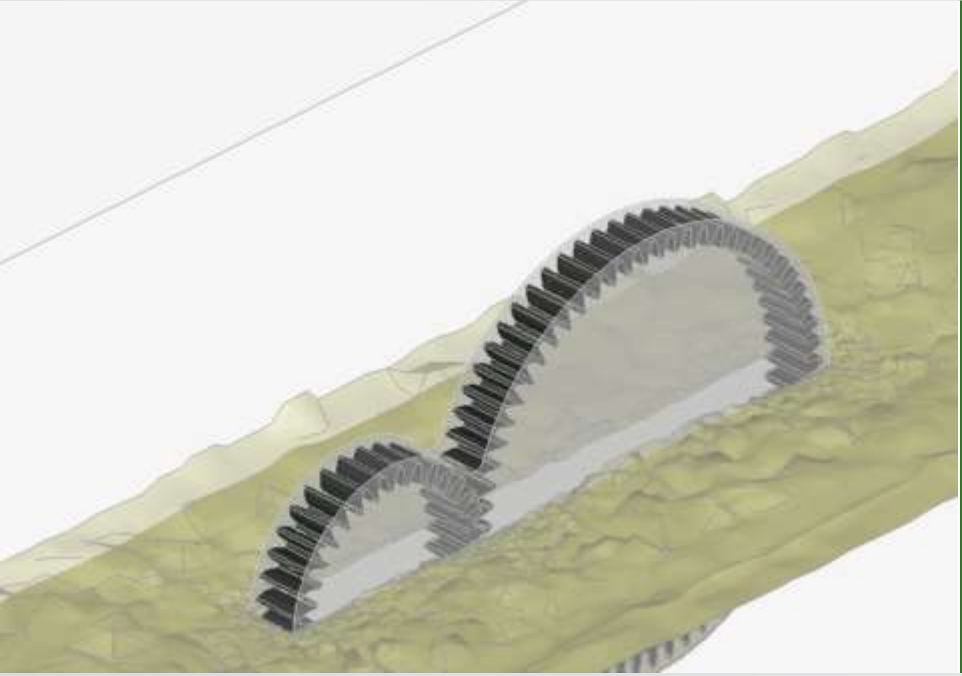


CFD Untersuchung von im Ölbad rotierenden Zahnrädern mit Fluent

CFD investigation of rotating gears in oil with Fluent

Paul Illg, Alexander Berg, Dmitrij Neufeld

John Deere GmbH & Co. KG, Mannheim

JOHN DEERE

Content

Content

John Deere Factory Mannheim and Bruchsal

Biggest John Deere factory outside of North America

- Producing AG equipment since 1867
- over 1.6 million tractors since 1921
- 2/3 of overall German tractor production
- 70 to 210 hp tractors (97/68/EC)
- 4,005 employees at the Mannheim site
- 1,375 employees at the Bruchsal site

6R Transmission - Power of Choice

Content

Background & Objectives

Model Order Reduction: From Tractor to Component Test Rig

Tractor

Lots of different systems & circuits

→ Different focus & analysis goals

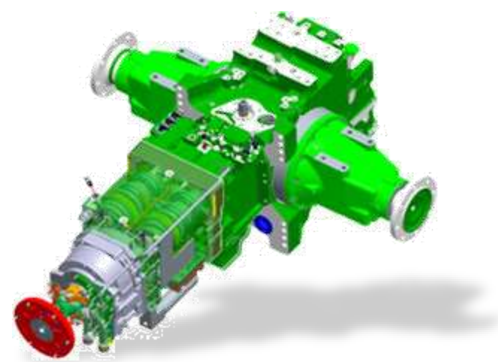
Gearbox

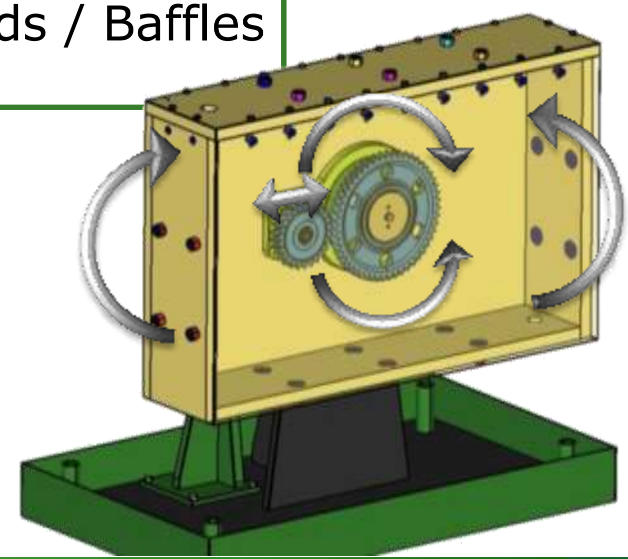
Lots of different
- gear pairs
- compartments
- subsystems

→ Limited access for detailed analysis

Test Rig (iGSL)

- Plexiglas box
- Gear interaction
- Splashing
- Losses
- Oil level & prop.
- Shields / Baffles

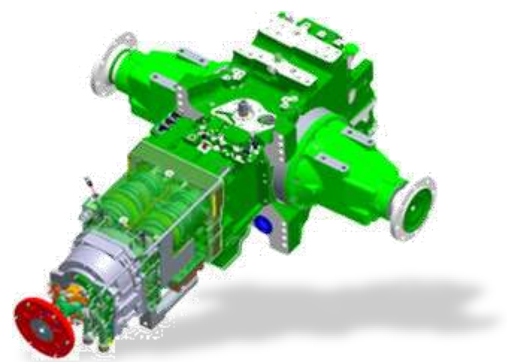


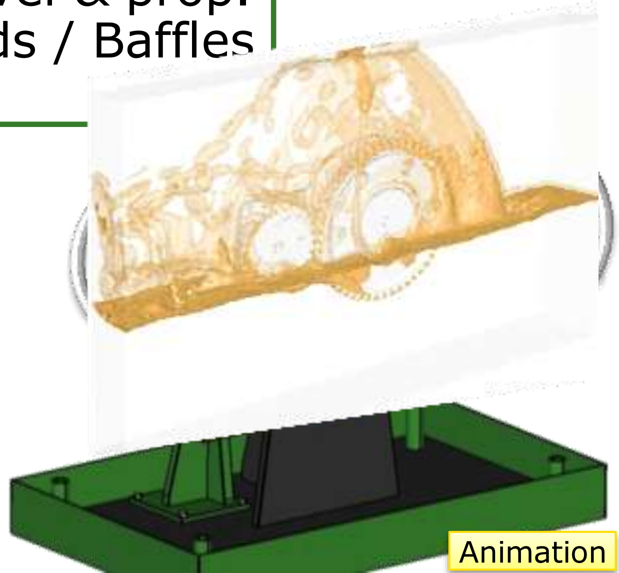


Background & Objectives

Model Order Reduction: From Tractor to Component Test Rig

Tractor	Gearbox	Test Rig (iGSL)
Lots of different systems & circuits → Different focus & analysis goals	Lots of different - gear pairs - compartments - subsystems → Limited access for detailed analysis	- Plexiglas box - Gear interaction - Splashing - Losses - Oil level & prop. - Shields / Baffles



