

The logo for the NAFEMS UK Conference 2016 is located in the top right corner. It features a stylized graphic of several overlapping triangles in shades of red, grey, and black. To the left of this graphic, the text "NAFEMS" is written in a large, bold, red sans-serif font.

NAFEMS

UK^{CONFERENCE}

2016

June 15-16
Telford

Advances in CFD Simulation of Positive Displacement Machinery

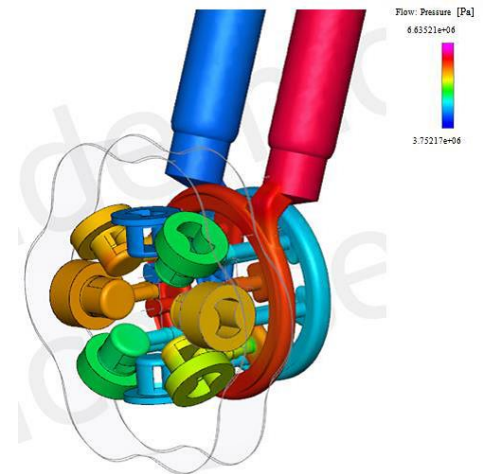
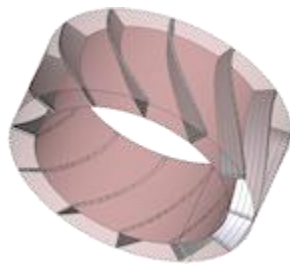
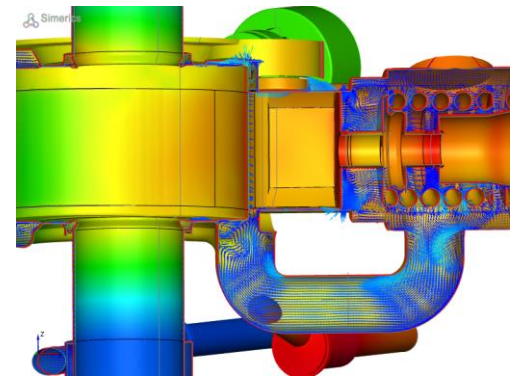
Sean Horgan, 80/20 Engineering Ltd
Michael Clapp, 80/20 Engineering Ltd



Advances in CFD Simulation of Positive Displacement Machinery

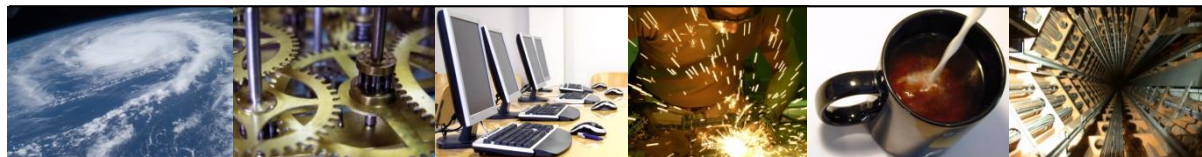
- **AGENDA – ‘NAFEMS UK - 15th June 2016’**

- Brief Company Overview – 80/20 Engineering Ltd
- Technology Advances in CFD for Fluid Machinery
 - Mesh Generation Adapted for Fluid Machinery
 - Machinery Specific Template Based Simulation
 - Advanced Cavitation Modelling
 - Accuracy, Speed and Robustness
- Bosch Rexroth – MCR Radial Piston Motor
- Compressor Modelling (Rolling Piston/Scroll/Screw)
- Conclusions



80/20 Engineering

- ***The Value 80/20 Engineering delivers:***
 - Design Engineers need to evaluate many concepts quickly and easily, so need a real alternative to traditional physical testing...
 - **CFD/CAE tools for Product Development**
 - Some Flow/Thermal/Structural applications are very complex in nature and often companies just don't possess the resources and/or competencies to perform in-house simulation....
 - **High Level Simulation Consultancy**



80/20 CFD Solutions

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***‘Turbo-Machinery Design
Software’***

CFturbo

***‘Design and Analysis of
Positive Displacement
Screw Machines’***

SCORG

***‘CFD Analysis for all
Pump types inc PD’***

Simerics-PD/Turbo
(PumpLinX)

Technology Advances in CFD

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- Mesh Generation Adapted for Fluid Machinery
- Fluid Machinery Specific Template based Simulation
- The Modelling of Aeration/Cavitation
- Accuracy, Speed and Robustness – Pumping Systems

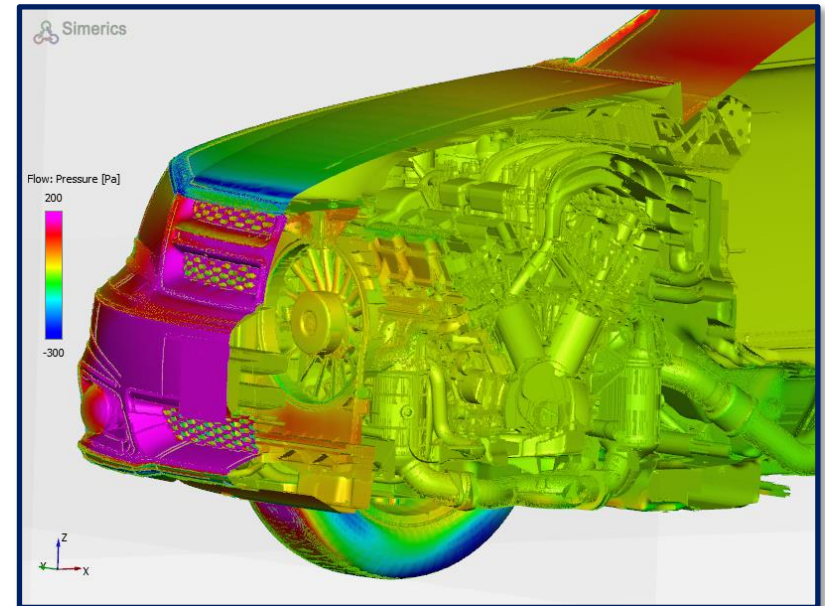


Mesh Generation for Fluid Machinery

Binary Adaptive Tree Methodology

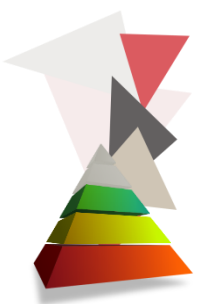
A Binary Adaptive Tree mesher can mesh very complex geometries and accept CAD geometry with flaws, as illustrated by the following example for under-hood airflow:

