NUMERICAL SIMULATION AS A TOOL FOR EV DEVELOPMENT

Multiphase SPH for powertrain applications

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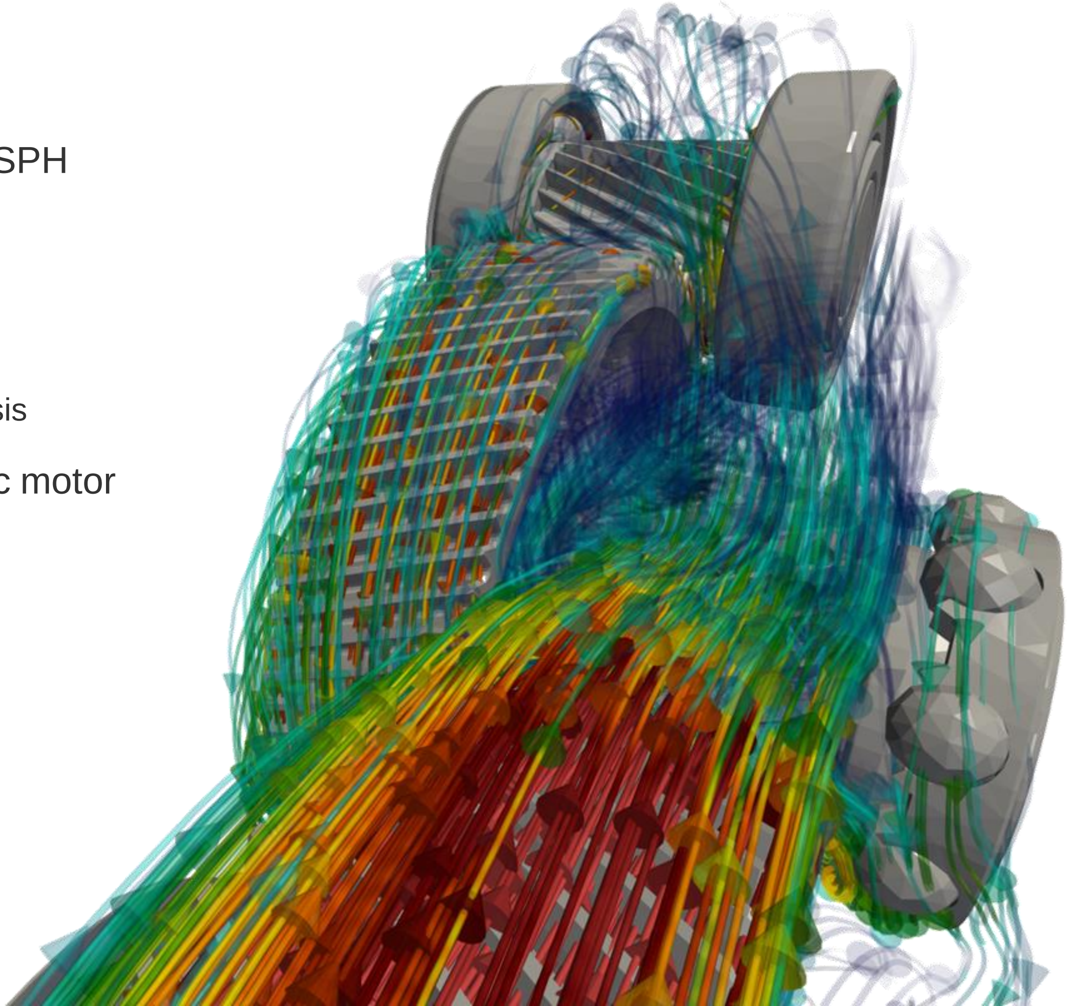
OUTLINE

1. Introduction to nanoFluidX & SPH
2. Oiling in an EV gearbox
   - Setup
   - Flow field analysis
   - Bearing supply and thermal analysis
3. Spray lubrication of an electric motor
   - Setup
   - Flow and thermal field analysis
4. Conclusions
5. Q & A



INTRODUCTION

ALTAIR AT A GLANCE

Founded 1985
Headquartered in Troy, MI US

71 office
in 24 countries

$396M
2018 Revenue

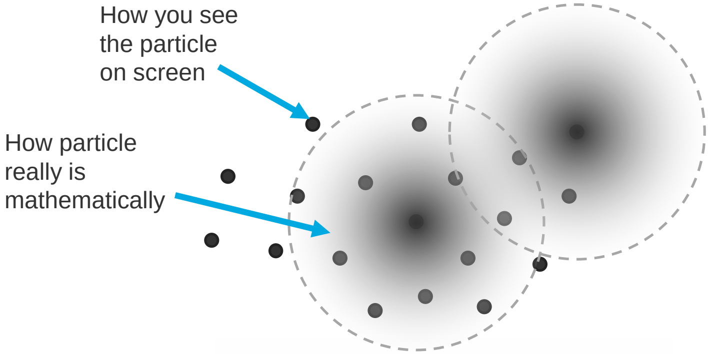
50+
ISV partners under our unique, patented licensing model

2000+
Engineers, scientists and creative thinkers

5000+
Customer installations globally

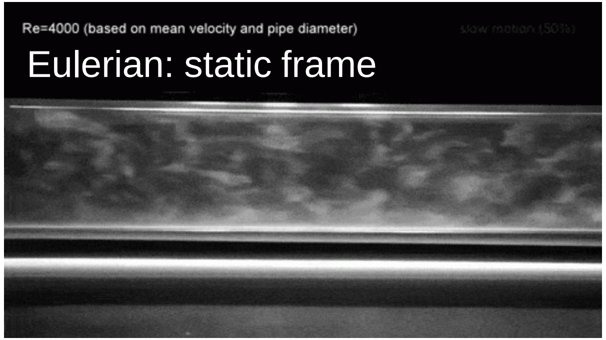
60,000+
Users

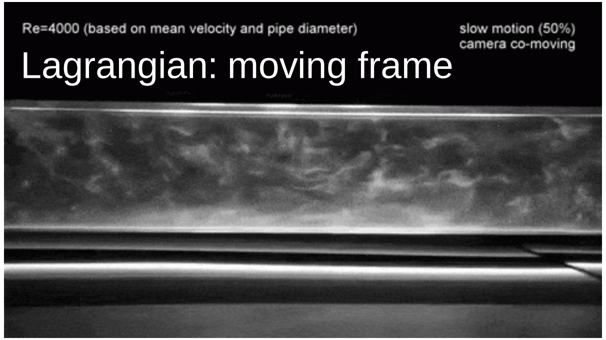
INTRODUCTION TO NANOFLUIDX

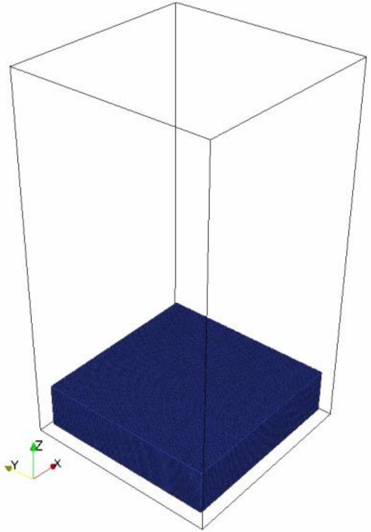


nanoFluidX is …

- based on the **S**moothed **P**article **H**ydrodynamics method (SPH).
- a **meshless** CFD solver (Lagrangian).
- **Navier-Stokes** equations.
- most powerful for **complex flows** in **arbitrary geometries**.
- **100% GPU** (Graphical Processing Unit) – therefore lightning fast.







Kuenen et al, 2015: http://dx.doi.org/10.1103/APS.DFD.2015.GFM.V0055#sthash.ZII8RphB.rHSVjkkI.dpuf

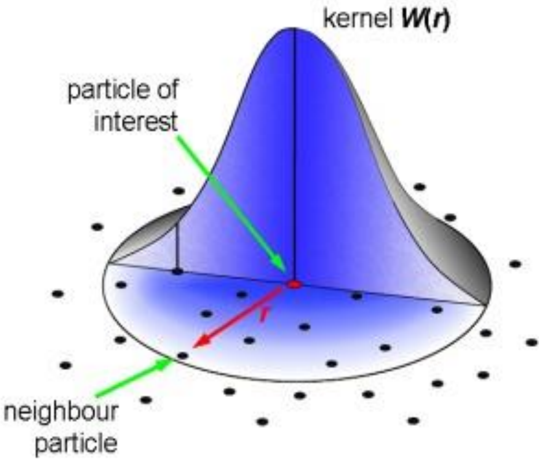
INTRODUCTION TO NANOFLUIDX

Although you see these particles as discrete, mathematically, they are a continuum (smooth).

- Every property of the owner particle can be expressed through the following volumetric integral:

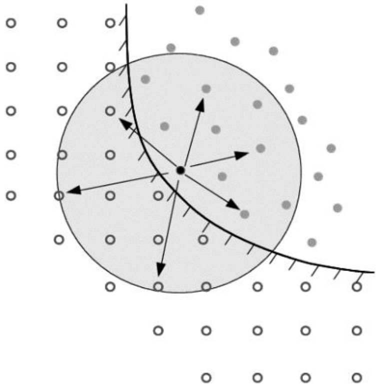
$$\underbrace{\bar{A}(\vec{r})}_{\substack{\text{Property}\\ \text{of the}\\ \text{owner}\\ \text{particle}}} = \int \underbrace{A(\vec{r}\,')}_{\substack{\text{Property}\\ \text{of the}\\ \text{neighbour}\\ \text{particles}}} \underbrace{W(\vec{r}-\vec{r}\,',h)}_{\substack{\text{Kernel}\\ \text{function}}}\mathbf{d}\vec{\mathbf{r}}' \approx \underbrace{\sum_b A(\overrightarrow{r_b})V_b W(\vec{r}-\overrightarrow{r_b},h)}$$

Discretized form of the integral.
Index b = number of the neighbour.



http://plaza.ufl.edu/jeffjtd/SitePics/kernelpic.jpg

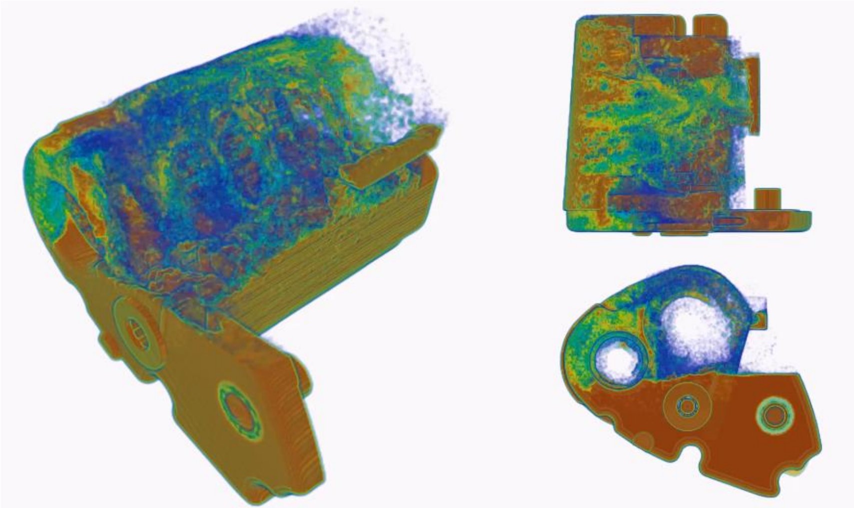
- We sum the influence of neighbouring particles.

