

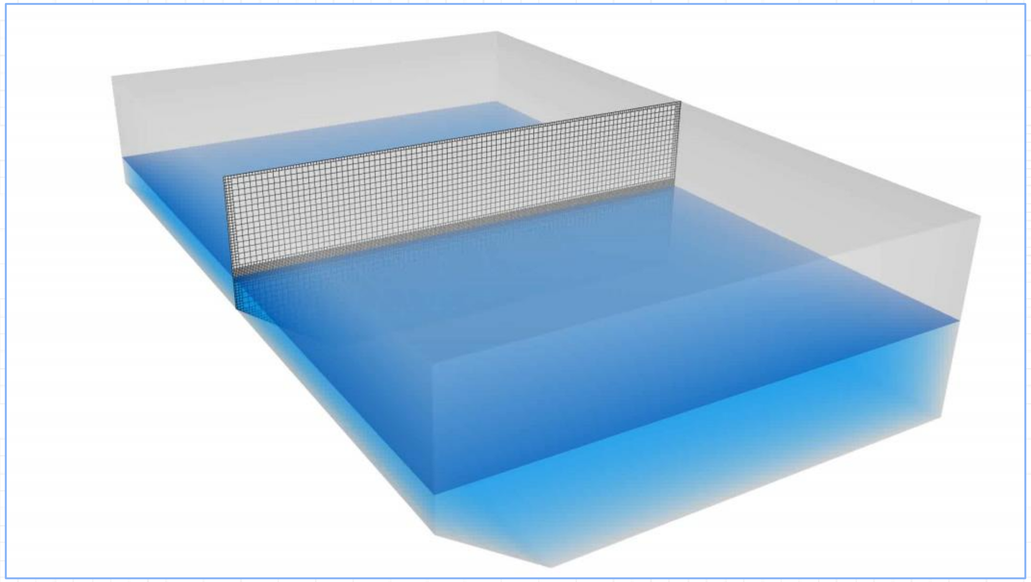
Model B: Basic PRV setup

Model C: PRV, leakage, 5% aeration, cavitation

Measured data and test case geometry supplied courtesy of: Mercury Marine, Fond du Lac, Wisconsin, USA (*www.mercurymarine.com*)

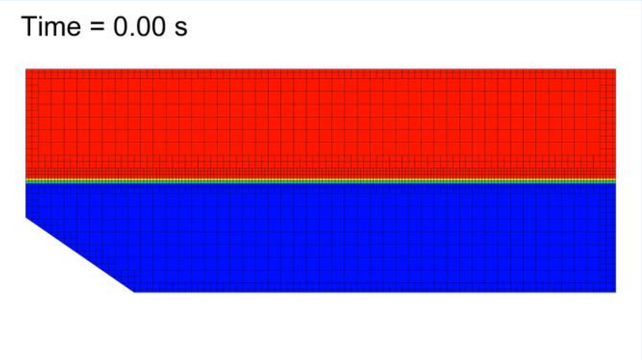
Modeling Fuel Tank Sloshing

- Liquid-carrying tanks (automotive, aerospace, transport, energy industries) can be subject to large structural loads caused by sloshing of the fluid
- Sloshing is typically induced by acceleration, cornering, braking
- Causes high impact pressures on walls
- Affected by tank geometry, motion, and liquid properties

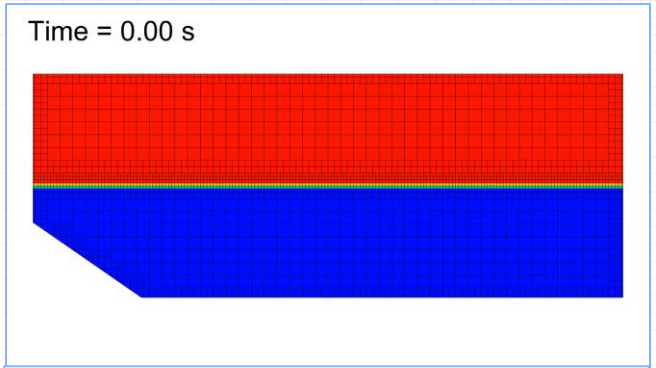


Modeling Fuel Tank Sloshing

- Two approaches for incorporating tank movement:
  - Moving geometry, inertial reference frame
  - Reference frame moving with tank, additional force term
- Both multi-phase models are evaluated:
  - PLIC, incompressible liquid and gas
  - HRIC, incompressible liquid, compressible gas
- Configurations studied:
  - No baffles: 25%, 50%, 60% fill levels
  - 0, 1, and 2 baffles