1. All the parts outside passenger cabin were meshed.
2. The starting point of this study was an CAD model in STL format (~11 million faces). The model was imported and meshed without any geometry repair operations.
3. The wall clock to mesh the entire model took about 2.5 hours*. The mesh size for the entire model: ~46 million cells*.
4. The simulation for one condition took about 18 hours*. (10 – 30 faster than for other methods)



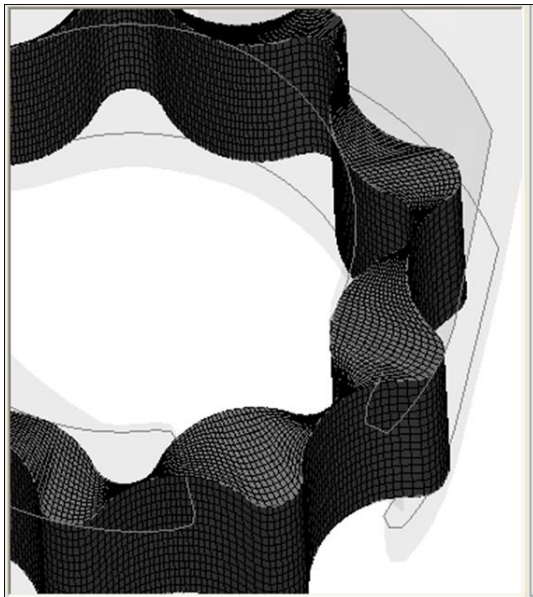
SPEED and DETAIL!

**Note: Computation was done on a dual quad core Xeon 5550 (2.67GHz) PC with 48 GB memory.*



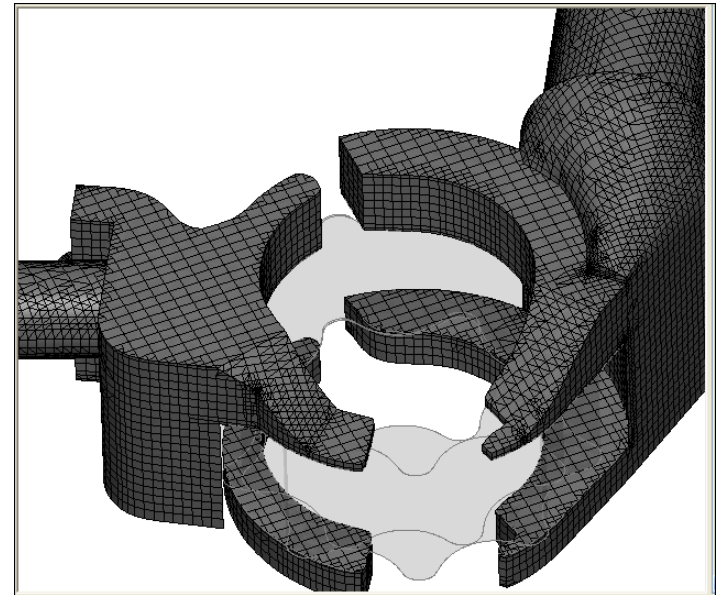
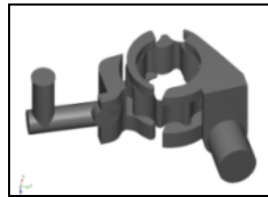
Optimized Mesh Topology and Dynamics

- Automatically generates an optimized grid for the specific positive displacement component.
- Automatically generates a Binary Tree mesh for general structures.



1) Structured Grid for Machine Specific Geometry

Start with a CAD
"stl" surface file



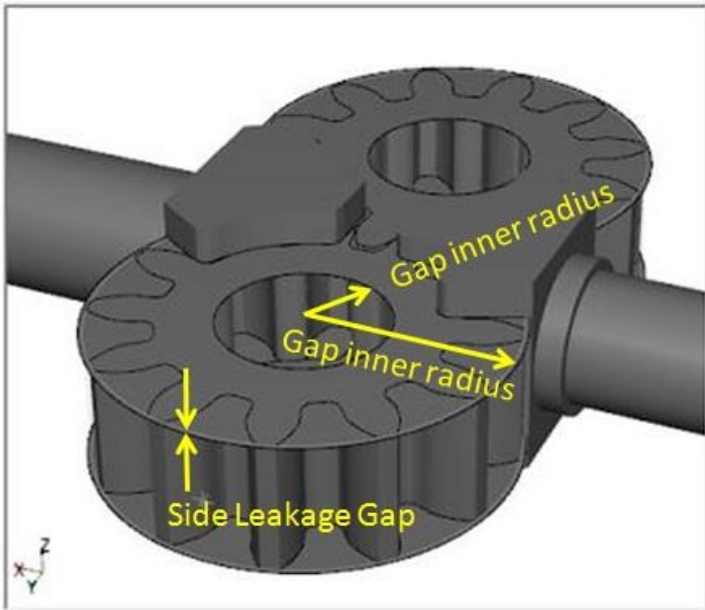
2) Automated Binary Tree Grid for General Structures

Typical time to generate a grid from CAD is 10-30 minutes



Modeling Leakage Gaps

The CFD technology needs the ability to add in pump specific micron-scale clearances that are not included typically in the 3D CAD geometry