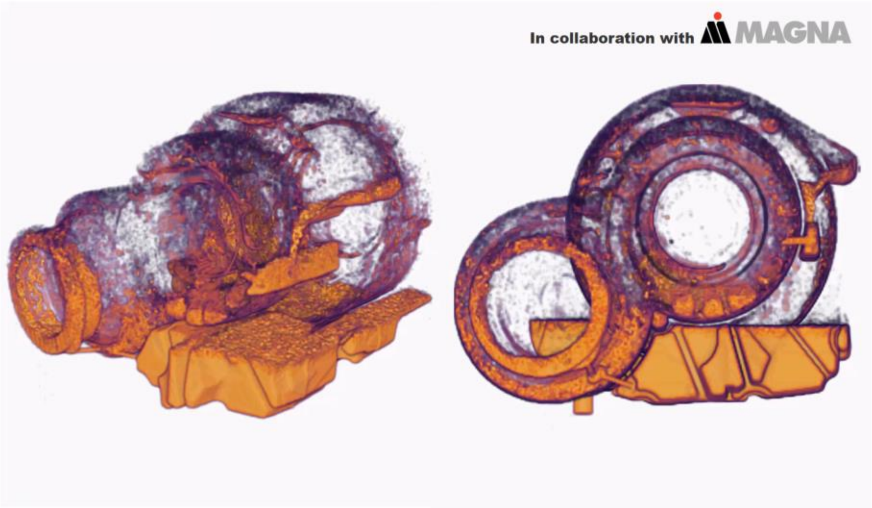


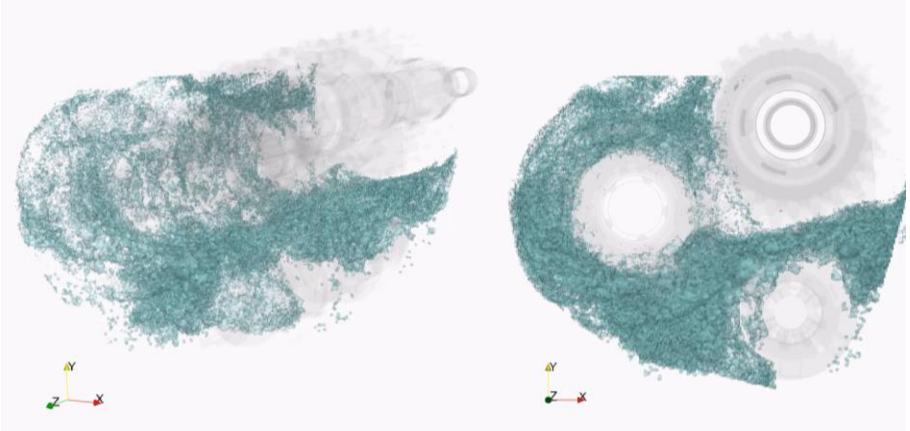
Wall Boundary Condition

- We use particle layers at the wall to give “full support”.
- This gives proper physical results, independent of the geometry.
- It is numerically elegant, and easy to parallelise, therefore very fast.

WORKFLOW - SIMULATION







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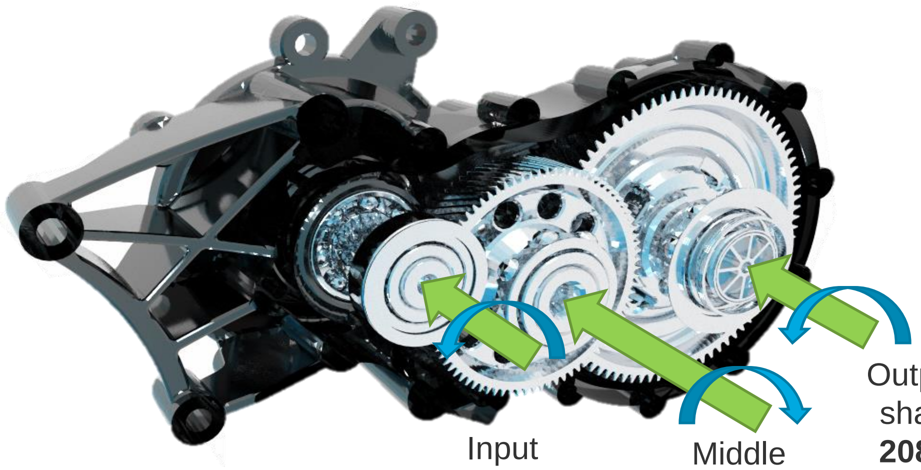
Electric Vehicle Gearbox