Moving geometry, inertial frame

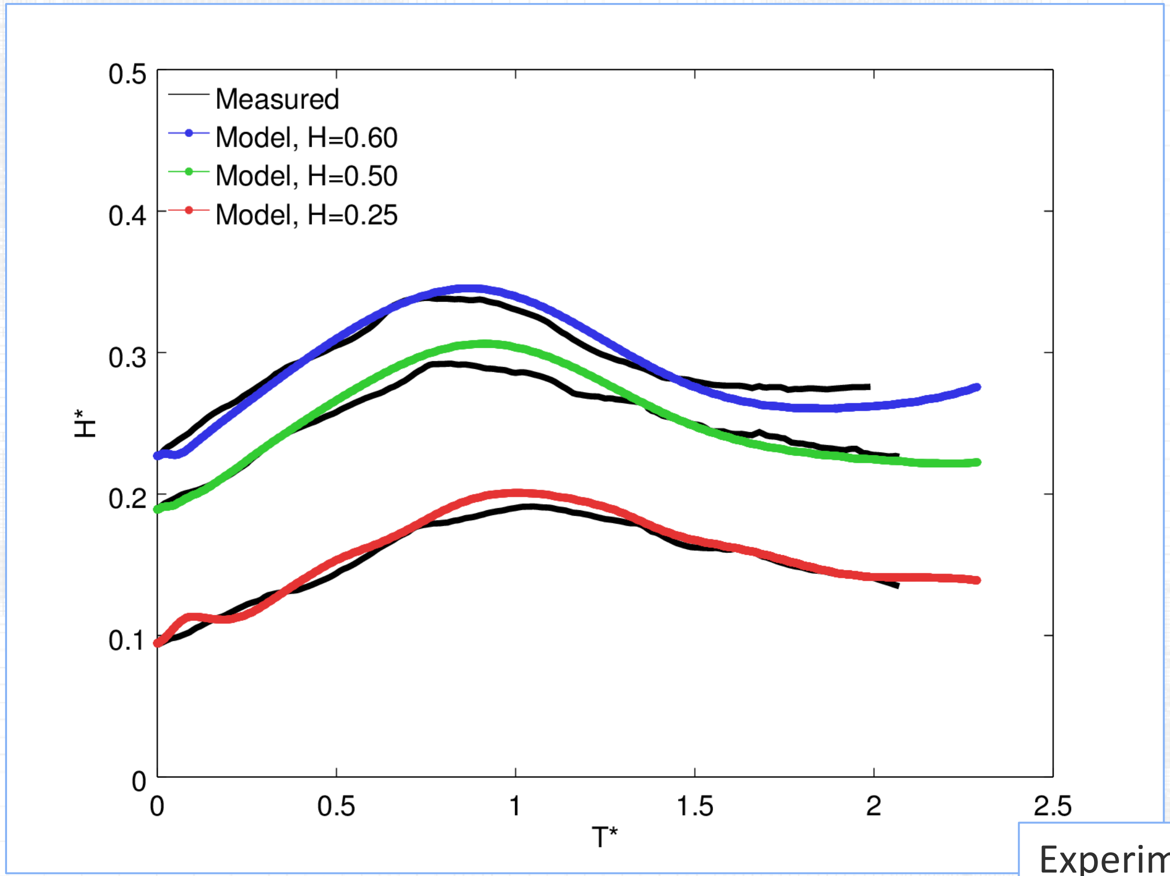


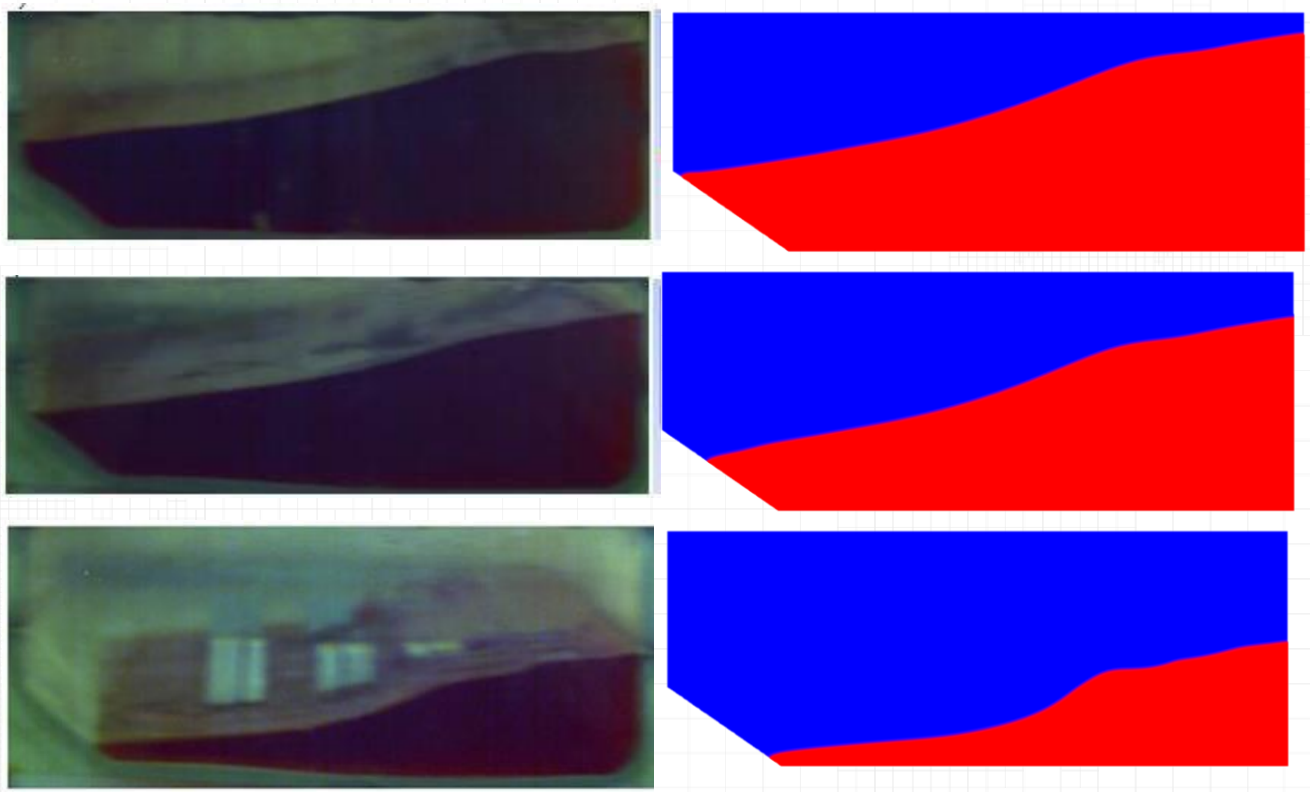
Frame moving with tank

Geometry and experimental measurements based on: Rajamani, R & Guru, V.M. & Prakasan, K. (2016). A Study of Liquid Sloshing in an Automotive Fuel Tank under Uniform Acceleration. Engineering Journal. 20. 71-85. 10.4186/ej.2016.20.1.71.