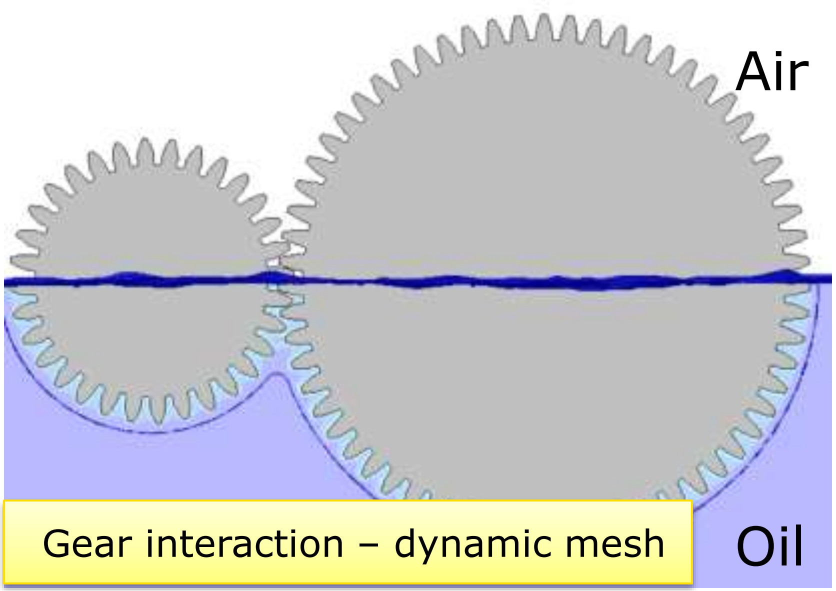


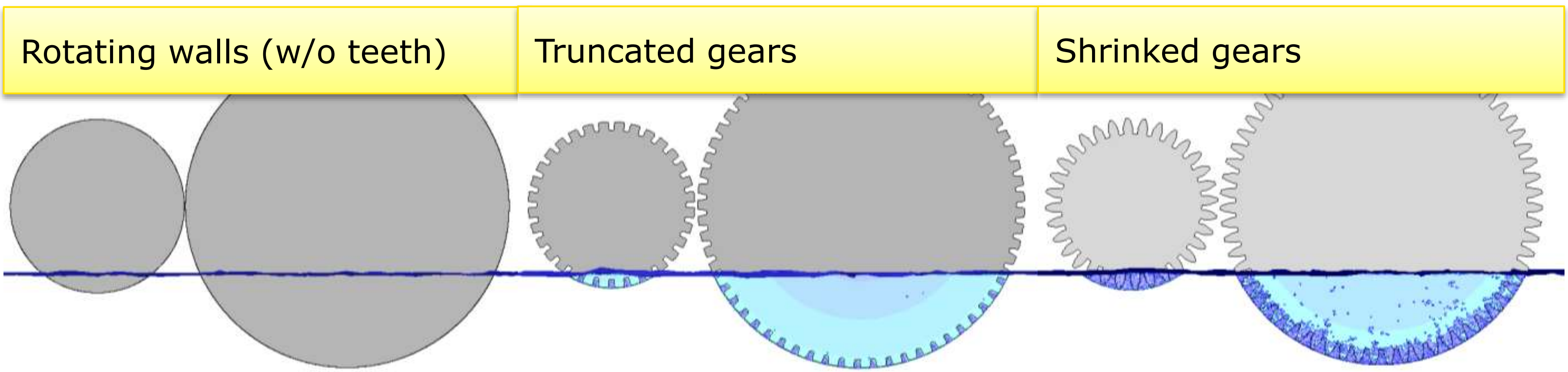
Animation

Background & Objectives

Gearbox CFD Challenges

- Gear interaction
  - Full, No, Partially
- Numerical approaches
  - E.g. MRF, sliding & dynamic meshes
- Multiphase & free surface flow
  - Mesh & time step size
  - Numerical modelling
- Calculation time & Scalability