SIMULATION SETUP

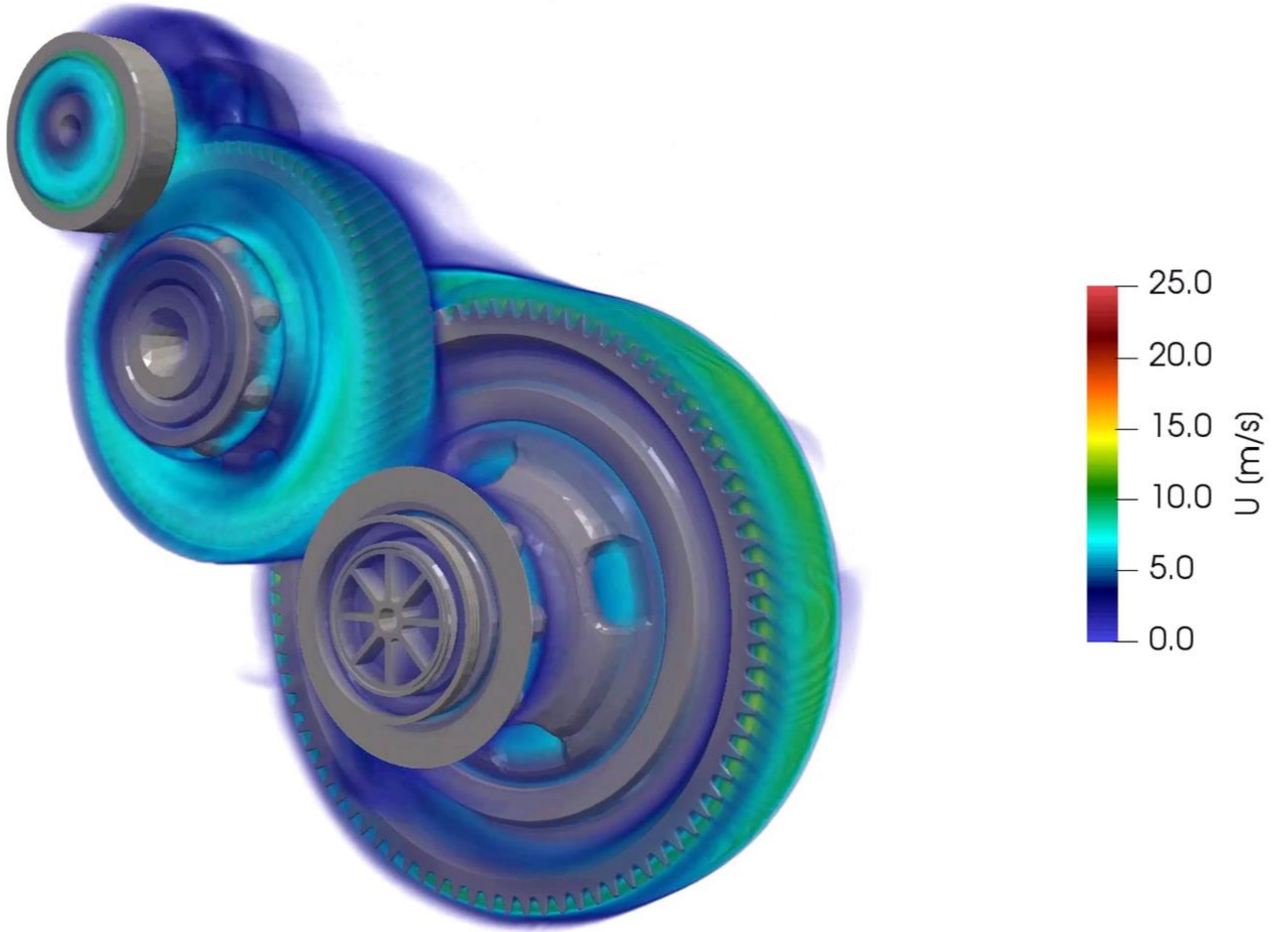


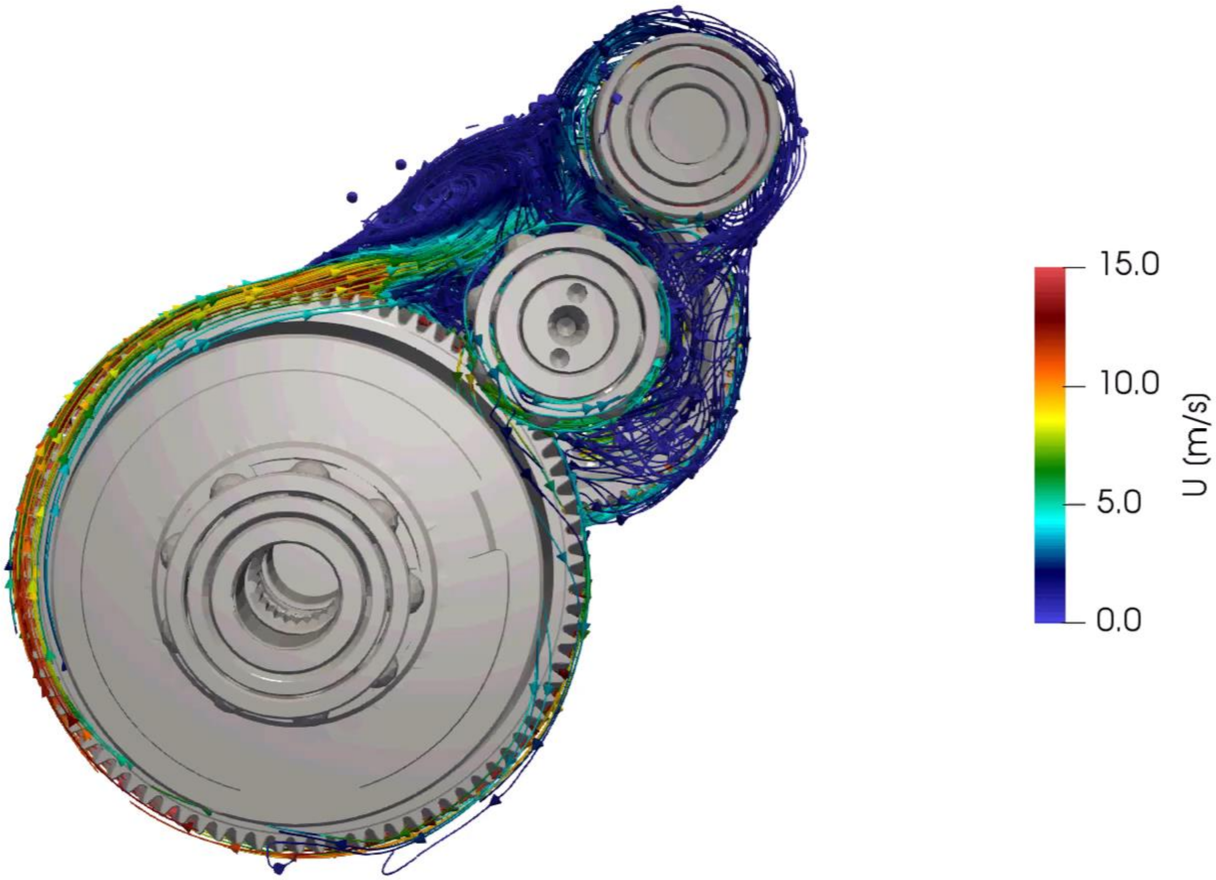
- Gearbox of an electric vehicle
- Multiphase
- Physical time: 2 s
- Resolution: 0.75 mm
- No. of particles: 11.8M
- Pre-processing: 1 h
- 8x NVIDIA Tesla V100: 2d

TIME AVERAGING

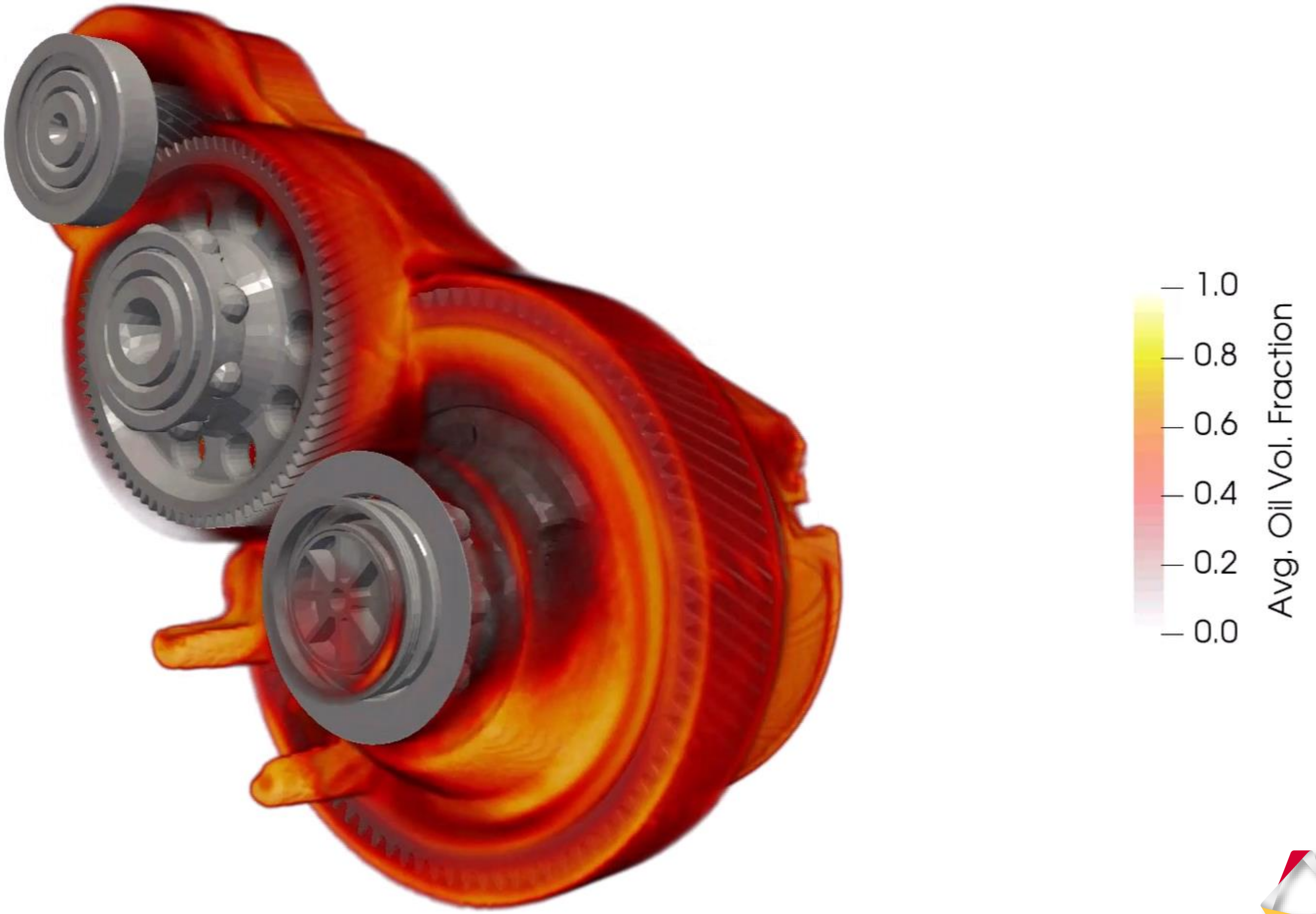
- Creating pretty rendered videos is great, but gives little engineering insight.
- We look for a quasi steady state (unsteady convergence) condition, and time average the flow field over that window.
- We time average the flow field → create a quasi-steady-state flow field.
- This provides more genuine flow insight answer the questions of **how does the flow behave on average.**

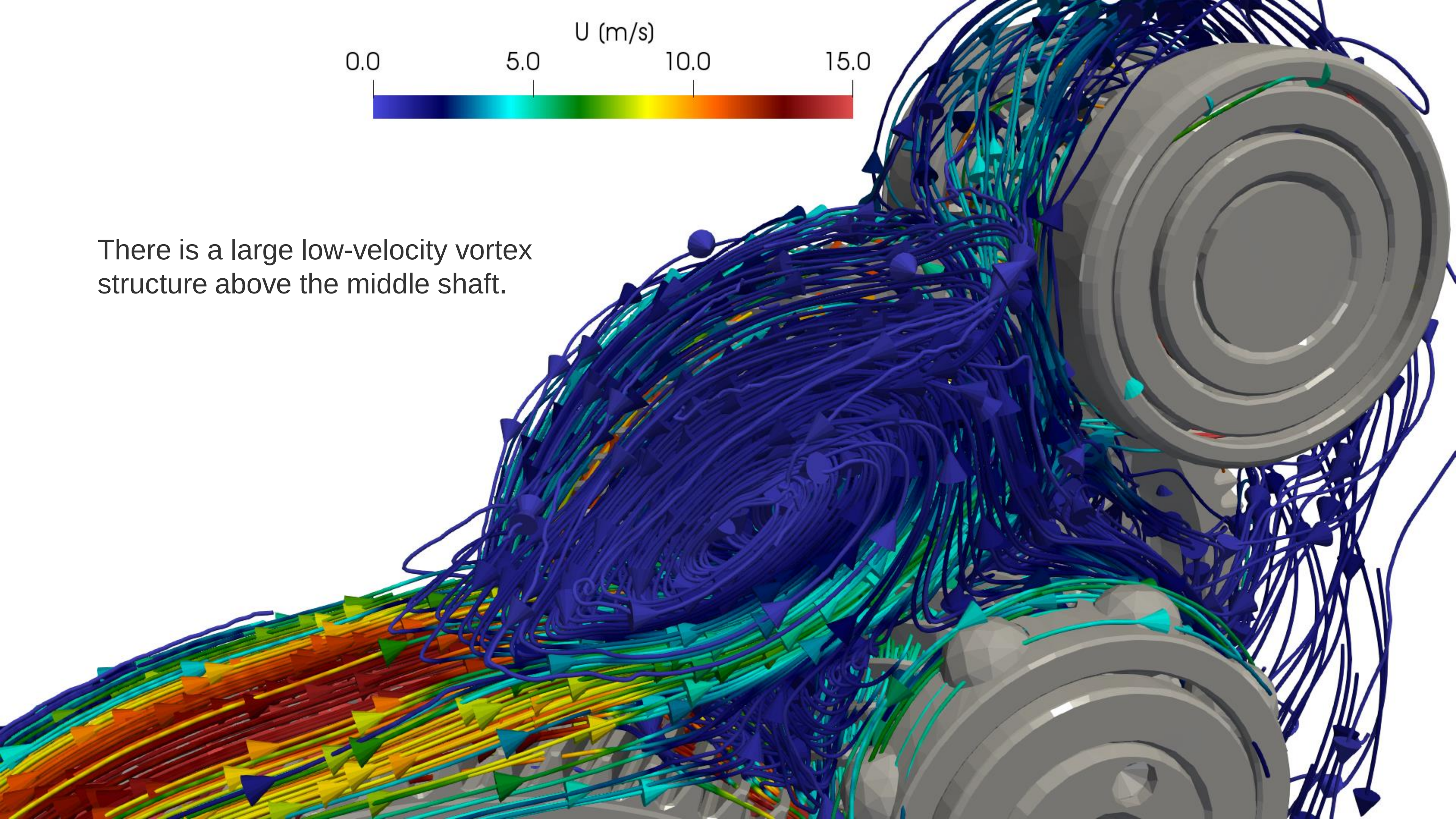
AVERAGE VELOCITY FIELD


25.0
20.0
15.0
10.0
5.0
0.0
U (m/s)