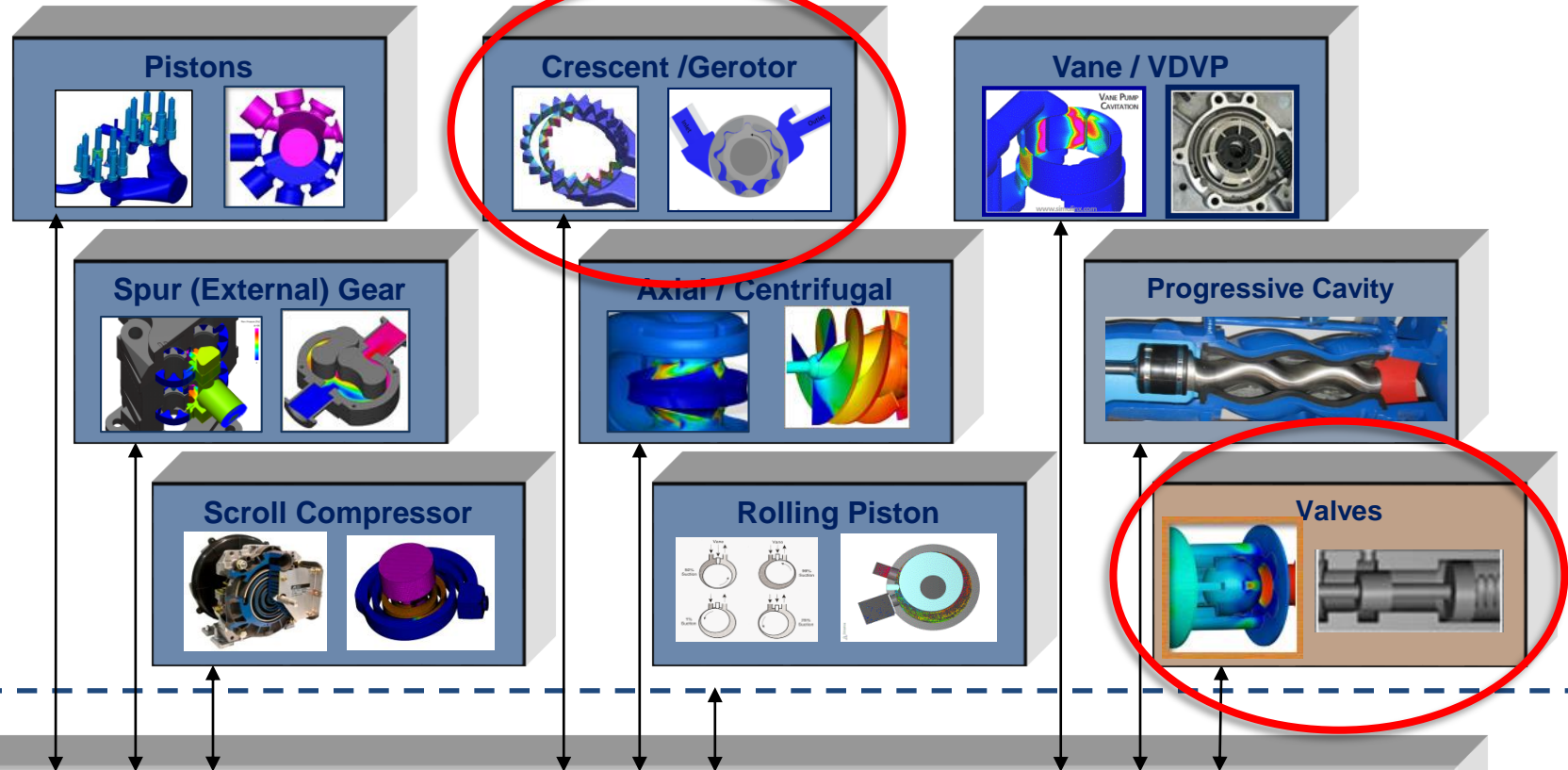


Reasons for including gaps

- Determine leakage/losses
- Compute torques and power
- Compute loads
- Identify the cause of cavitation damage

Machinery Specific Templates

A Templates Structure

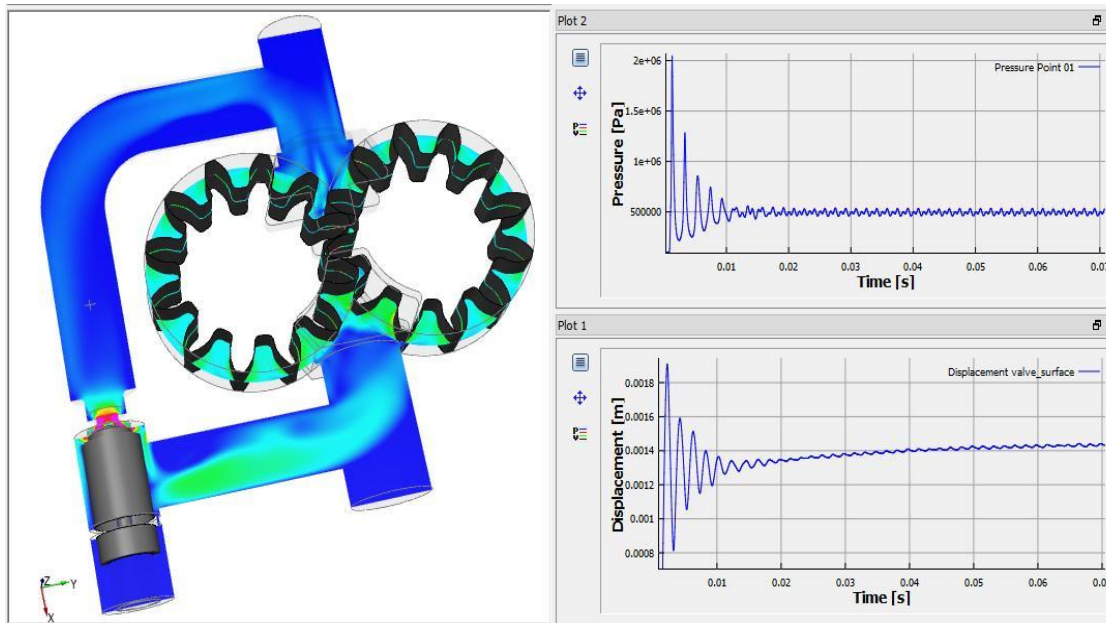


- Flow, Pressure, Heat, Species, Particles
- Aeration & Cavitation: Non-Condensables / Vapor / Compressibility
- Volume Motion and Deformation: Rotation / Translation / Scaling
- Automated Binary-Tree Mesh & Implicit Matching Across Interfaces (MGI)
- Engineering Output: Points / Integrated Data (Volumes & Surfaces)