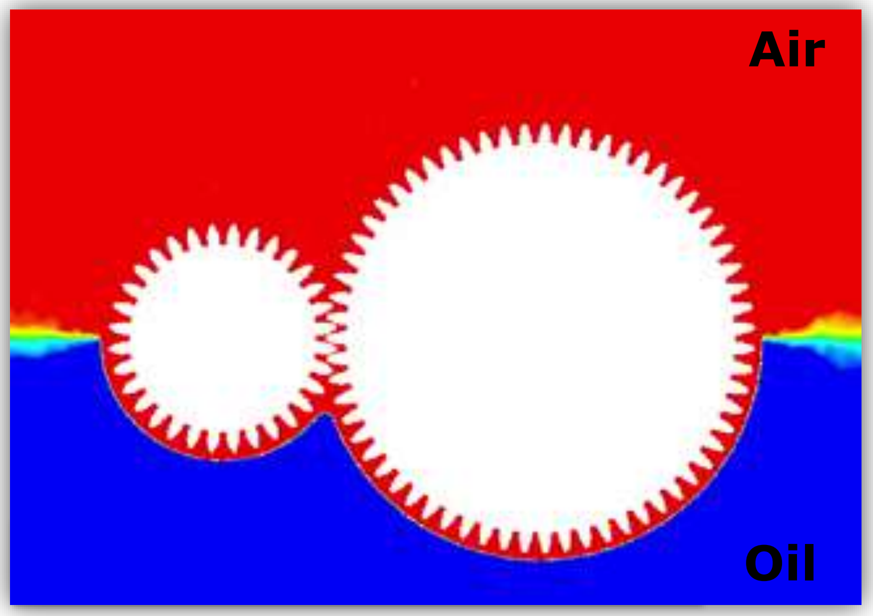


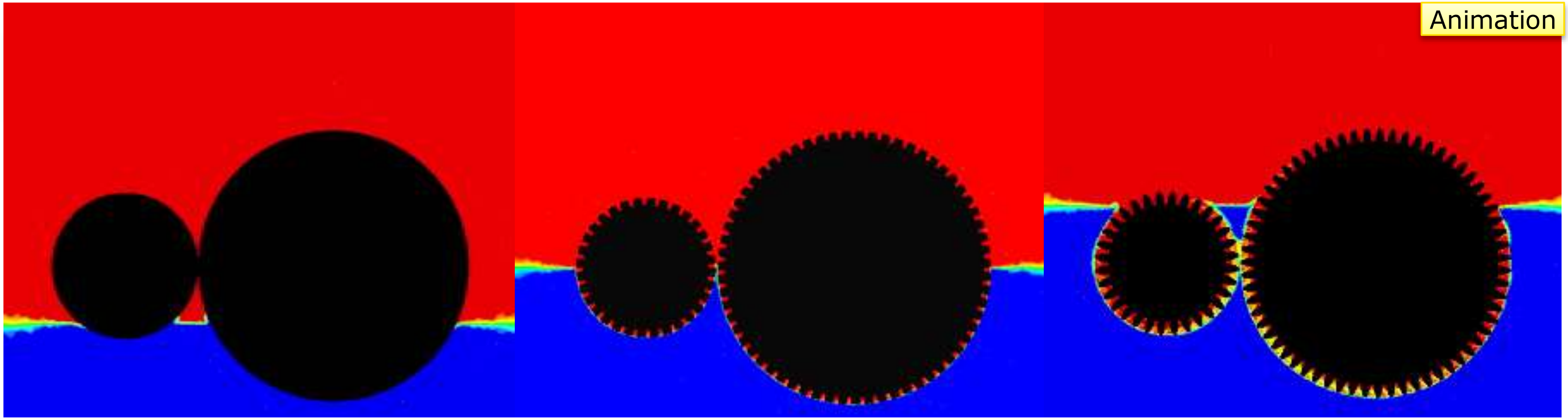


Background & Objectives

Gearbox CFD Challenges

- Gear interaction
  - Full, No, Partially
- Numerical approaches
  - E.g. MRF, sliding & dynamic meshes
- Multiphase & free surface flow
  - Mesh & time step size
  - Numerical modelling
- Calculation time & Scalability

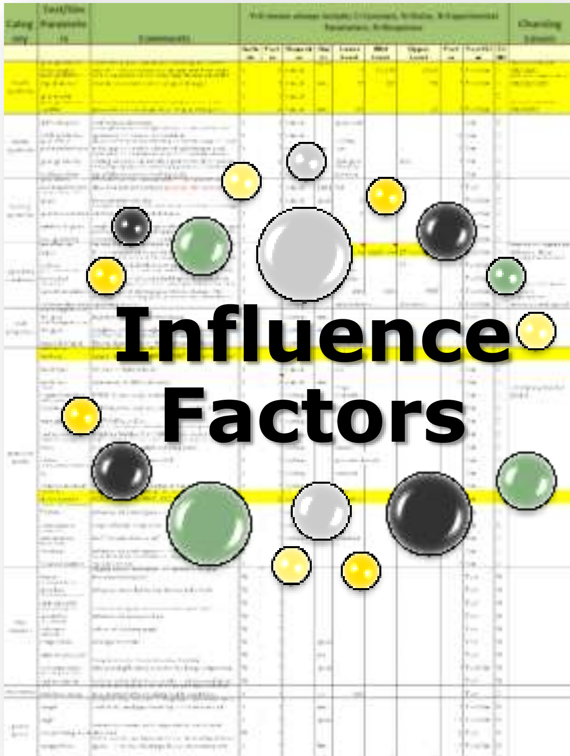


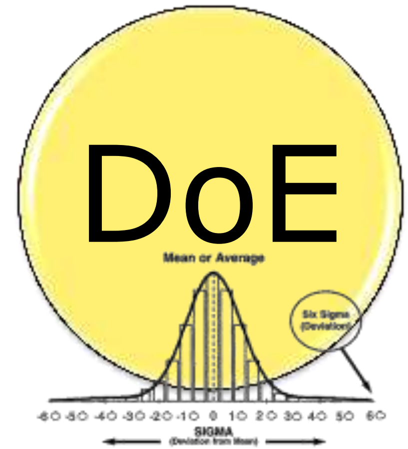


Content

Verification Procedure

Identify Dominant Influence Factors





<u>Brainstorming sessions</u>, team effort: collect physical & numerical factors

<u>Personal screening</u> identify & select factors with highest impact on splashing & losses

<u>Numerical screening</u>
→ CFD meets DoE
→ which factor has dominant influence on which answer?

Verification Procedure

Solution Concept: Design of Experiments (DoE)

Most important 8 physical & numerical factors:

- DoE considering factor interaction:
  → 864 CFD runs
  → not feasible

CFD Run	Rotation	Gear model	Temperature	Oil level	Rot. Speed	Mesh size	Time step	Met-hod
levels	L/R	disc trunc shrink	low mid high	low mid high	low mid high	coarse mid fine	coarse mid fine	fast stable accurate

Verification Procedure

Solution Concept: Design of Experiments (DoE)

Most important 8 physical & numerical factors:

- DoE considering factor interaction:
  → 864 CFD runs
  → not feasible
- Screening DoE: Taguchi L18 Design
  - Full orthogonality
  - 18 Runs

Responses:

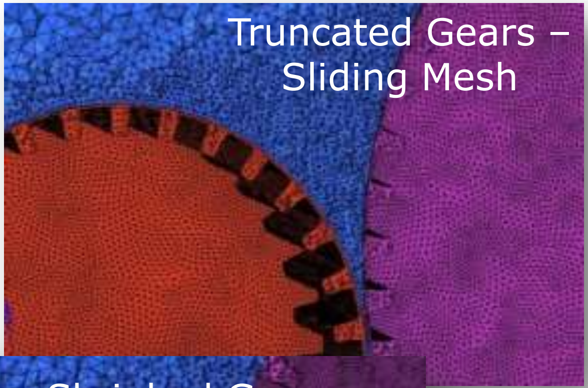
- Power losses
- Oil behavior
- Calculation time

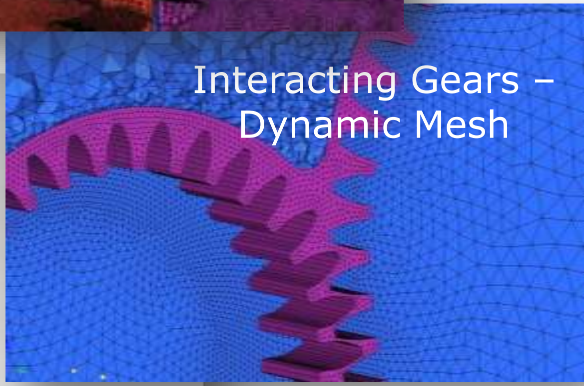
CFD Run	Rotation	Gear model	Temperature	Oil level	Rot. Speed	Mesh size	Time step	Method
1			-1	-1	1	1	1	1
2			0	0	0	0	0	0
3			1	1	-1	-1	-1	-1
4			-1	-1	0	0	-1	-1
5			0	0	-1	-1	1	1
6			1	1	1	1	0	0
7			-1	0	-1	-1	0	-1
8			0	1	1	1	-1	1
9			1	-1	0	0	1	0
10			-1	1	0	0	0	1
11			0	-1	-1	-1	-1	0
12			1	0	1	1	1	-1
13			-1	0	1	1	-1	0
14			0	1	0	0	1	-1
15			1	-1	-1	-1	0	1
16			-1	1	-1	-1	1	0
17			0	-1	1	1	0	-1
18			1	0	0	0	-1	1