Modeling Fuel Tank Sloshing

- Results compared to experiment for different levels: 25%, 50%, 60%

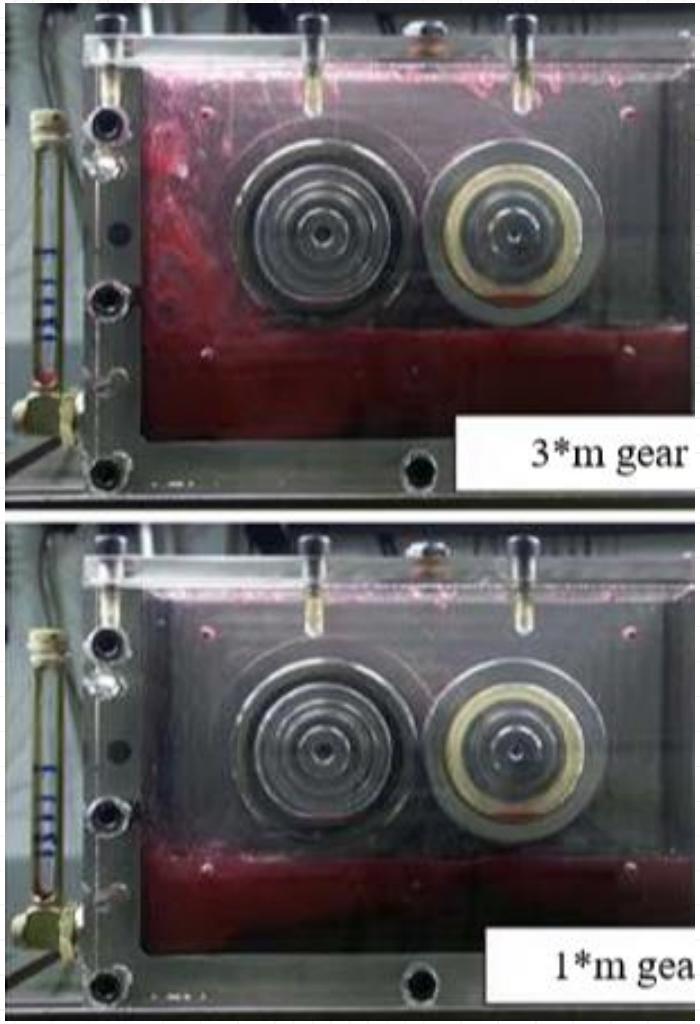




Experimental images and measurements from: Rajamani, R & Guru, V.M. & Prakasan, K. (2016). A Study of Liquid Sloshing in an Automotive Fuel Tank under Uniform Acceleration. Engineering Journal. 20. 71-85. 10.4186/ej.2016.20.1.71.

Modeling Power Losses in a Dip Lubricated Gearbox

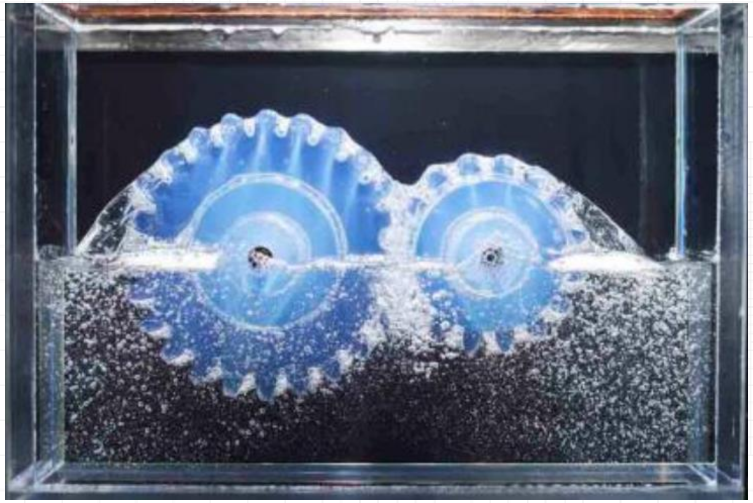
- Gearboxes common in power transfer / synchronization: vehicle transmissions, compressors, pumps, turbines
- Gearbox power losses:
  - Load dependent: Intergear rolling/sliding friction
  - Load independent (spin): Windage, churning, pocketing/squeezing, bearing friction
- Methods of lubrication: jet (higher speed), dip (lower speed)



Images from: Otto, H.-P. (2009), "Flank load carrying capacity and power loss reduction by minimised lubrication", Thesis, TU Munchen, Munchen.