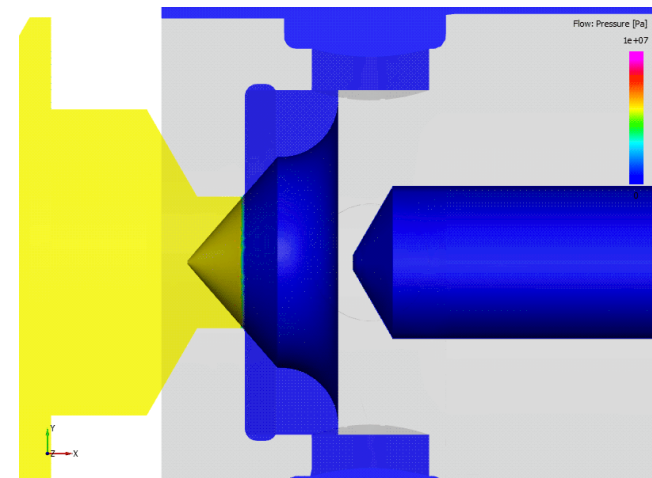
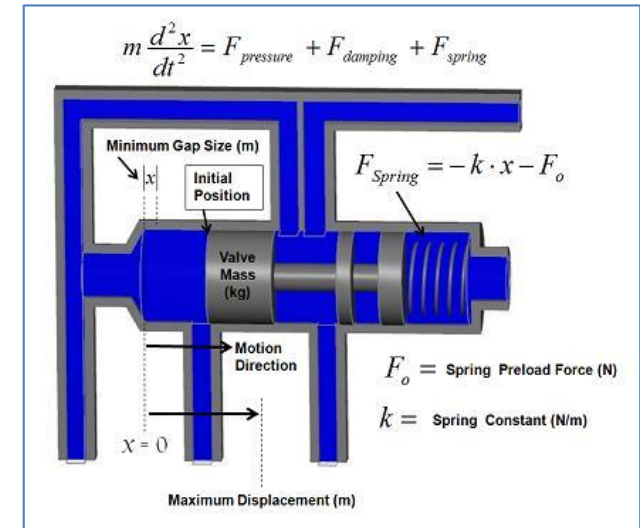
Component-specific mesh generator

Coupled transient valve and External pump simulation:



Facilitates Valve Dynamics

Predicts Cavitation





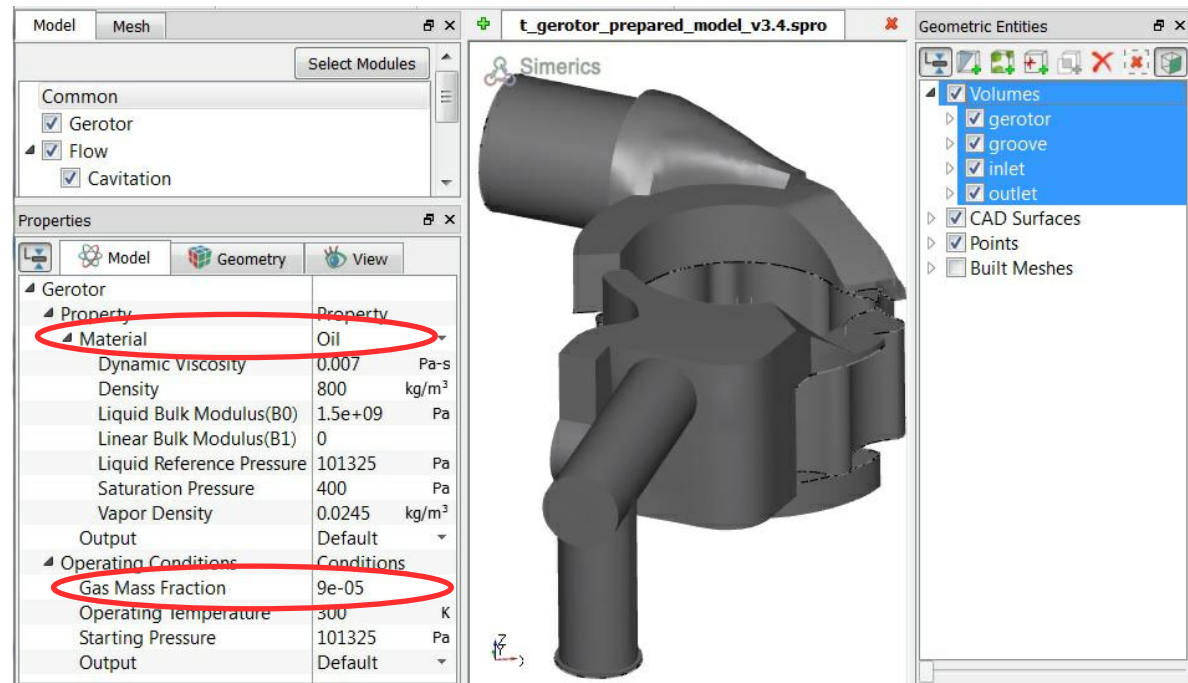
Protective Logic to reduce the potential for errors

Material Properties

- Select oil (from template db)
- Use default air mass fraction (6% by volume at 1 atm)

Property Options

- Read from external source (e.g. NIST database)
- Non-Newtonian
- Input functions (e.g. $\mu=f(T)$)
- Change default values