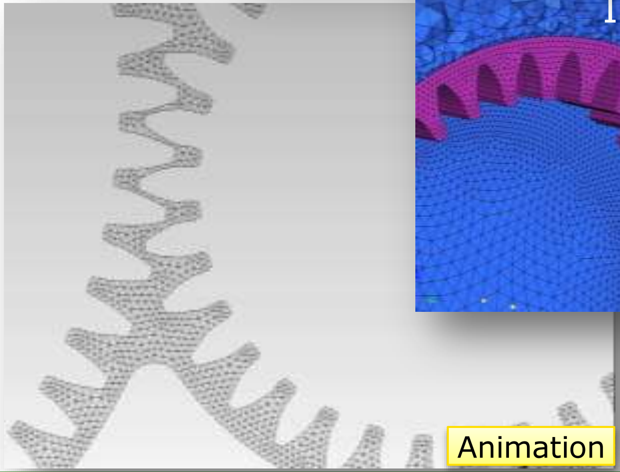
Verification Procedure

Numerical Modelling with ANSYS Fluent

- Meshing gear interaction:
  - Rotating sliding & dynamic mesh zones vs. static zones.
- Solver Settings:
  - Multiphase flow: Volume of Fluid (VoF)
  - Turbulent, incompressible, isothermal
  - 3 mesh sizes: 1,4~11 Mio Tets
  - 3 sets of solution methods: fast/accurate/stable
  - 3 time step sizes: CFL 0,2~14







Content

John Deere – Today

Background & Objectives

Verification Procedure

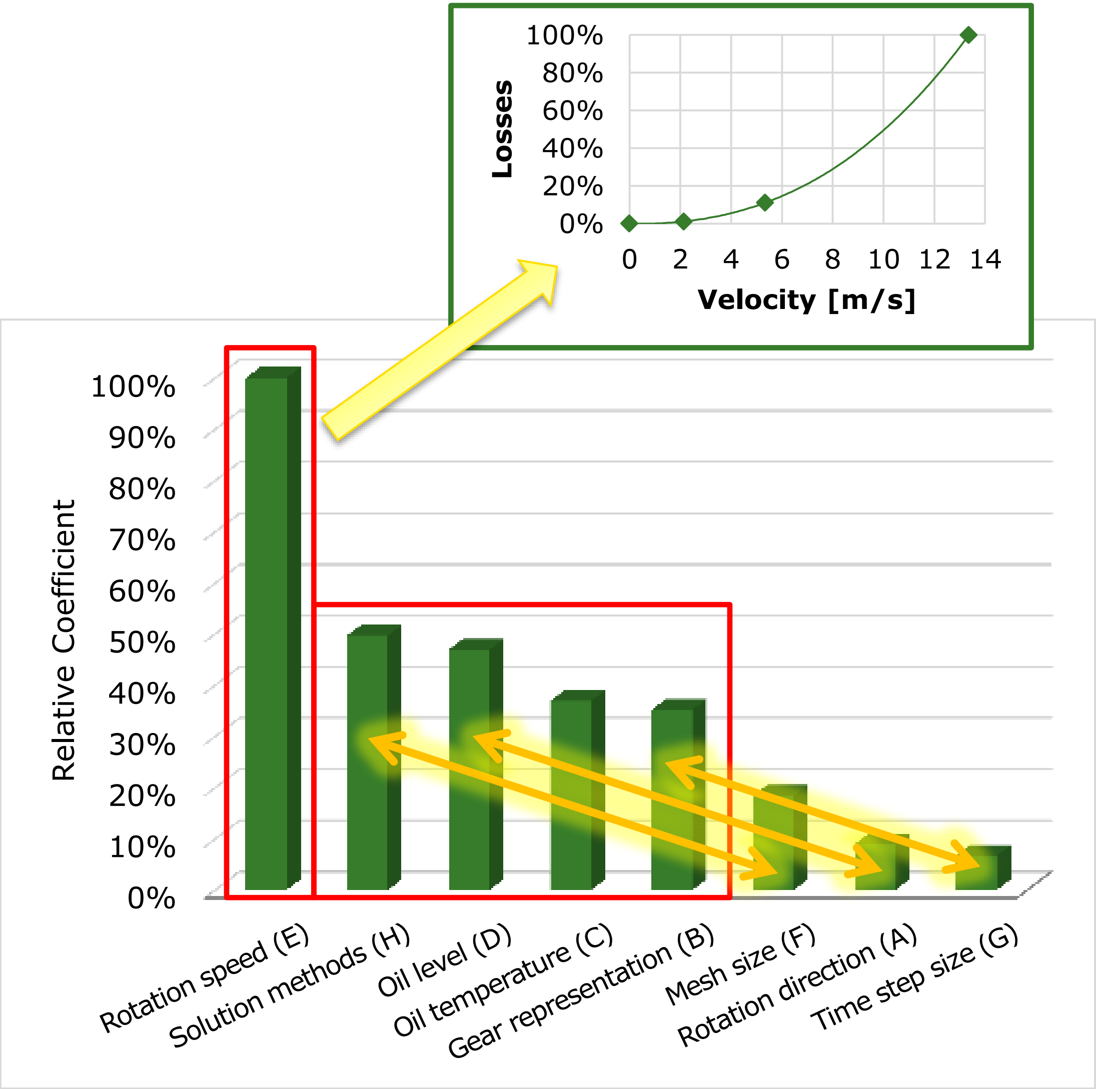
Results

Conclusion

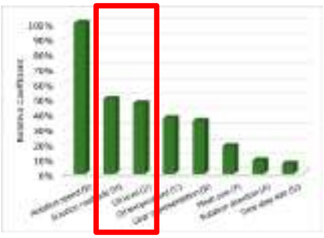
Results #1: Losses

Pareto Chart: Dominant Factors

- Rot. speed dominant.
- Top 5 factors:
  - Physical & numerical “pairs”.
- Findings:
  - Solution methods & gear representation more important than mesh size & time steps.
  - Oil level & temperature more important than rot. direction.