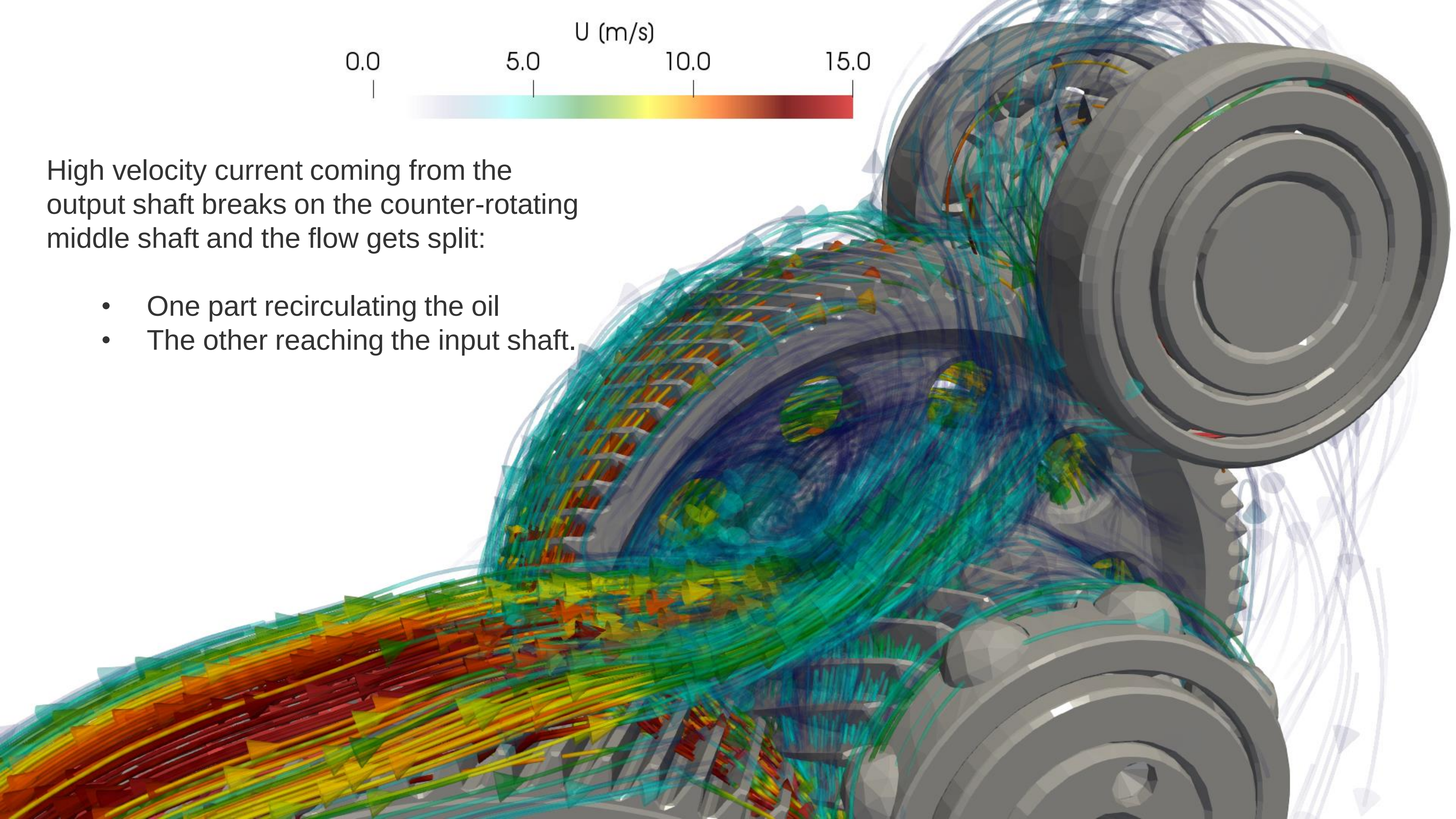

15.0
10.0
5.0
0.0
U (m/s)

AVERAGE OIL DISTRIBUTION


1.0
0.8
0.6
0.4
0.2
0.0
Avg. Oil Vol. Fraction

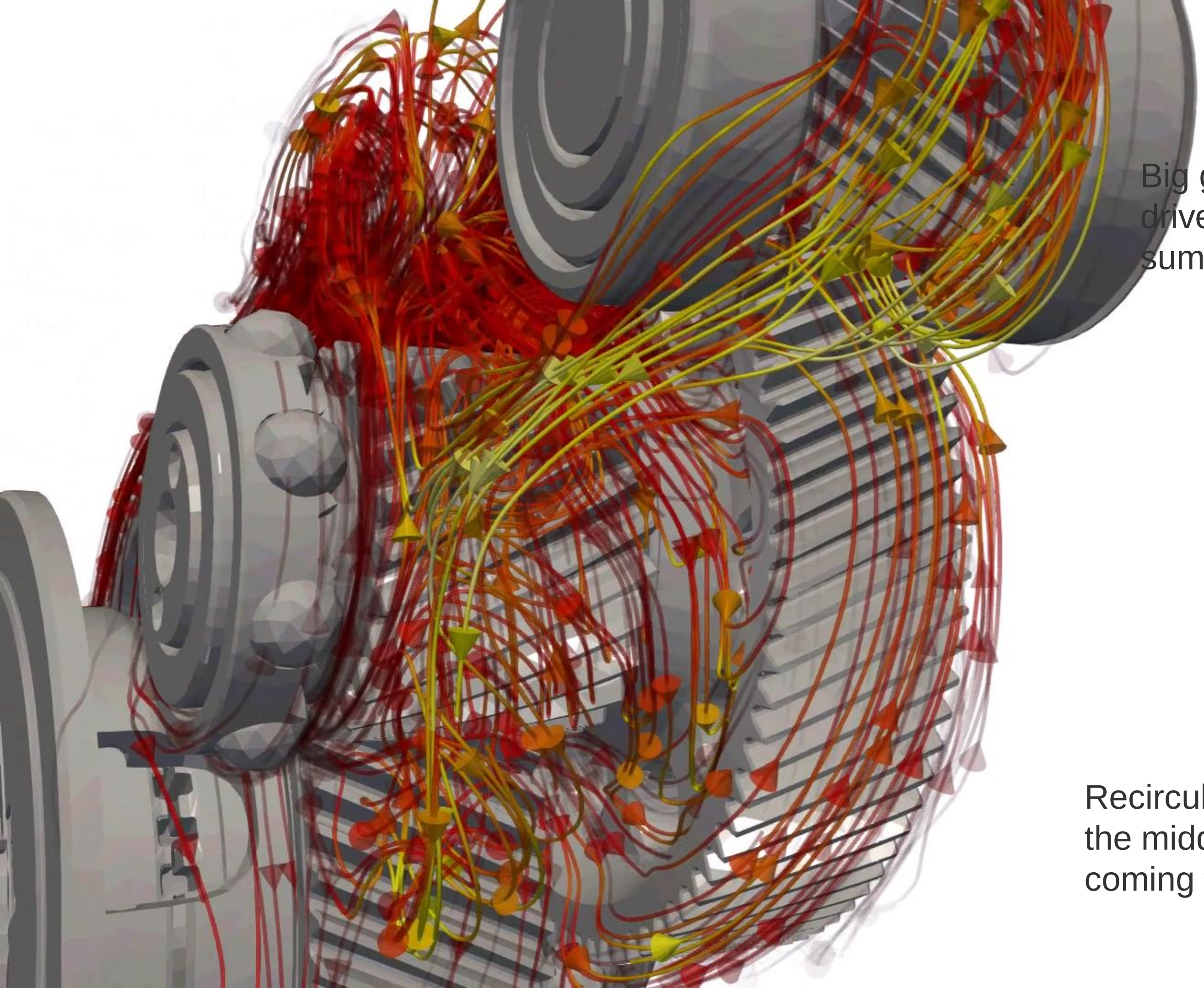


There is a large low-velocity vortex structure above the middle shaft.

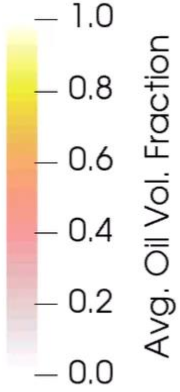


High velocity current coming from the output shaft breaks on the counter-rotating middle shaft and the flow gets split:

- One part recirculating the oil
- The other reaching the input shaft.

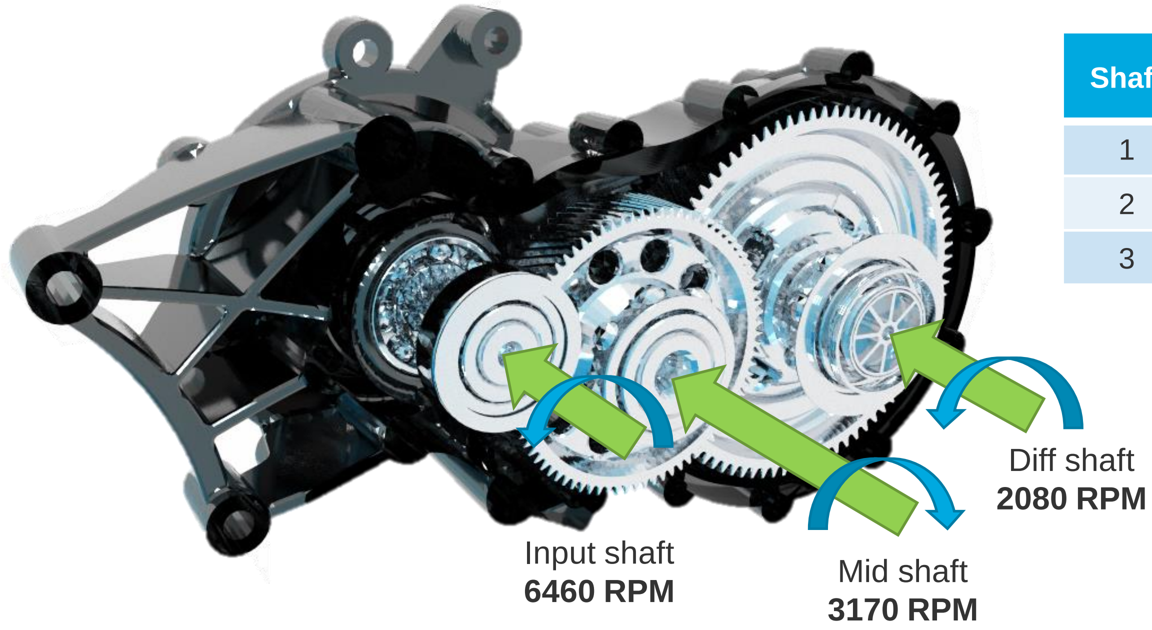


Big gear on the middle shaft drives the oil back into the main sump.