Modeling Aeration / Cavitation

Predicting the dynamics of aeration and cavitation in liquids

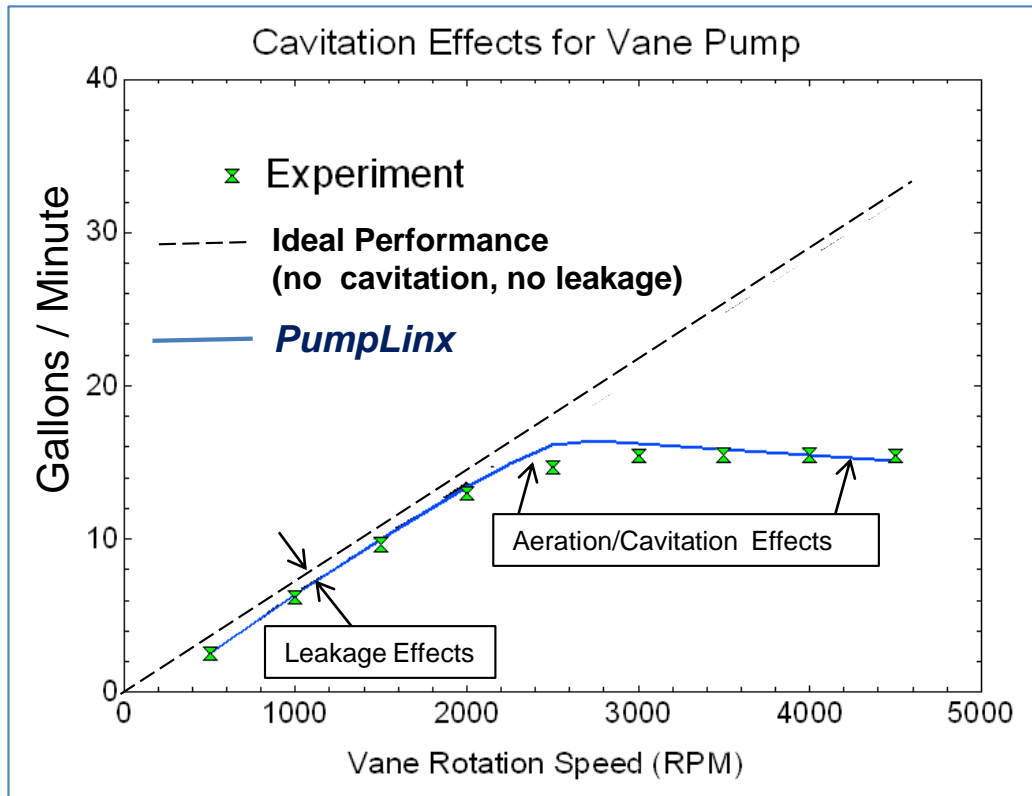
Five Aeration/Cavitation mechanisms that are important when modeling PD Machines:

- Dissolved Gas (Equilibrium and finite rate)
- Free/Undissolved Gas (Fixed or variable mass fraction)
- Liquid Compressibility

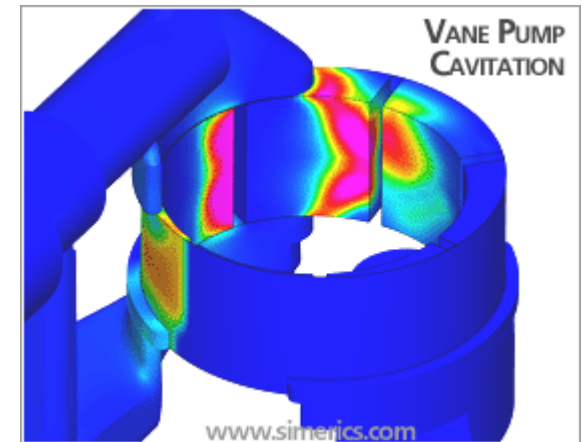
Robust, accurate and efficient Cavitation Modeling

Ding, H., Visser, F.C., Jiang, Y. and Furmanczyk, M. 2011 "Demonstration and validation of a 3D CFD simulation tool predicting pump performance and cavitation for industrial applications", J. Fluids Eng. – Trans ASME, 133(1), 011101

Validation a Pump Performance Curves

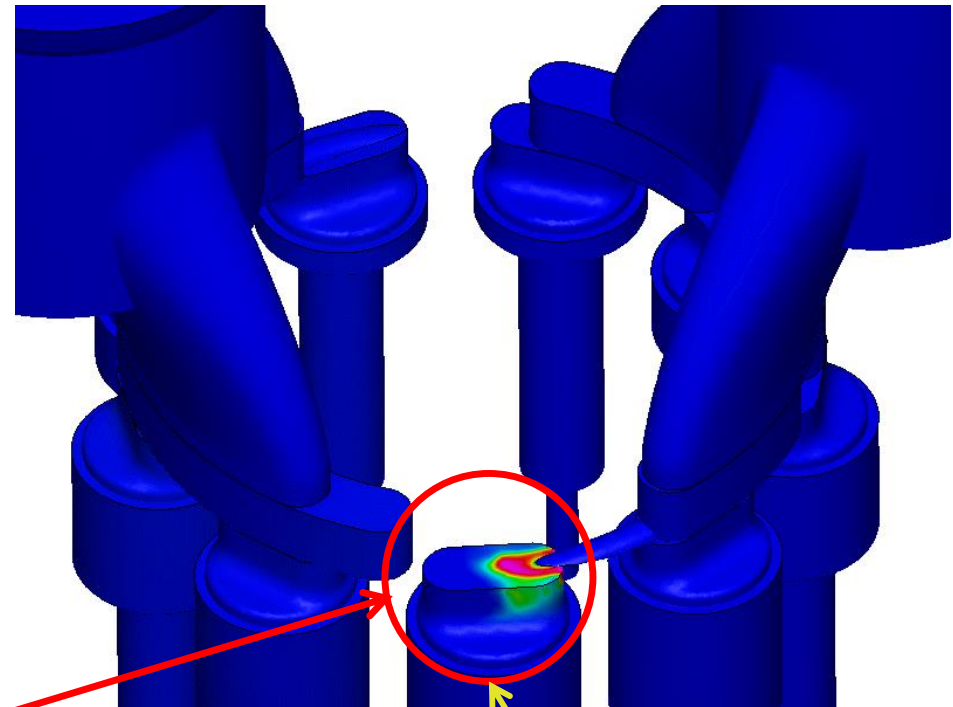
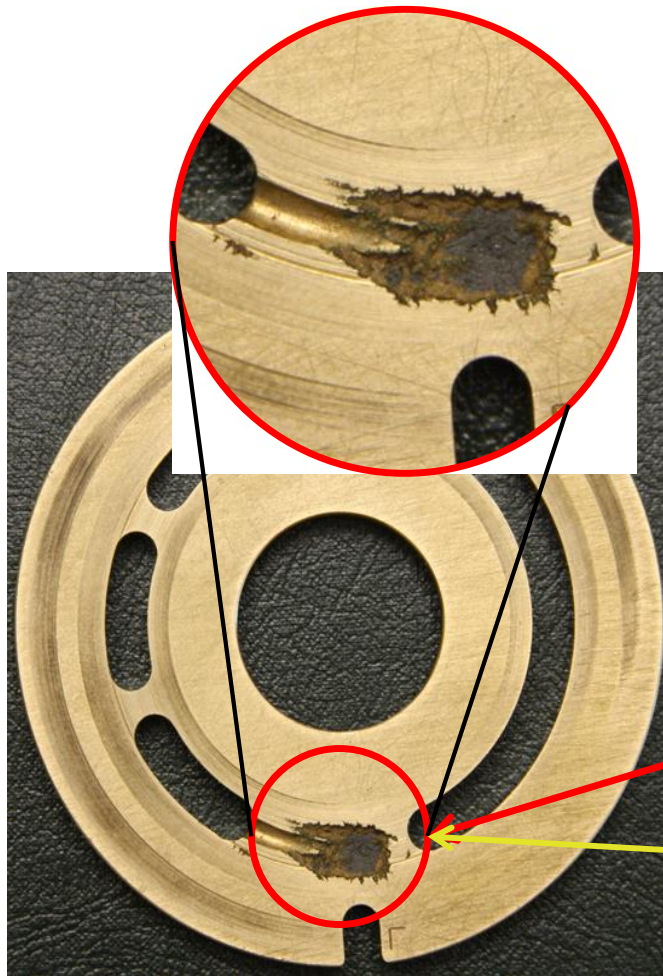