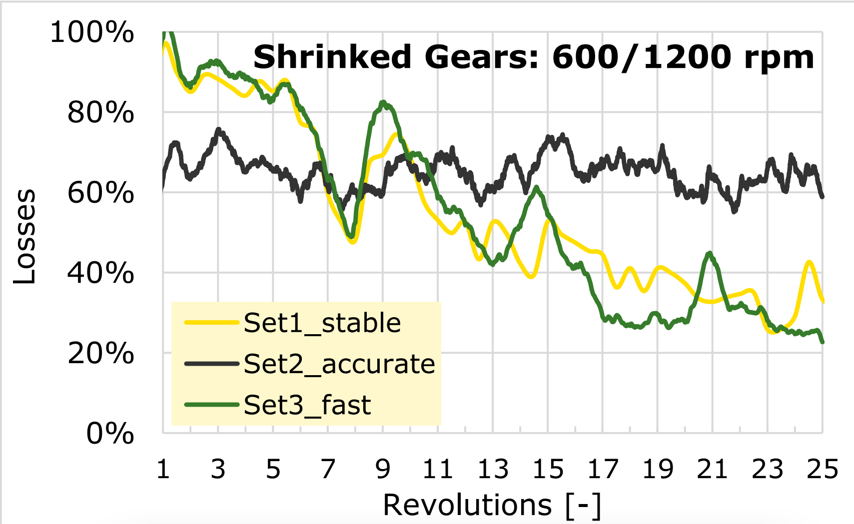
Results #1b: Losses Top3



Solution Methods & Oil Level

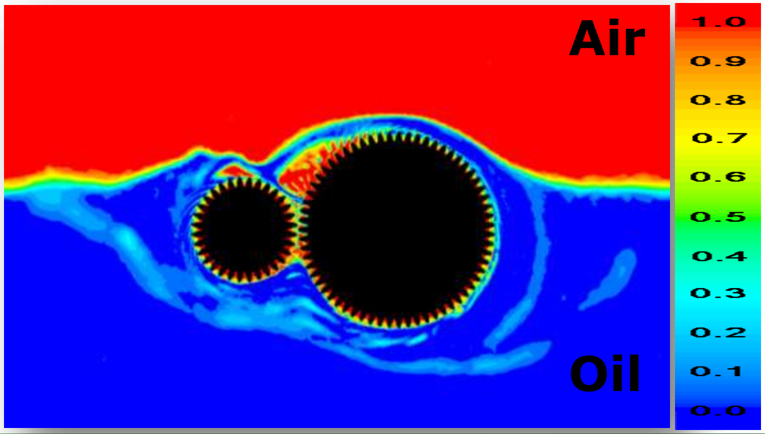
- Solution Methods:
  - Accurate method calculates slower but moment converges faster
  - Methods focusing on calc. speed & stability → 50% lower losses

➔ Accurate methods:
more conservative loss prediction
& overall faster converged solution.



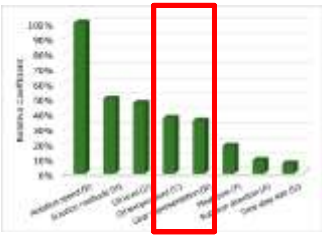
- Oil Level:
  - Losses increasing with oil level
  - Same influence level as num. settings

➔ To decrease losses decrease oil level.