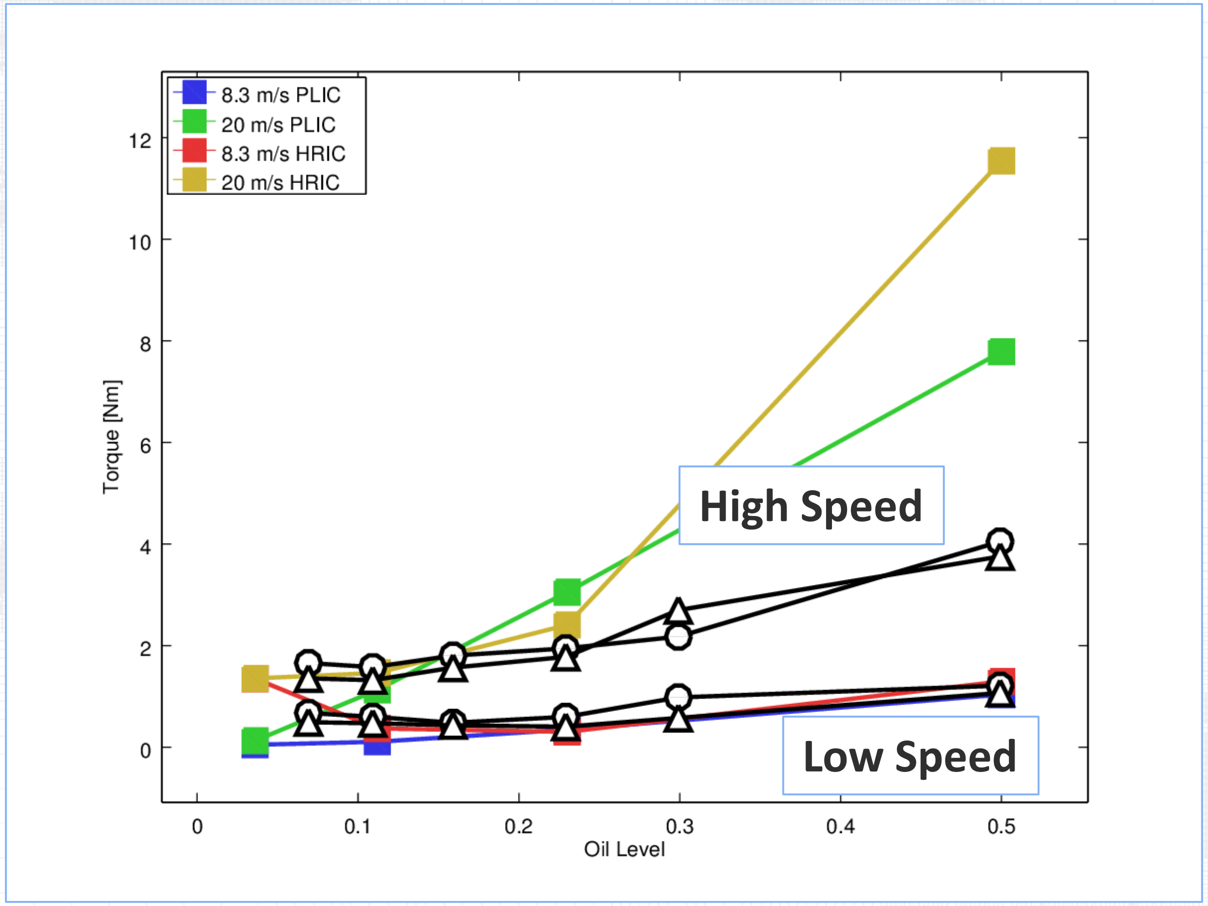
Modeling Power Losses in a Dip Lubricated Gearbox

- Grid generation strategies:
  - Sliding mesh, keyframe remeshing, overset mesh
    - User setup time, mass conservation, numerical diffusion
  - CONVERGE™ cut-cell based meshing
    - Easy set up, allows conservation, low numerical diffusion
- Two experimental studies of dip lubricated gear pairs in various levels of oil
  - Technical University of Munich (TUM)
  - Ohio State University (OSU)



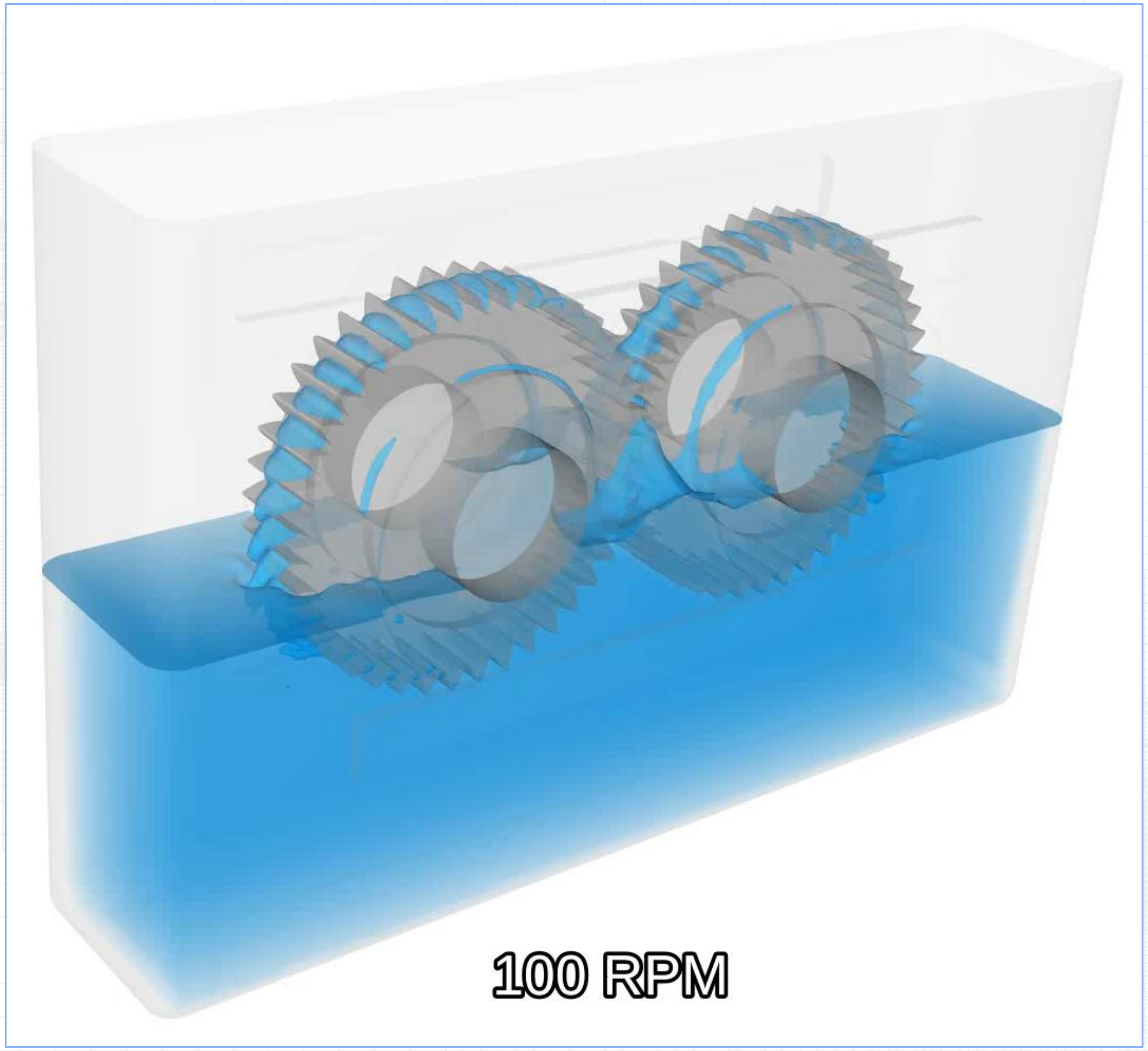
Images from: (2) Andersson, M. "Churning losses and efficiency in gearboxes", Thesis, Department of Machine Design KTH Royal Institute of Technology S-100 44 Stockholm Sweden. (3) Seetharaman, S. "An investigation of load-independent power losses of gear systems", Thesis, Ohio State University, Columbus, Ohio, USA.