Geometry &
Data
Courtesy of
Ford Motor
Company





Indicates Location of Potential Cavitation Damage



Cavitation
erosion on the
valve plate

CFD predicted
cavitation bubble

Pump Courtesy of Parker Hannifin

Bulk Modulus

Compressibility =
f (air, vapor, bulk modulus)

Bulk Modulus Model in Pumplinx

Pumplinx uses Nykänen et al's model^{*}, where the bulk modulus B is modeled as:

$$B = \frac{\rho_0}{\frac{\partial \rho}{\partial P}} = B_0 + B_1(P - P_0)$$

When $B_1 = 0$,

$$\rho = \rho_0 \left[1 + \frac{(P - P_0)}{B_0} \right]$$

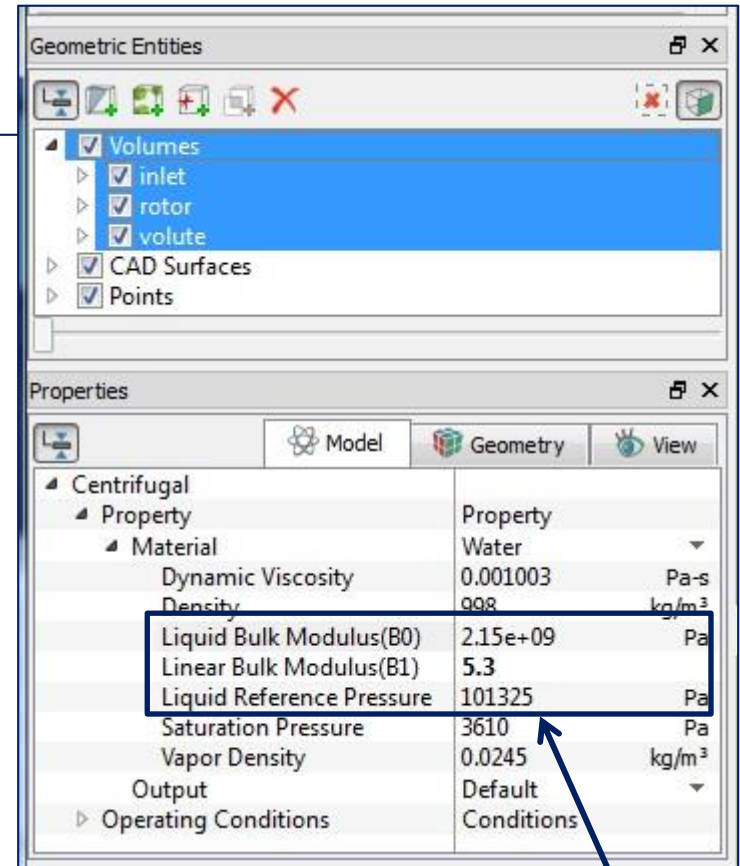
When $B_1 \neq 0$,

$$\frac{\partial \rho}{\partial P} = \frac{\rho_0}{B_0 + B_1(P - P_0)}$$

$$\text{Then } \rho = \rho_0 \left[1 + \frac{1}{B_1} \ln \left(1 + \frac{B_1}{B_0} (P - P_0) \right) \right]$$

Where ρ_0 and P_0 are the reference density and pressure.

^{*} Reference: Nykänen T., H., A., Esque, S., Ellman, A., U. (2000) Comparison of different fluid models. Bath workshop on Power Transmission and Motion Control (PTMC2000), Bath, 2000, P101-110