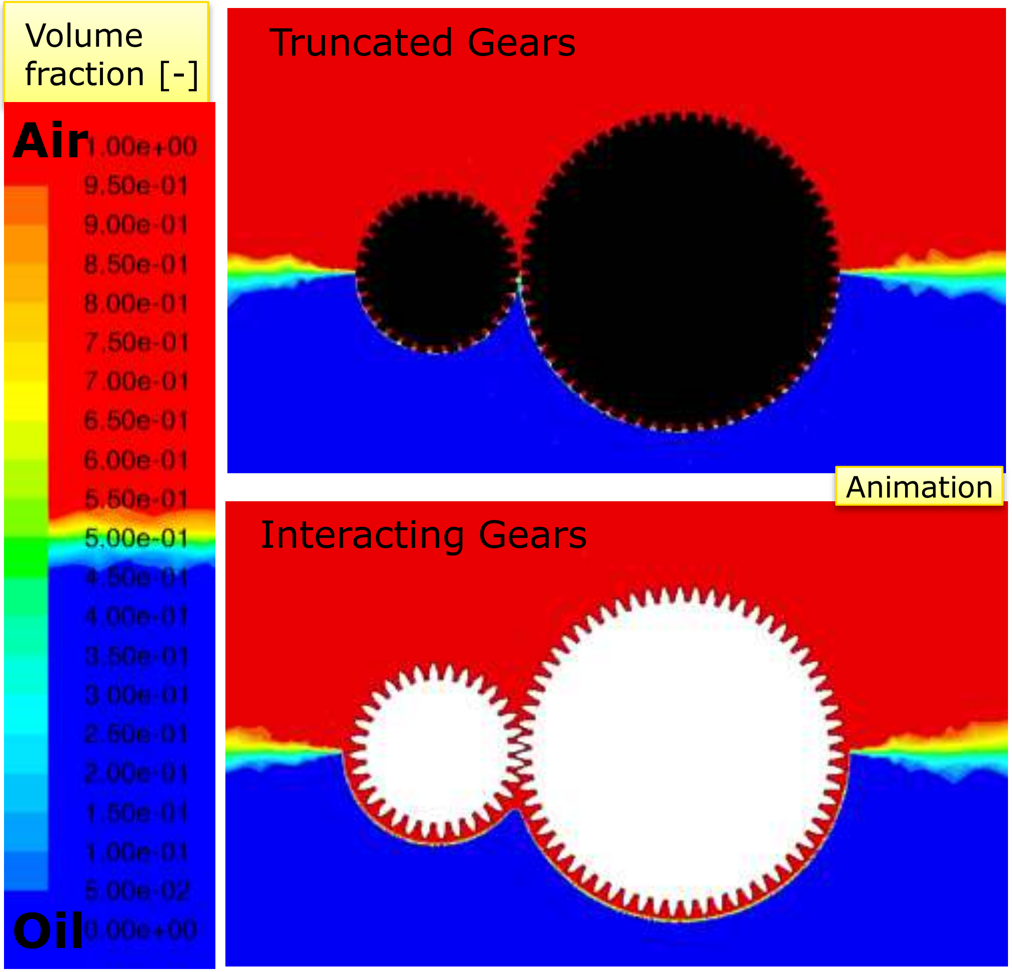


Results #1c: Losses Top5

Gear Representation & Oil Temperature

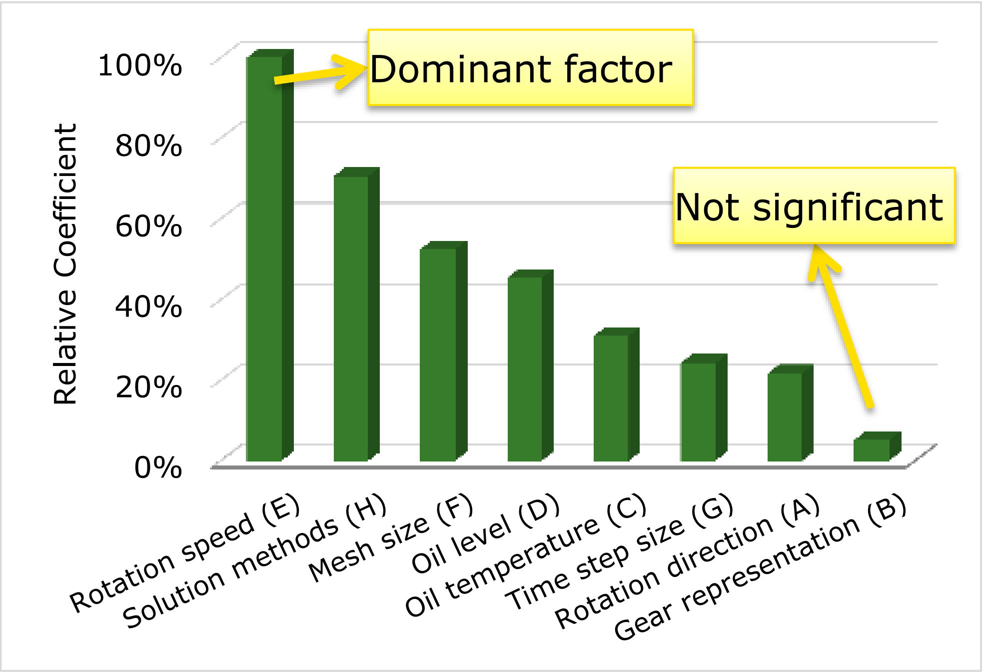


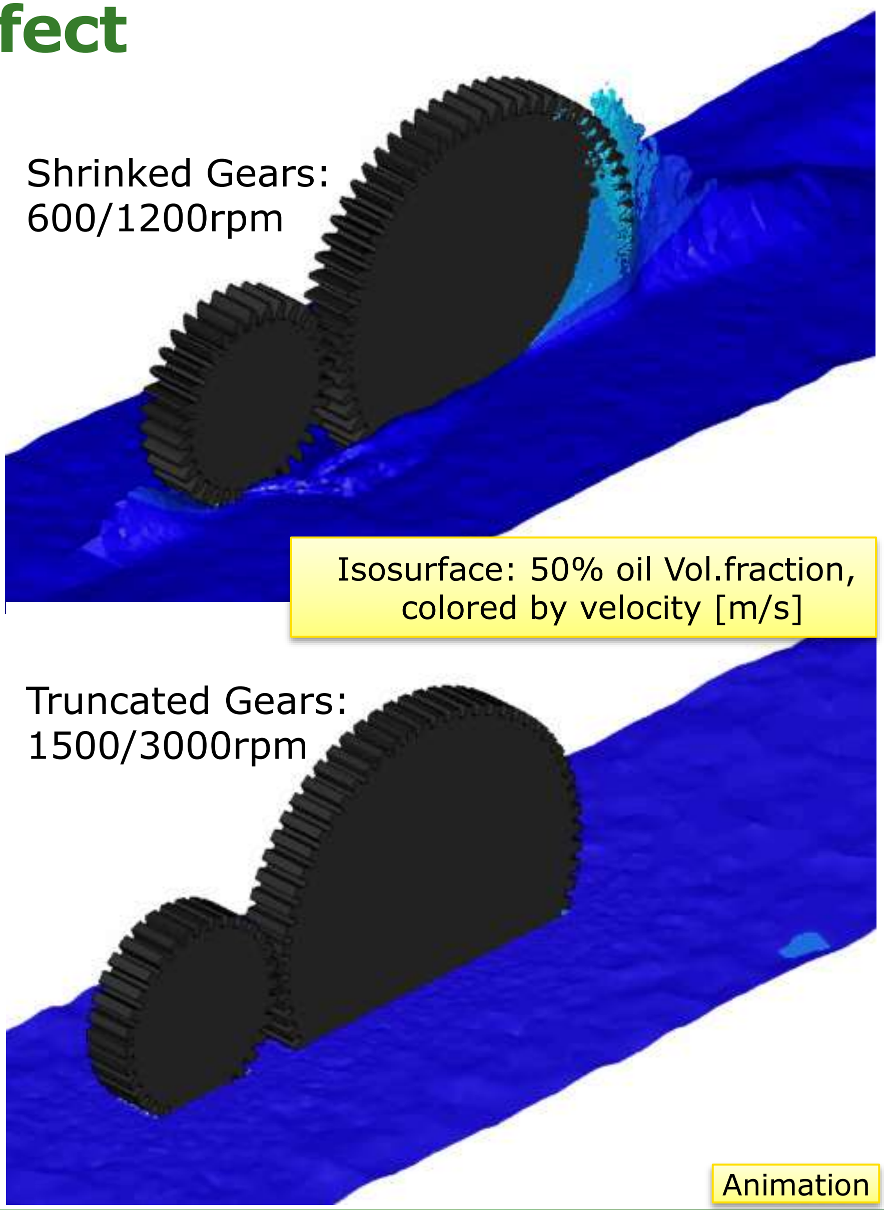
- Gear representation:
  - Significant influence on losses
  - considering gear interaction:
    → Losses x6 ↑
    → Faster moment stabilization
- Oil temperature:
  - T_{oil} ↑
    → density & viscosity ↓
    → losses ↓