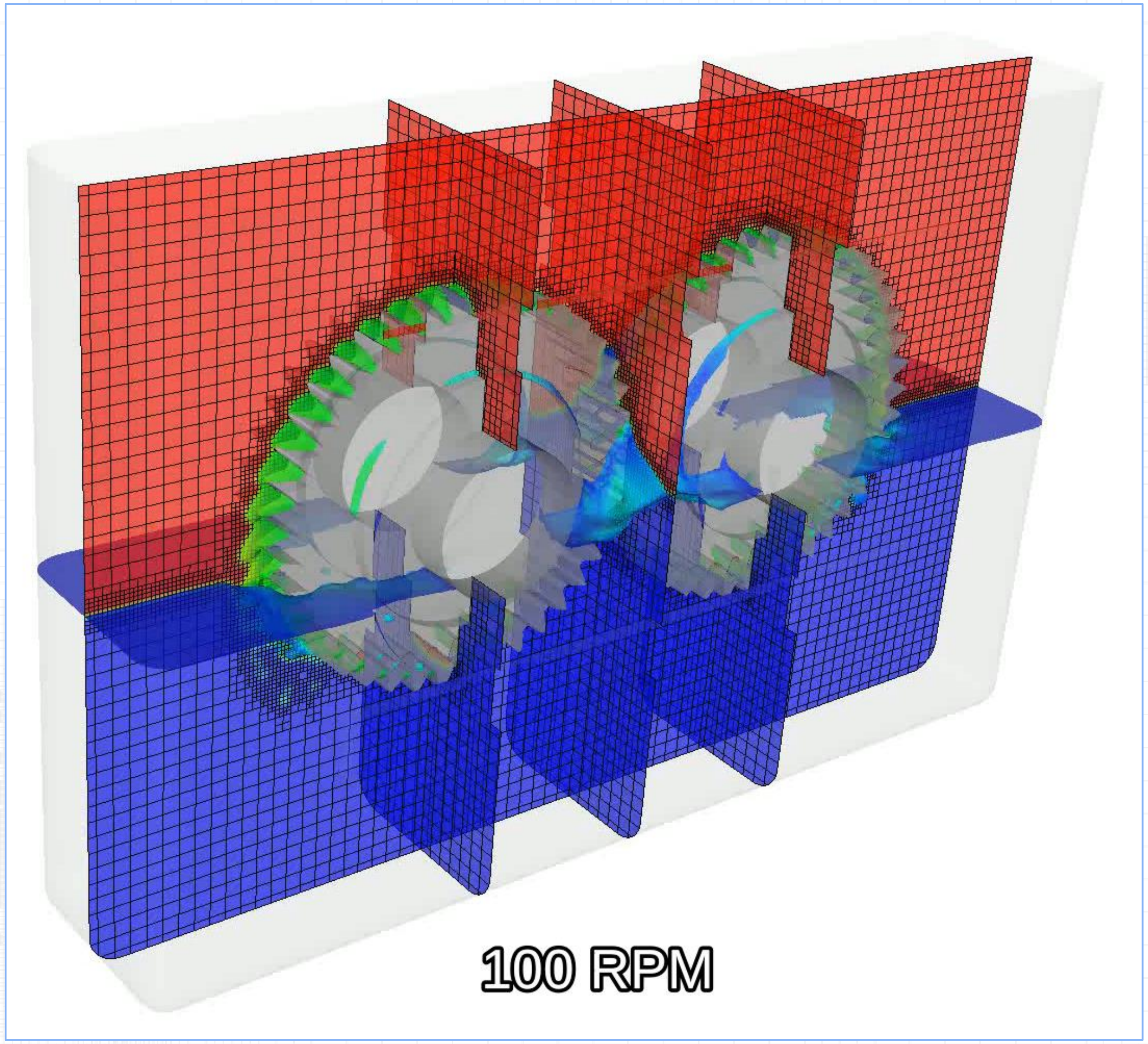
Modeling Power Losses in a Dip Lubricated Gearbox