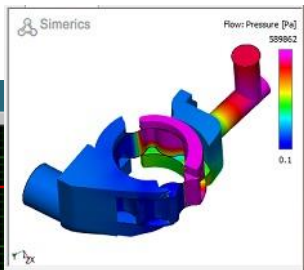
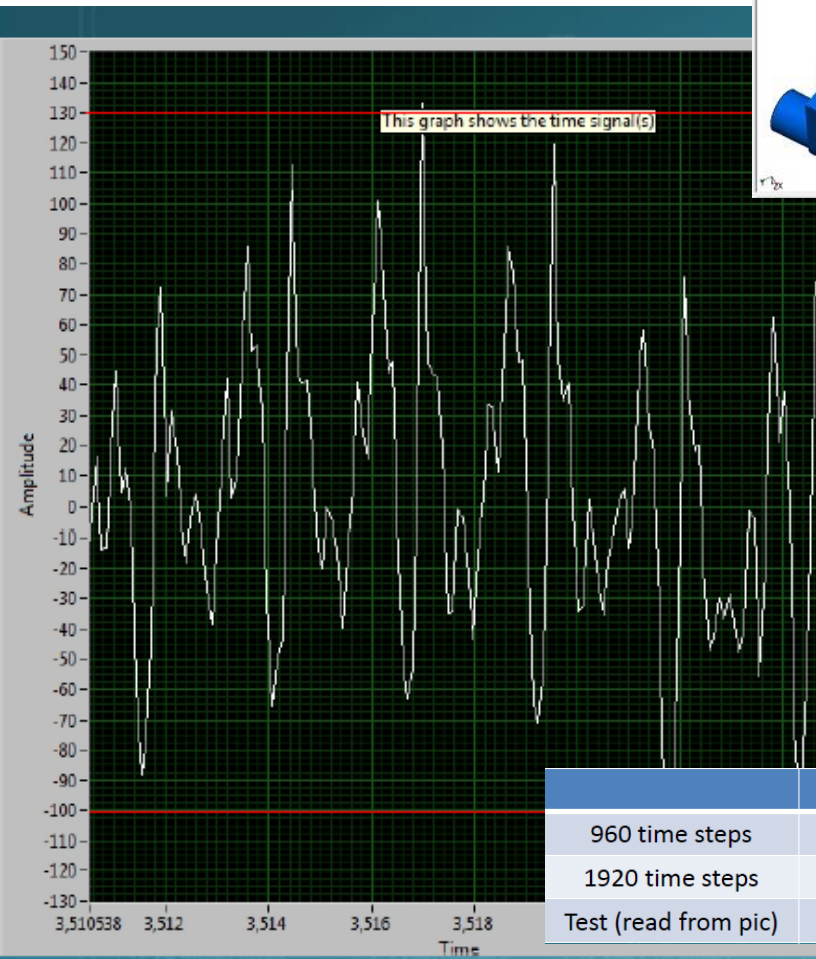


The Bulk Modulus can be made a function of pressure

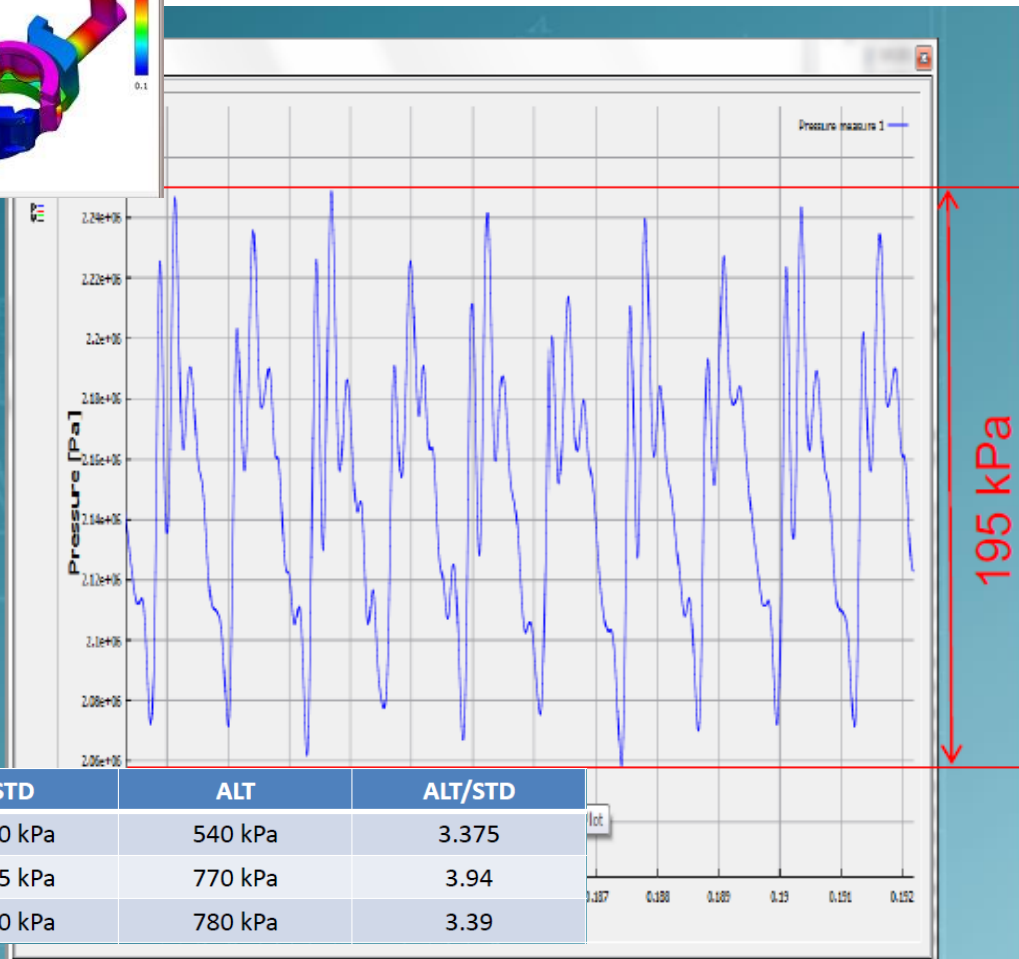


Predicting Pressure Ripples / Noise

Measured



PumpLinx



	STD	ALT	ALT/STD
960 time steps	160 kPa	540 kPa	3.375
1920 time steps	195 kPa	770 kPa	3.94
Test (read from pic)	230 kPa	780 kPa	3.39