Recirculation zone formed below the middle shaft (supplied by oil coming from the input shaft)

CHURNING LOSSES



Shaft	RPM	Torque [Nm]	Power [kW]
1	2080	2.5	0.54
2	3170	0.43	0.1
3	6460	0.13	0.09

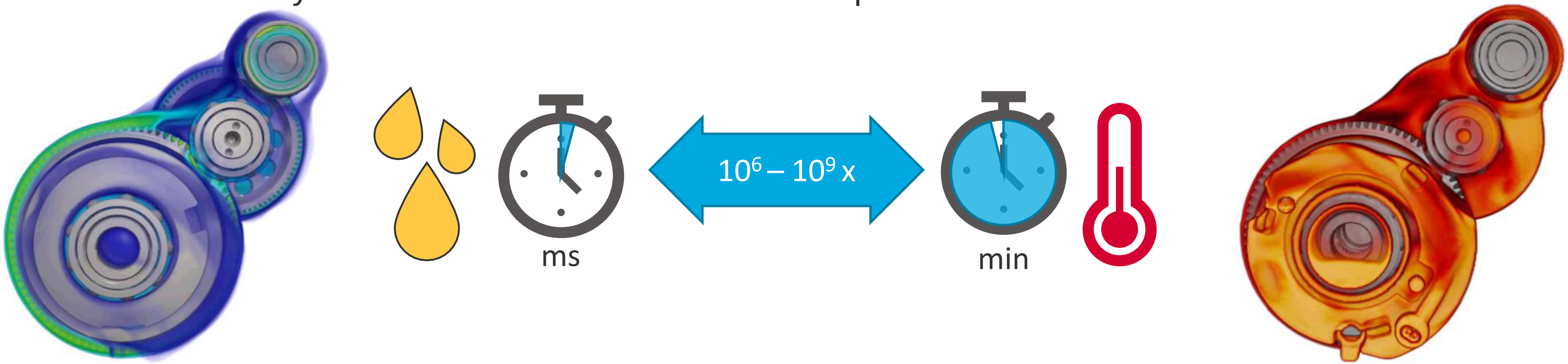
Total power loss: 0.73 kW

BEARING OIL SUPPLY and thermal results

TIMESCALE ISSUE – FLOW VS THERMAL

Thermal situation is very critical in electric drivetrains.

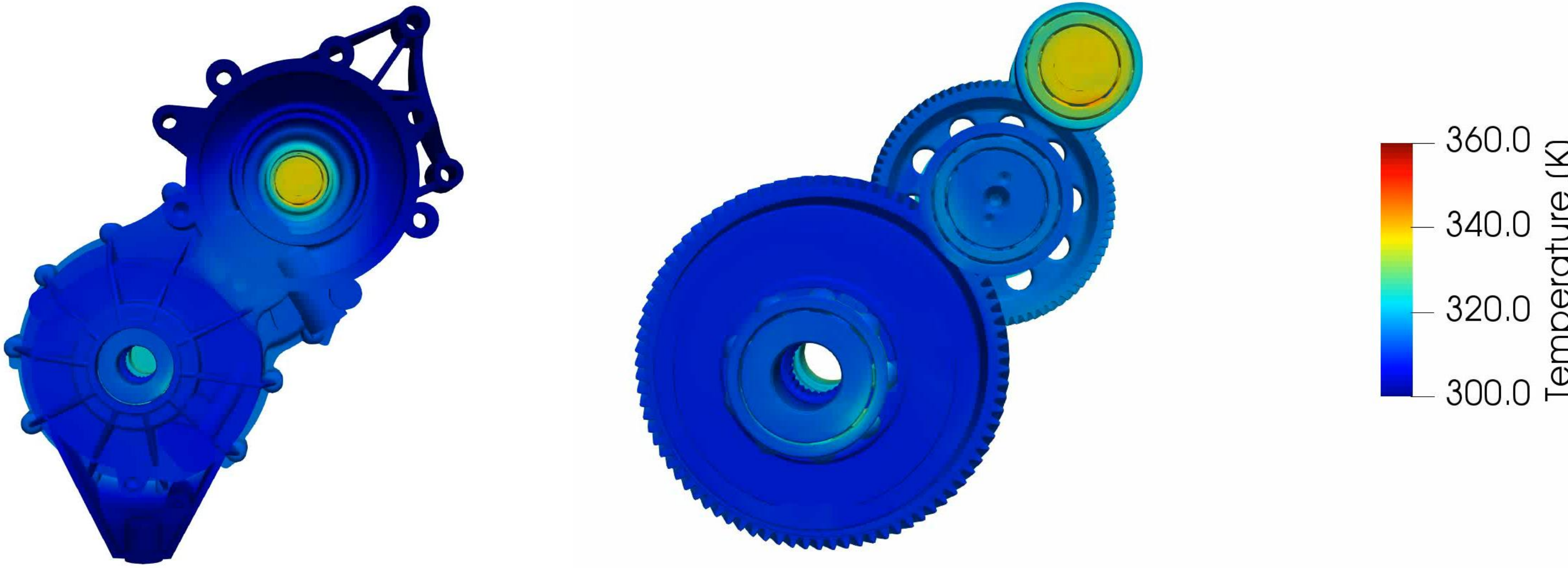
- Oil flow affects temperature distribution.
- Timescales are very different between flow and thermal phenomena.



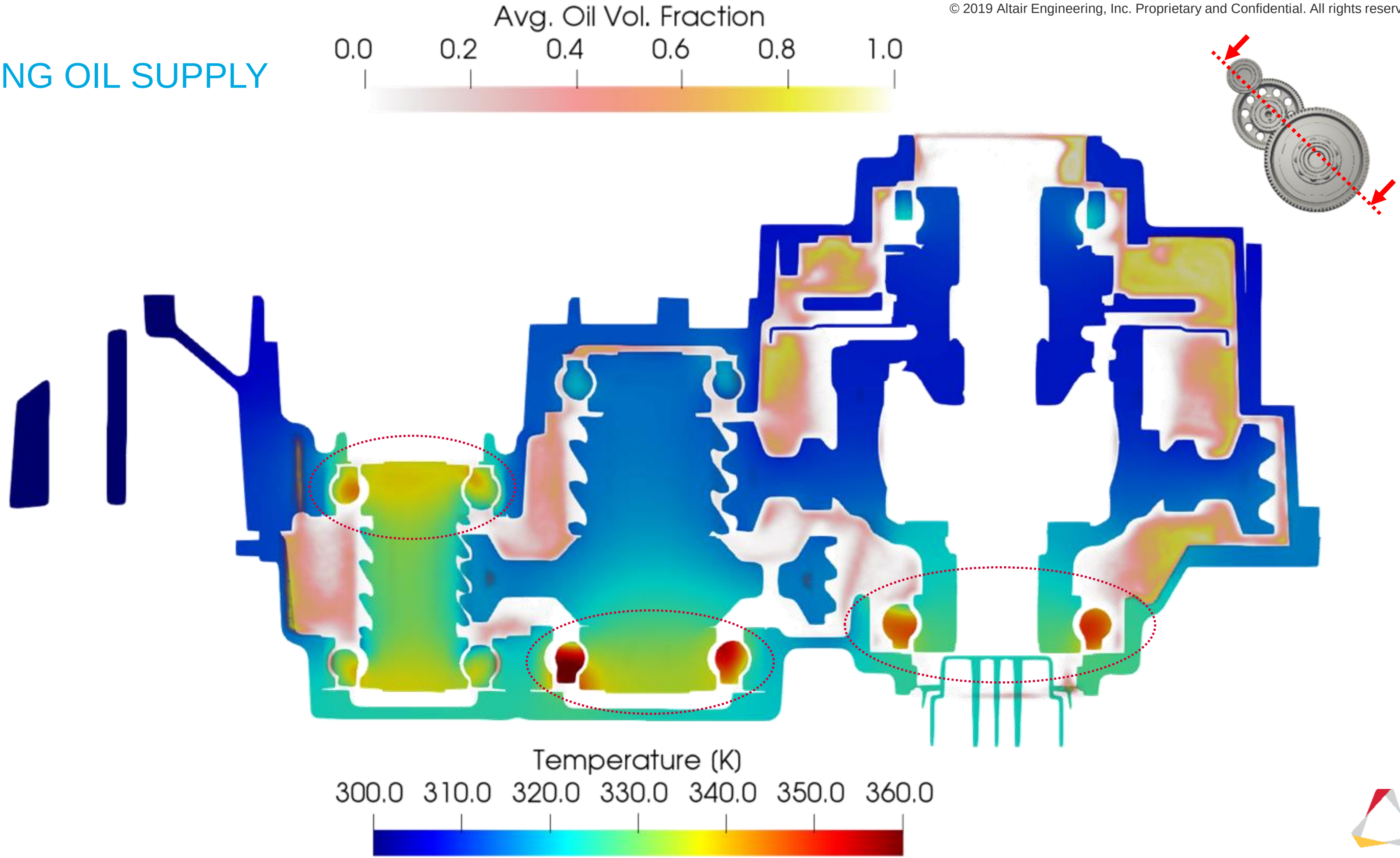
- Solution – separate thermal and flowfield simulations.