Results #2: Oil Pumping Effect

Pareto Chart: Oil Volume above Initial

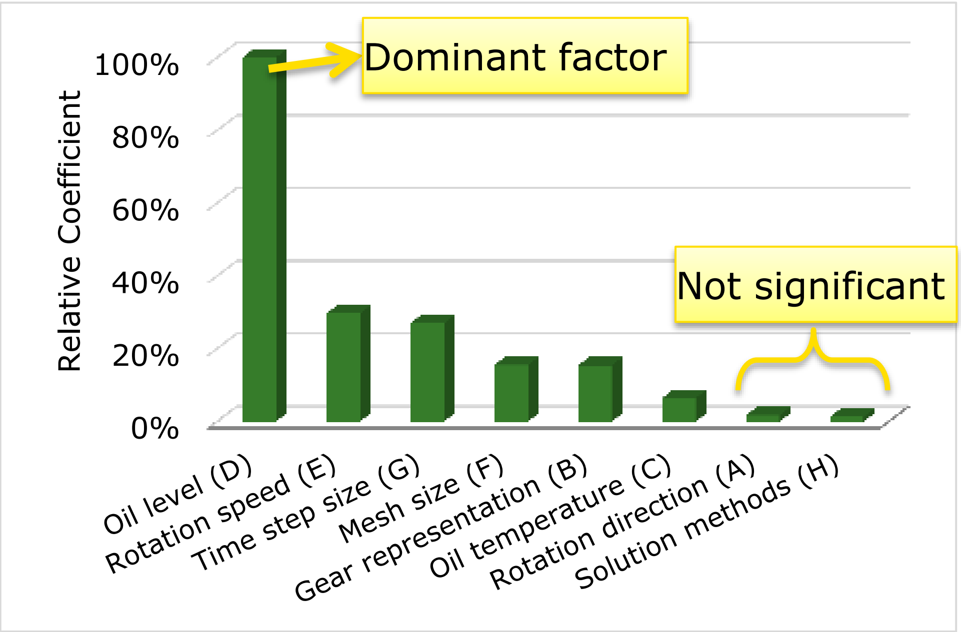




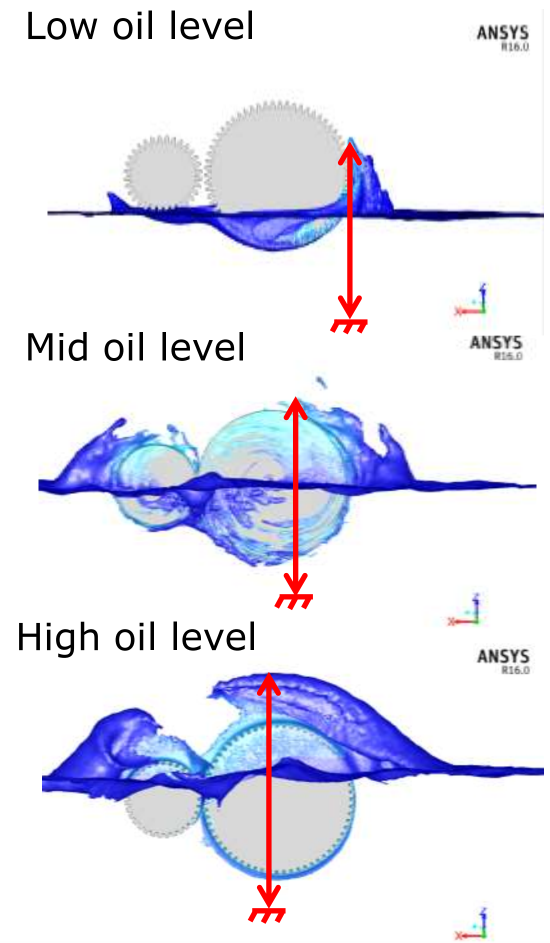
- Rotation speed dominant
- Solution methods:
  - Fast method → pumping effect ↑
- Gear representation:
  - Not significant for pumping effect

Results #3: Oil Splashing Intensity

Pareto Chart: Max Oil Height



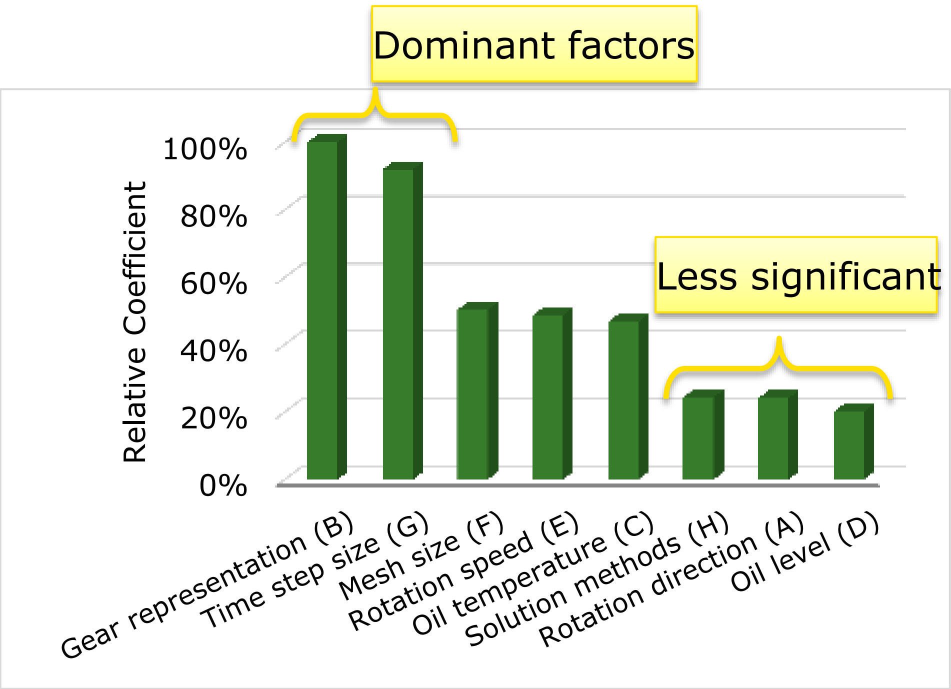
- Oil level dominant
  - Oil level reduction → less oil splashing
- Rot. speed & mesh size → Top3
- Rot. direction & solution methods
  - Not significant



Isosurface: 50% oil vol.fraction,
High speed: 1500/3000 rpm

Results #4: Calculation Time

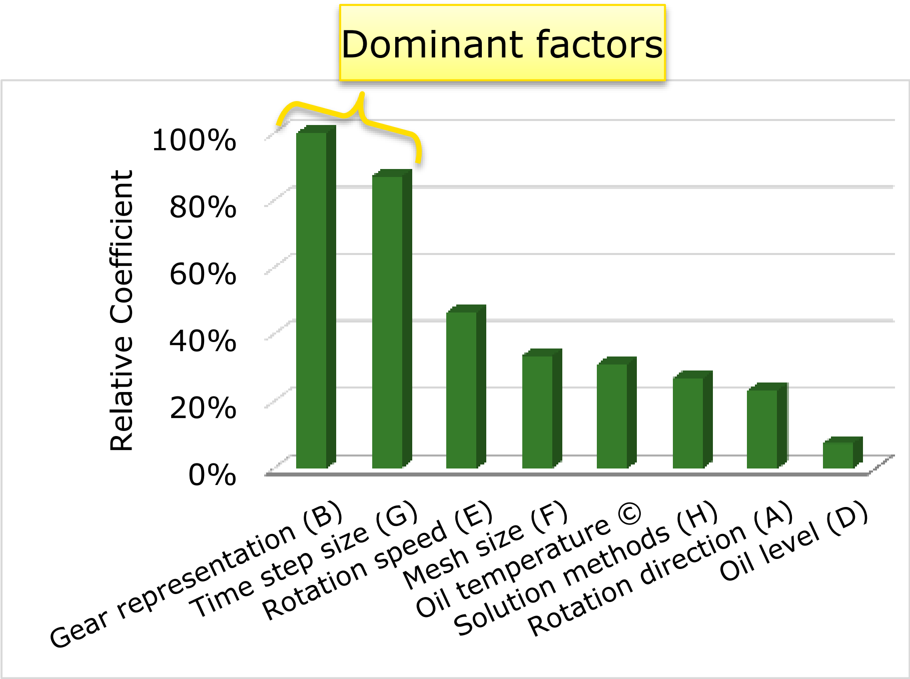
Pareto Chart: Calculation Time per Simulated Second