- Model results are compared to experimental measurements
- For low oil levels, in the oil-return regime, the model results for both PLIC and HRIC methods are acceptable
- At high speed and high oil levels, in the vortex regime, both approaches over-predict the torque

Modeling Power Losses in a Dip Lubricated Gearbox





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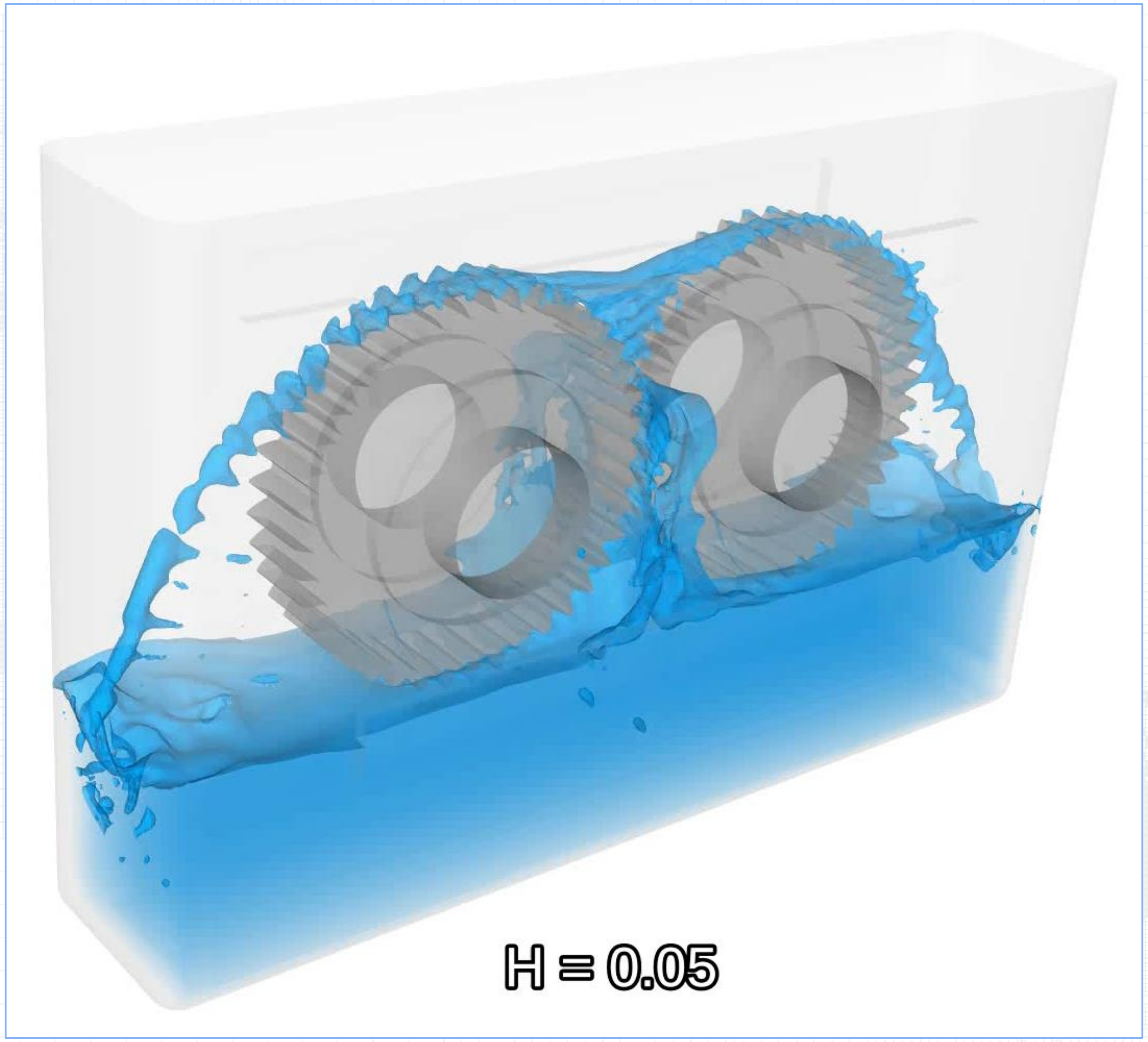
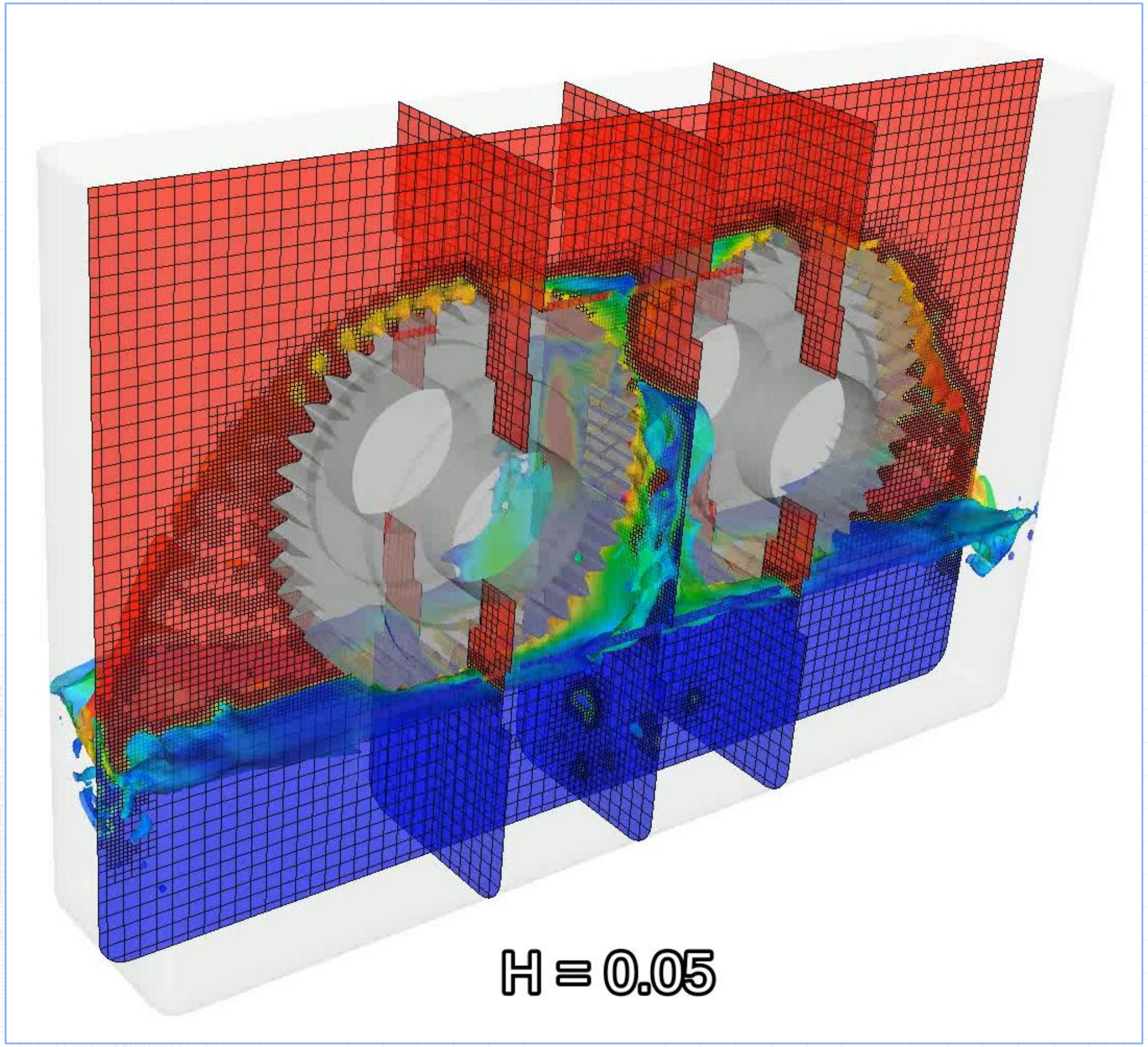
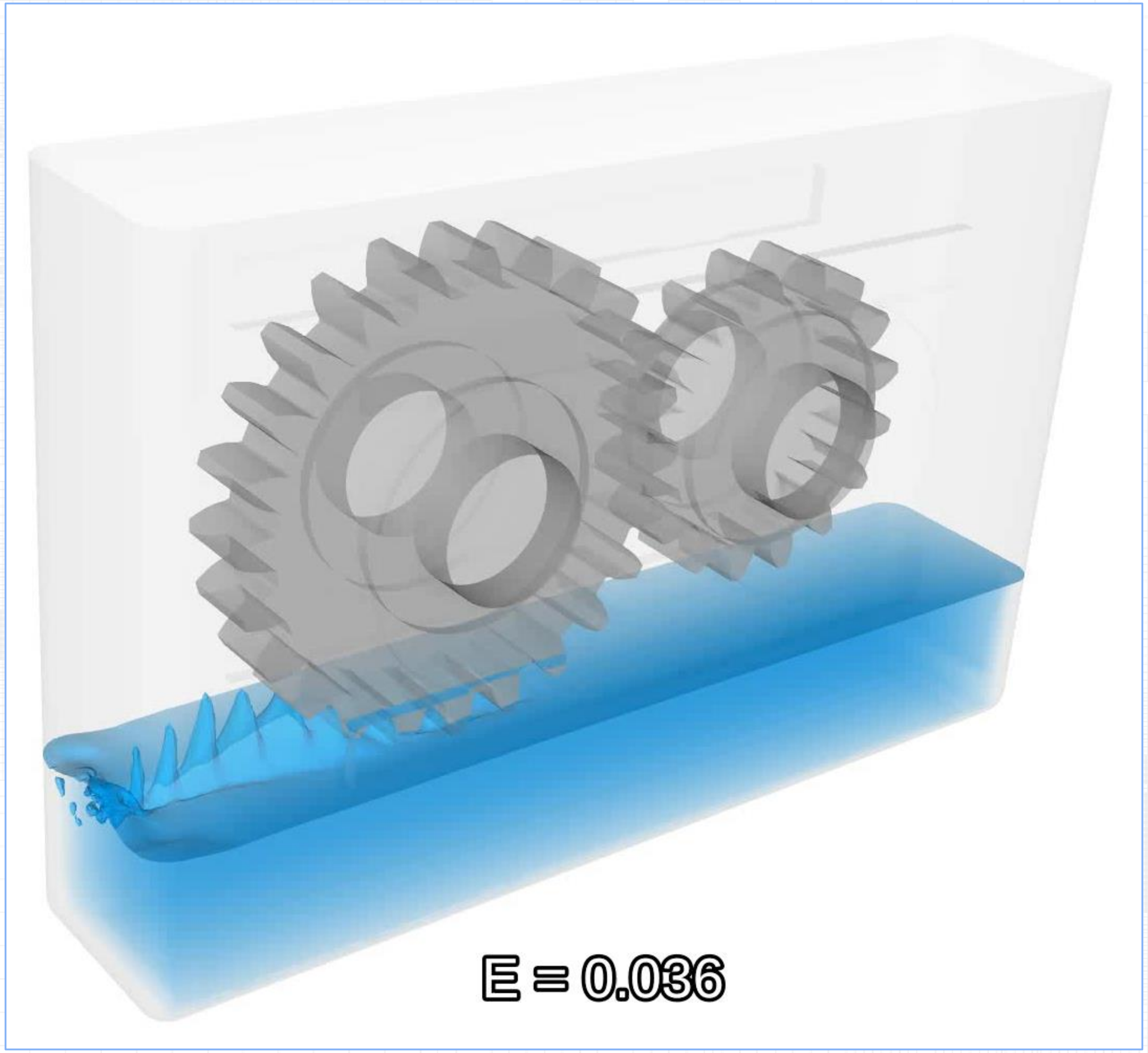
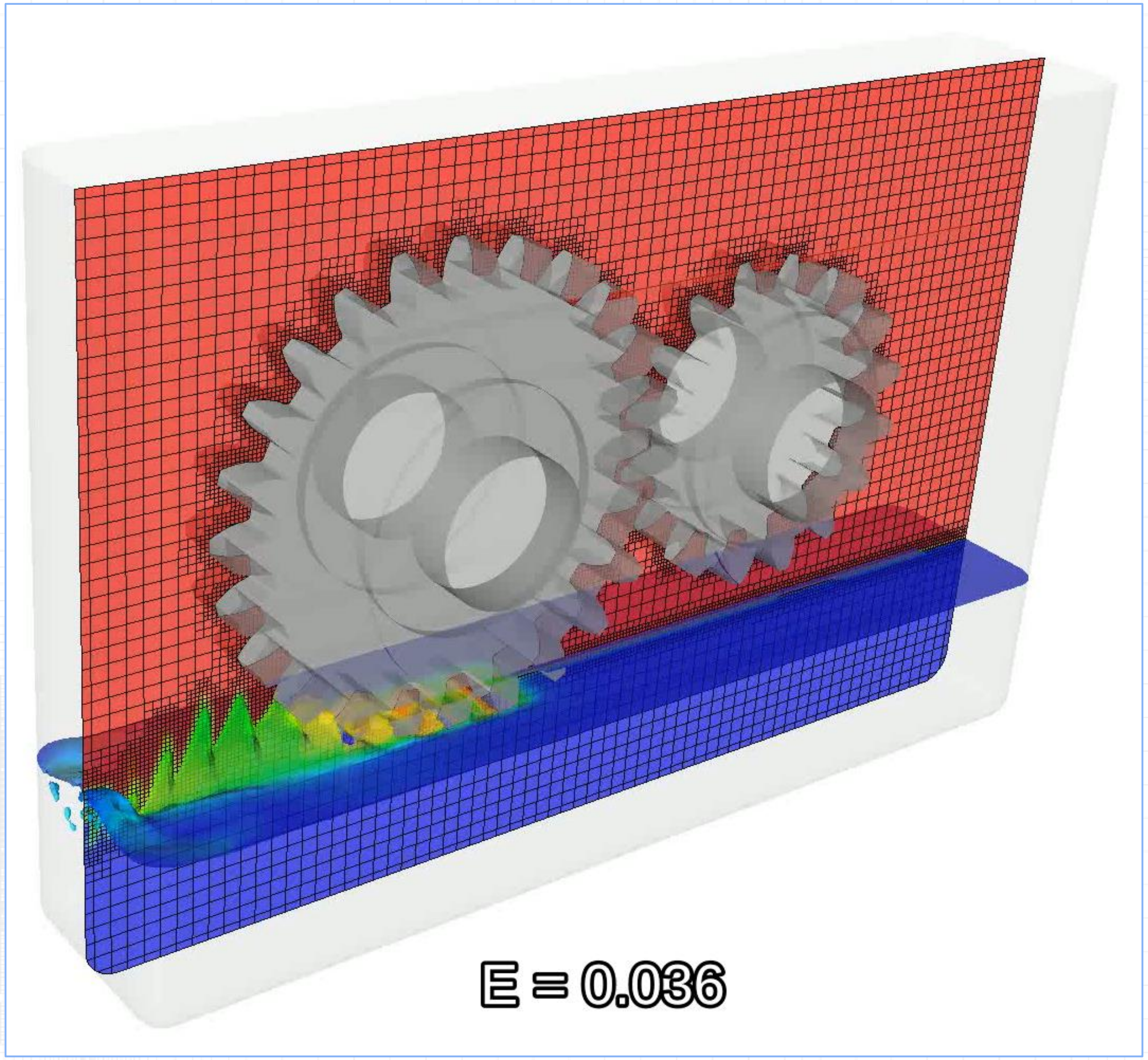




Modeling Power Losses in a Dip Lubricated Gearbox





Modeling Power Losses in a Dip Lubricated Gearbox

- Conclusions
  - Regime transition (oil-return to vortex) is observable in model results
  - For low oil levels, windage dominates -> compressible fluid model
  - For higher oil levels (or complete submersion) -> incompressible fluid model okay for low speeds / oil-return regime
  - For conditions in vortex regime, both models tend to over-predict losses
- Future work
  - Improvement of prediction accuracy in vortex regime
  - Validation for alternate gear and box arrangements
  - Validation on alternate lubrication types, e.g., jet-lubrication

Conclusions and Future Work

- CONVERGE™ is a great tool for modeling many different types of multi-phase flows. More work is needed in improving:
  - model accuracy at challenging operating conditions
  - solution stability for some sets of boundary conditions
  - run-time especially for flows with large time-scale disparities
  - validation tests in additional multi-phase application areas
  - further work with additional physics: heat transfer, structures, phase-change