Transient fluid solver → Time averaging and mapping of the flowfield → Conjugate heat transfer simulation

HOUSING TEMPERATURES



BEARING OIL SUPPLY



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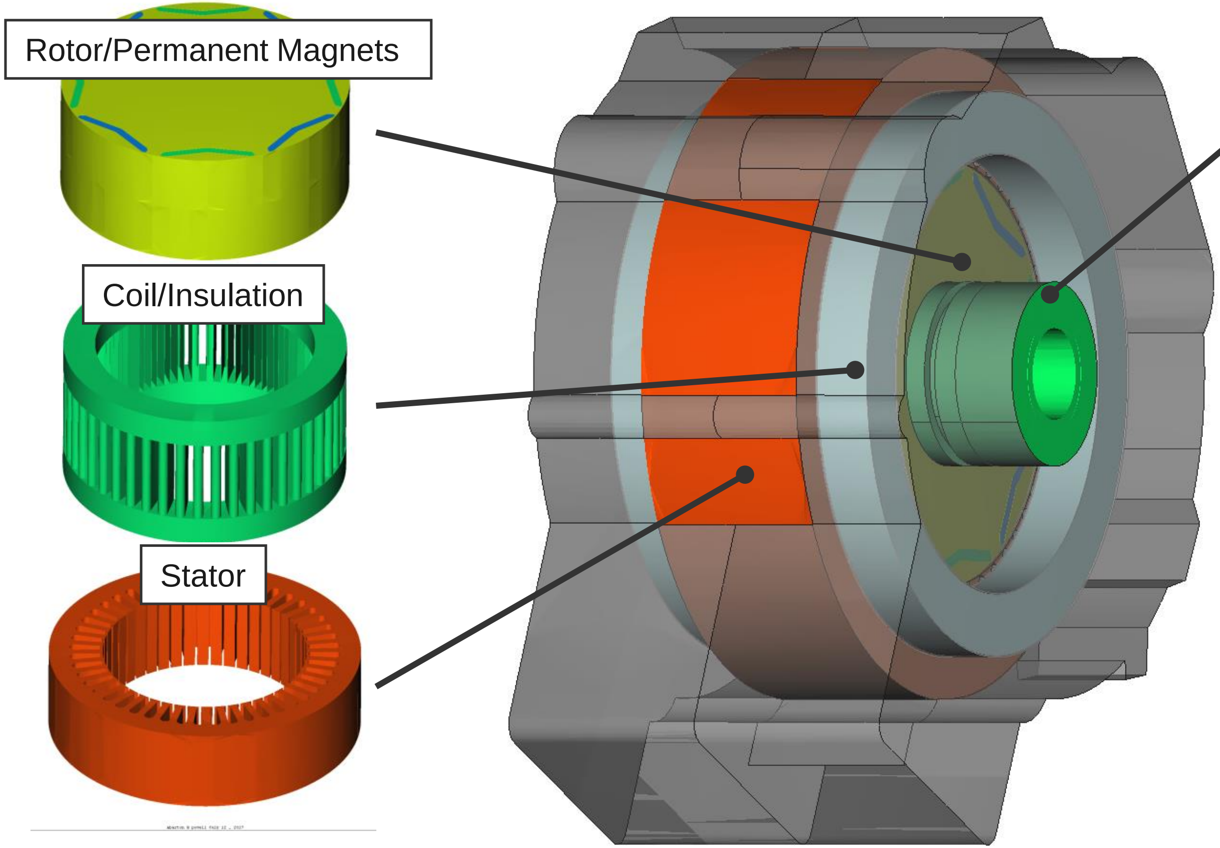
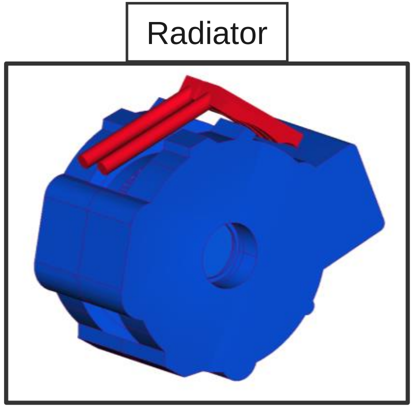
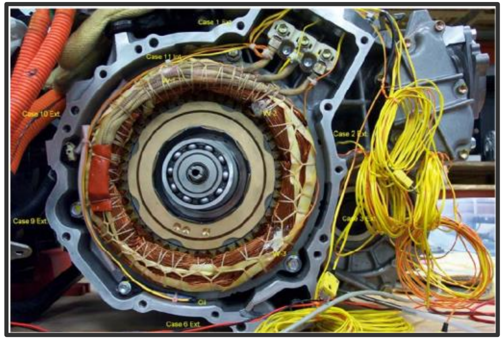
E-Motor Cooling in Conjunction w/ AcuSolve

ELECTRIC MOTOR EXAMPLE

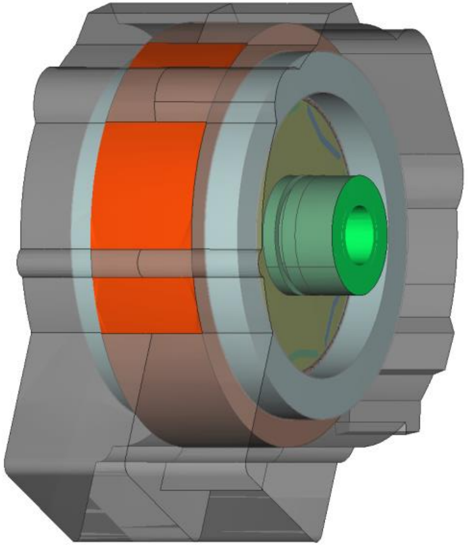


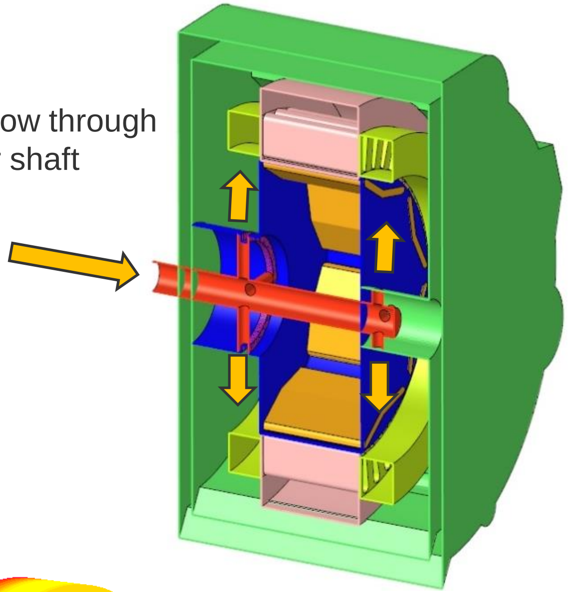




 ORNL, Hsu, J.S. et. Al, Report on Toyota Prius Motor Thermal Management, Feb 2005.

SIMULATION SETUP



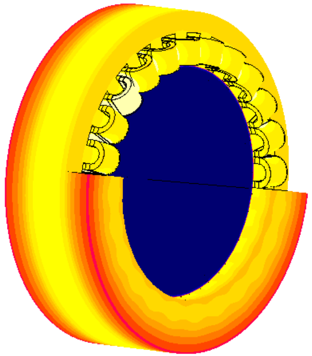


Flow Simulation with nFX

- Multi-Phase Simulation
- Simulated time $t_{sim} = 1.5$ s
- Particle Size: dx = 1 mm
- Rotor speed: 4000 RPM
- Oil volume flow: $\dot{V} = 7.53$ l/min
- 8x NVIDIA Tesla V100: 18 h

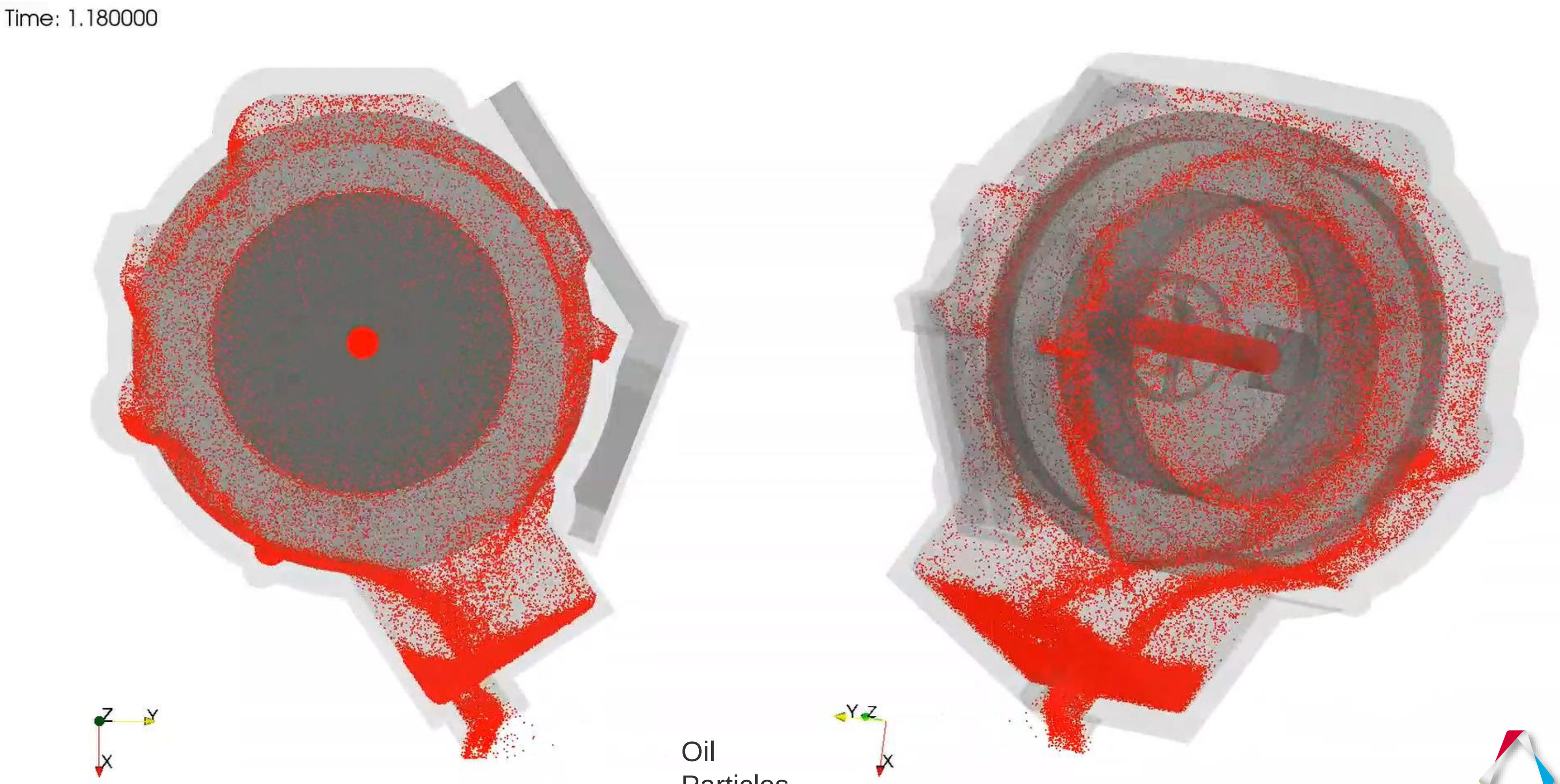
Thermal simulation

- Anisotropic material properties to represent coils and magnets
- Heat sources imported from Electromagnetic simulation.
- Water flow through radiator.
- Convective Heat Coefficient: 25 W/m2-K