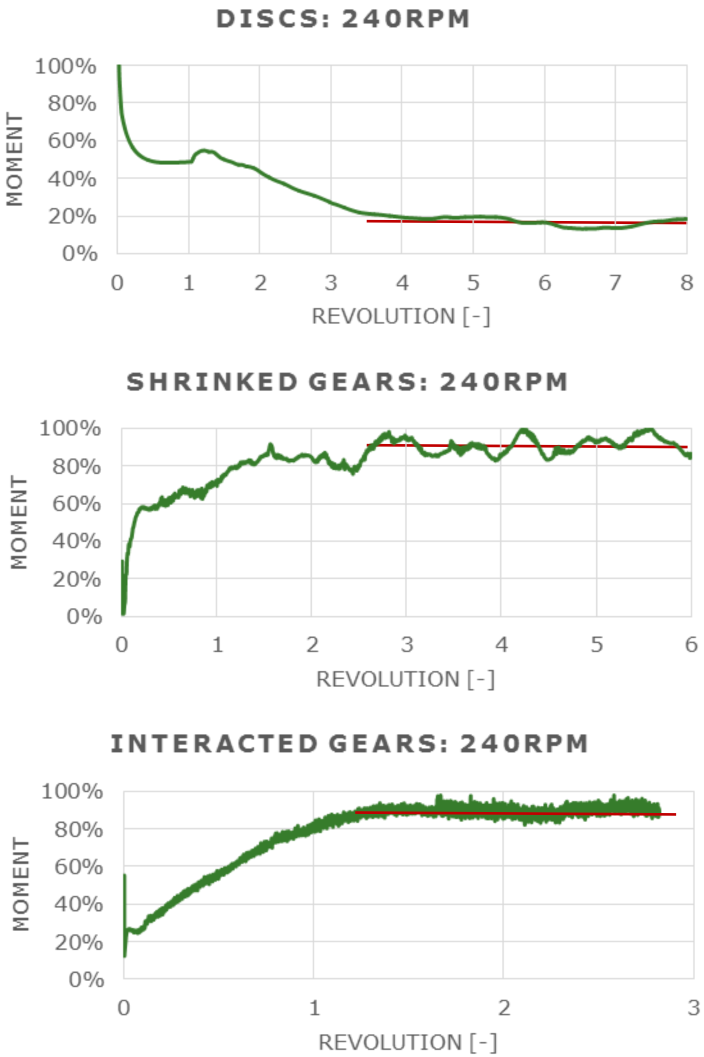


- Gear representation & time step size → dominant factors
  - Dynamic mesh models need smallest time steps
    → Calc. time 30x higher compared to truncated gears
  - CFD cases w/o gear teeth accept biggest time steps
    → Rotating discs → fastest approach

Results #5: Calculation Time

Pareto Chart: Calculation Time until Moment Stabilization



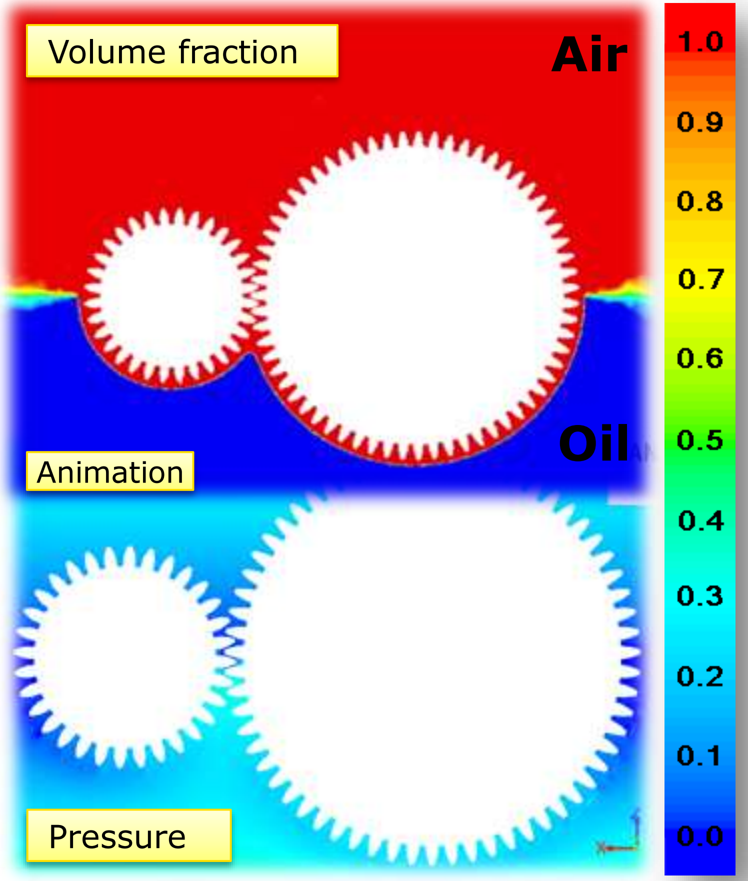


- DoE CFD runs: huge calc. time variation.
- Faster moment stabilization with more complex methods.
- Improvement of speedup & scalability desired!

Content

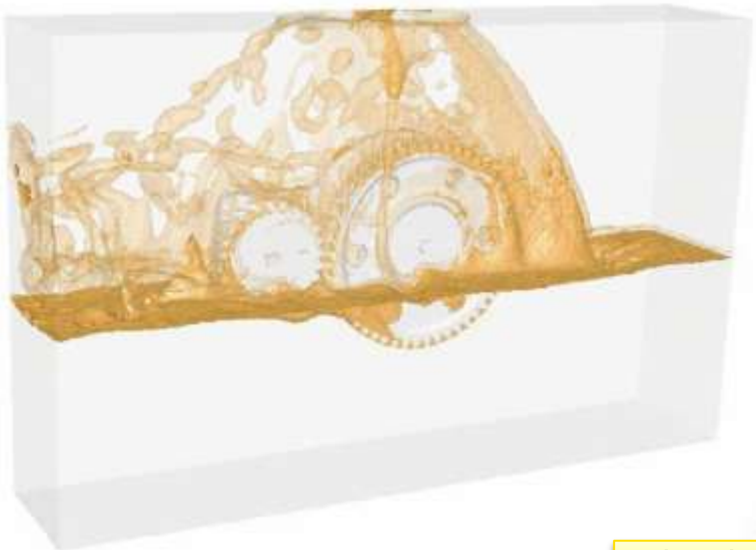
Conclusions

- Numerical models developed to use CFD in transient multiphase gearbox applications.
- Performed DoE to screen most important factors on oil splashing, losses & calculation time.
- Approaches with more physics and higher order solution methods are:
  - More compute intensive, but show a faster moment stabilization.
  - Show more realistic effects and are closer to literature results.
- Early design stages with simplified gears, detailed analysis needs more physics.



Outlook

- Test rig investigations to receive known accuracy or deviation of stronger idealized models.
- Further investigations with numerical methods needed:
  - Turbulence models & near wall treatment with boundary layers
  - Surface tension models
- Speedup & Scalability improvements desired.
- Investigation of the interaction between the influencing factors.
- ANSYS Support extremely valuable in case of new methodology or any issues! Thank you!



Animation

JOHN DEERE