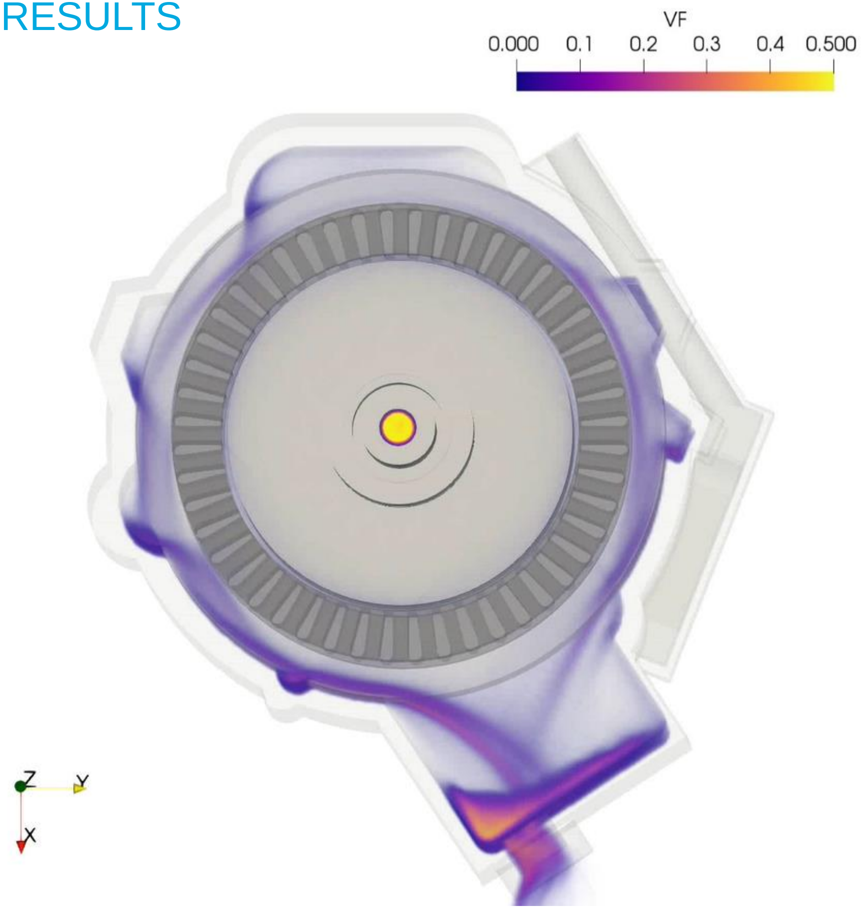
RESULTS

RESULTS

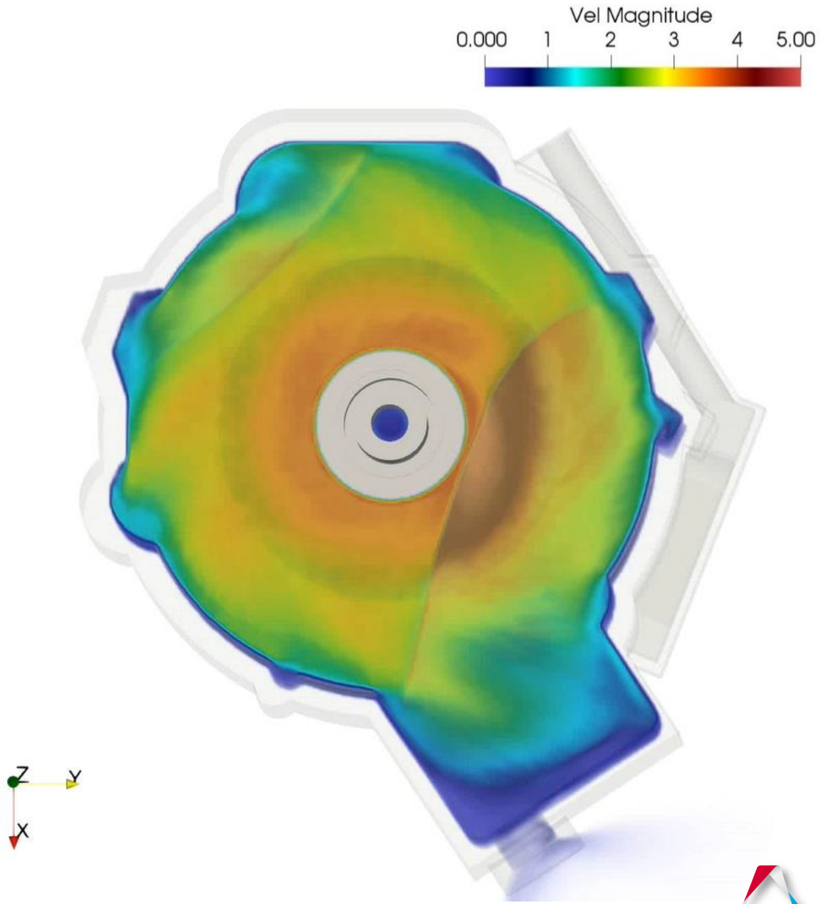


Oil Particles

RESULTS

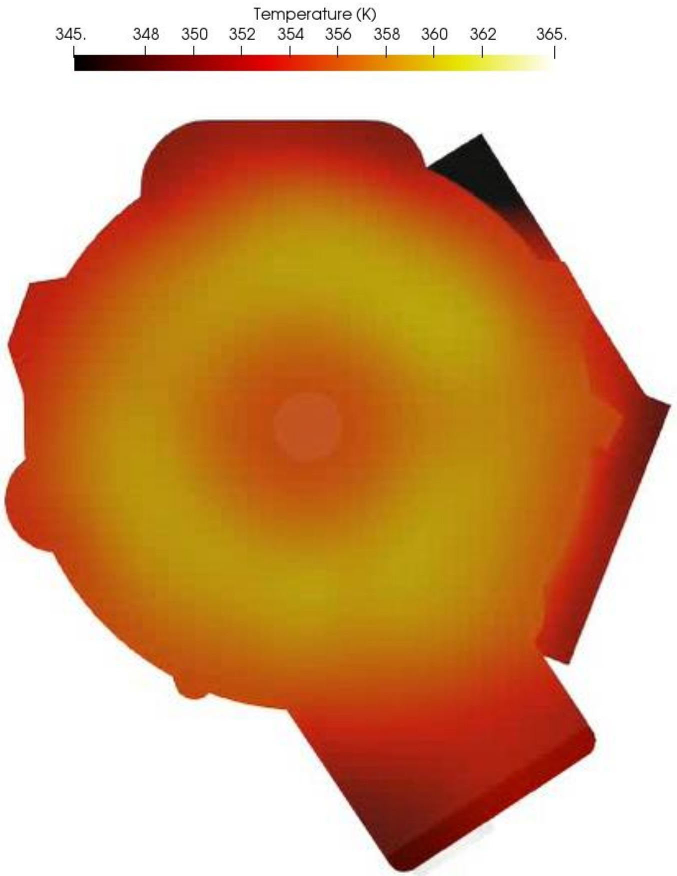


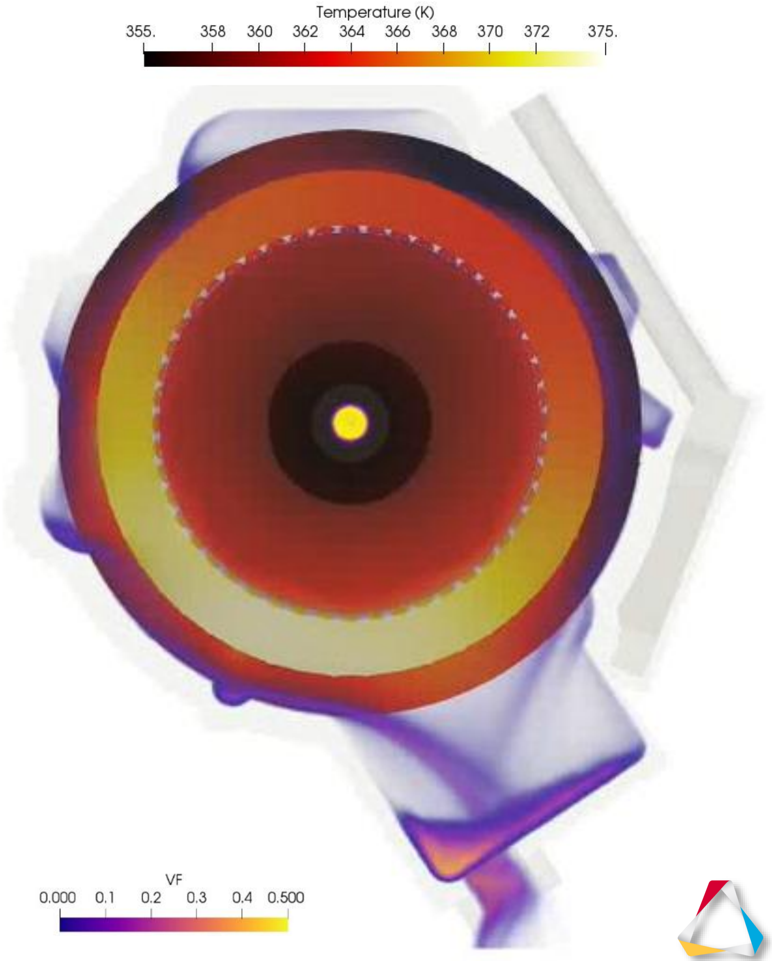
Time Average Volume Fraction



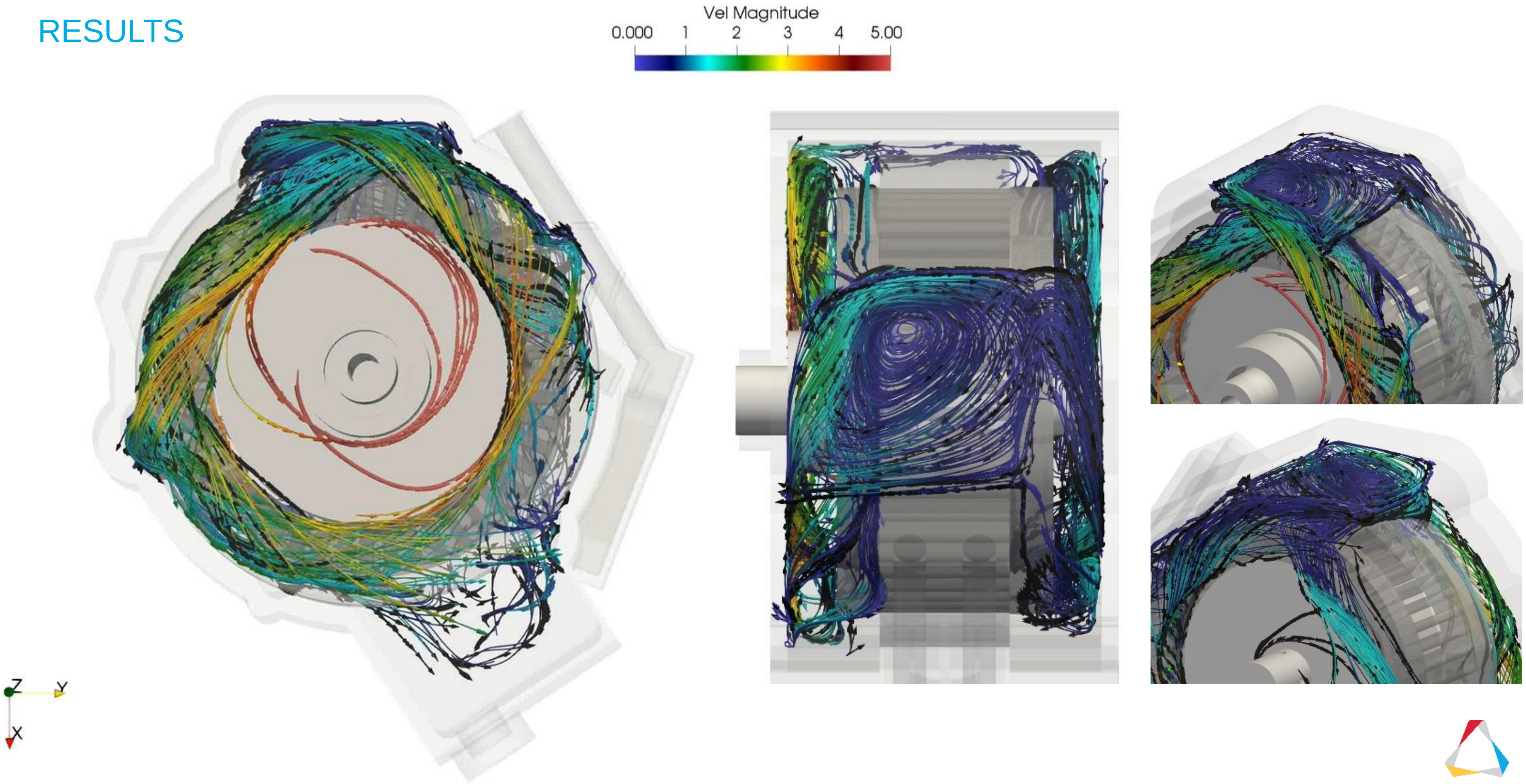
Time Average Velocity Field

RESULTS


Temperature (K)
345. 348 350 352 354 356 358 360 362 365.


Temperature (K)
355. 358 360 362 364 366 368 370 372 375.
VF
0.000 0.1 0.2 0.3 0.4 0.500

RESULTS

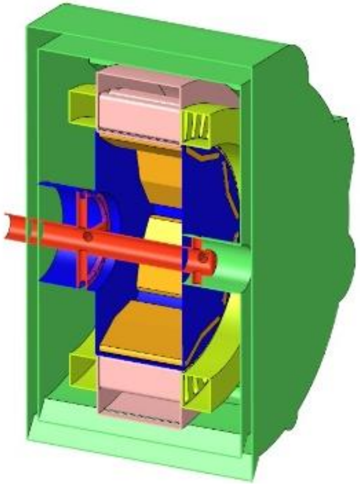


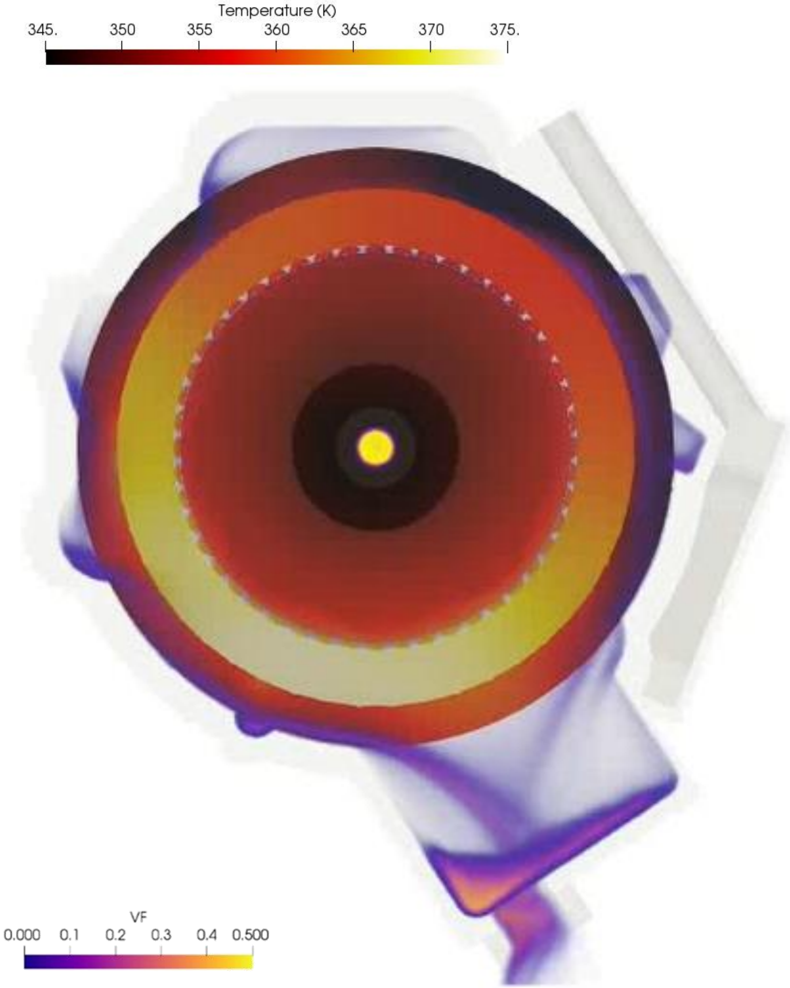
RESULTS

Thermal Field (AcuSolve)

- The lower half of the coils has the highest temperature in the system.
- There is a temperature difference between the front and back coils, with the back one being hotter.
- The temperature difference is likely caused by two mechanisms:

  - Difference in mass flow of the oil in front and back of the shaft (pressure drop in the shaft). → Less oil in the back → Higher temperatures
  - Also, the large cylindrical protrusion (see slide 4) on the front of the shaft causes higher velocities in the front of the motor → Better cooling.





CONCLUSIONS

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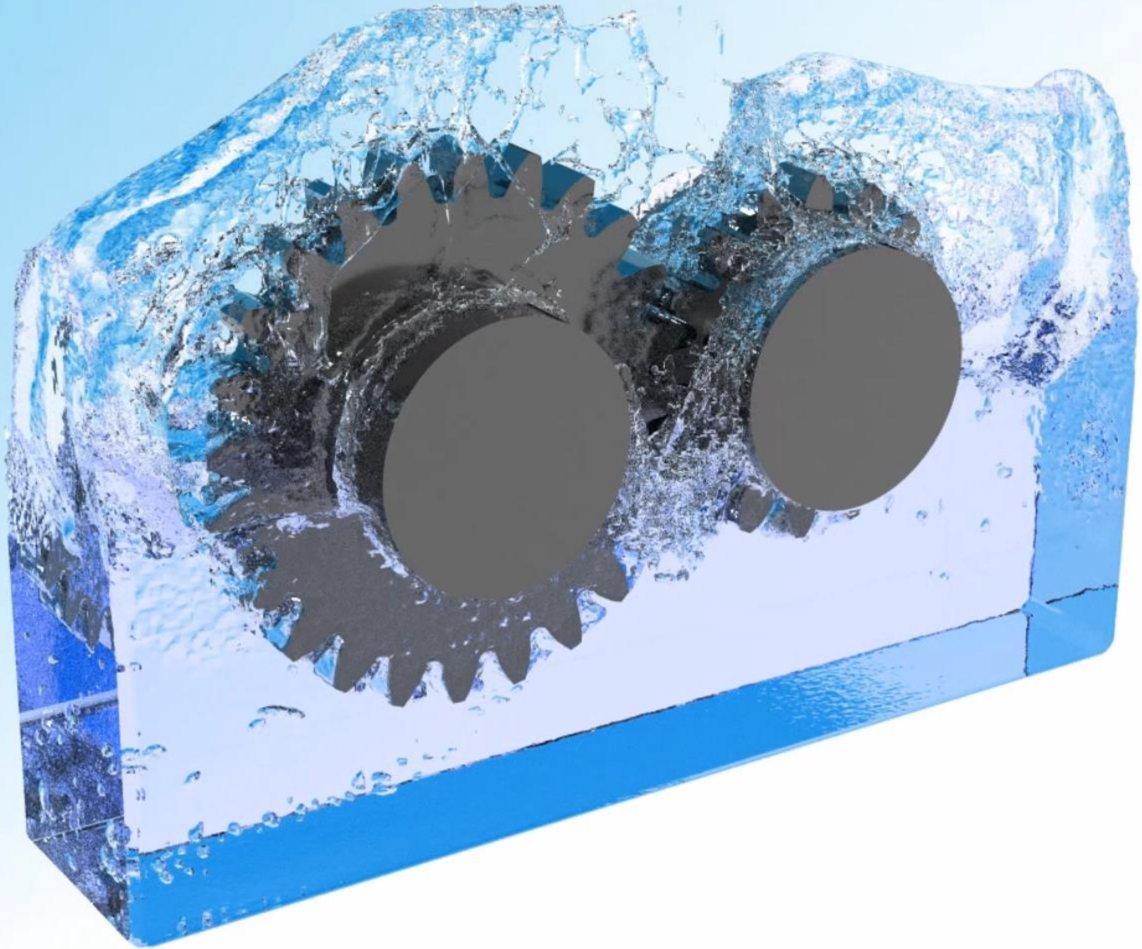
- Transient nanoFluidX solution is time averaged to extract a quasi-steady-state flow field, providing engineering insight to the average flow behavior.
- Strong interaction between oil spray and air flow, especially vortex interaction in high RPM cases.
- Capturing this effect means that realistic thermal simulations can be carried out and temperature related effects studied.
- Being able to run these simulations in a short timescale with GPUs means that they can be part of an industrial design cycle.
- All simulations shown are the start of an engineering process, not the end.

THANK YOU FOR YOUR ATTENTION.



Altair nanoFluidX™