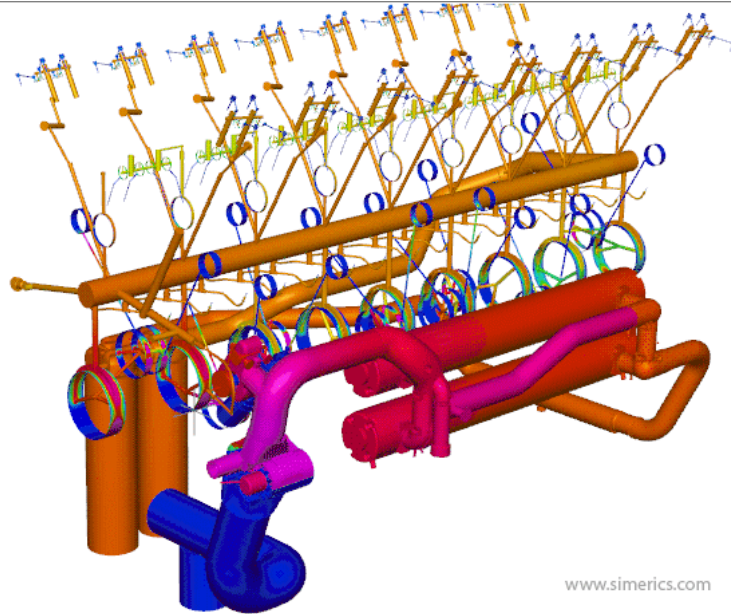
Gerotor Outlet Pressure vs. Time



Accuracy, Speed and Robustness

Complete Lubrication System Of A 16 Cylinder Engine Including:

Pickup Tube
Gear Pump
Pressure Regulator
Oil Cooler
Oil Filter
9 Main Bearings
16 Conrod Bearings
16 Piston Pins
7 Camshaft Bearings
32 Valve Lifters
16 Piston Cooling Jets
And More...



www.simerics.com

Pumping (or Lubrication) Systems



Pump Systems

Enables large / Complex systems

Imprint

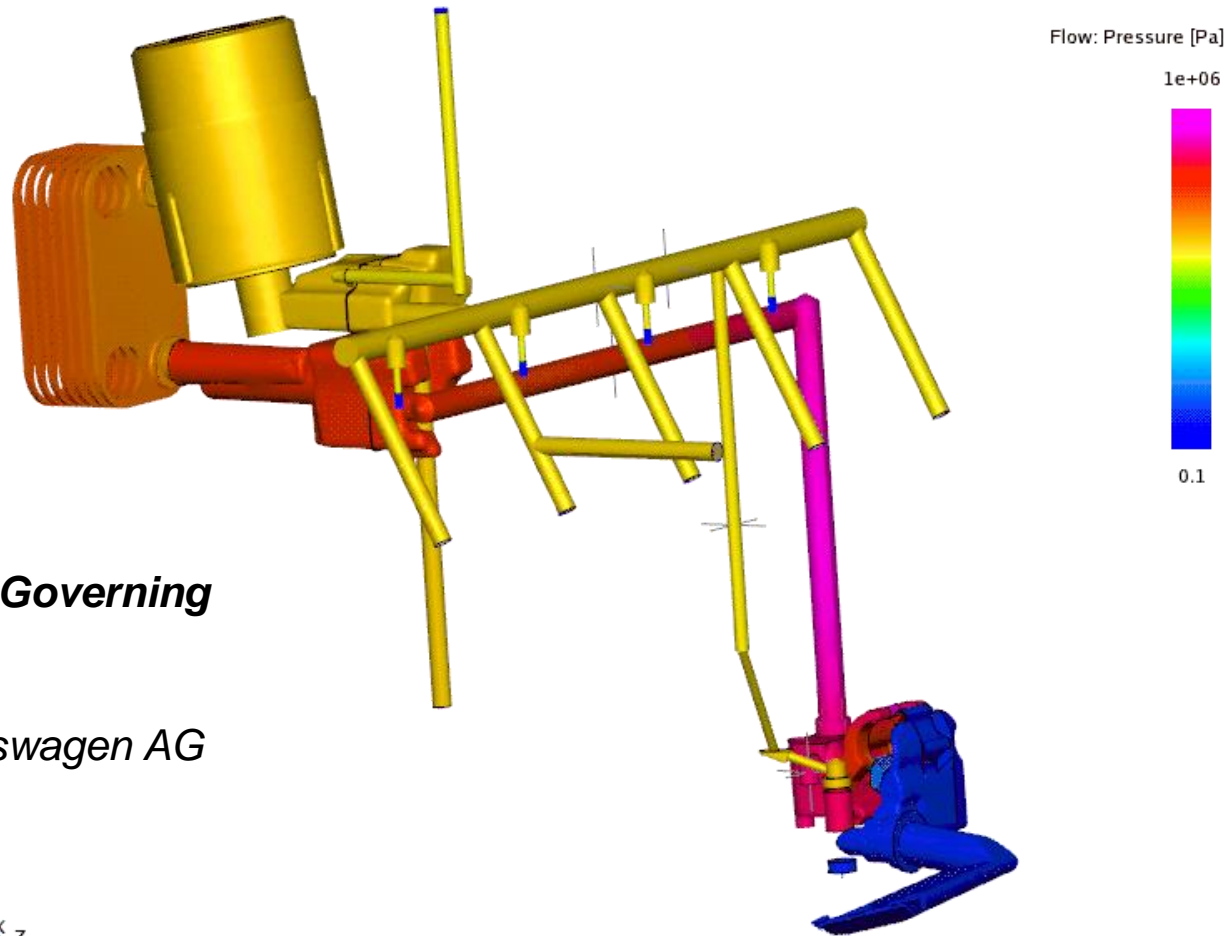
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Advanced Simulation of the Governing Oil System of an Engine

Dr. Andreas Gitt-Gehrke, Volkswagen AG
Tobias Duffe, Volkswagen AG

Dr. Hui Ding, Simerics Inc.





Bosch Rexroth - Radial Piston Motor

Rexroth
Bosch Group

The Drive & Control Company

‘Computational Fluid Dynamics Modeling of a Hydraulic Radial Piston Motor’ was presented at the International Conference on Mechanics, Building Material and Civil Engineering (MBMCE 2015), Guilin, China with joint authors from Bosch Rexroth and Leicester University.



Bosch Rexroth - Radial Piston Motor

- Bosch Rexroth
 - The Drive and Control Company
 - Develop and Manufacture Hydraulic Machinery
 - User Experience is from Glenrothes, Scotland
 - Specific Example – Radial Piston MCR Motor
 - Objective to increase the understanding of the MCR motor's function through modelling and simulation
 - Optimization in terms of flow losses and pressure fluctuations leading to enhanced mechanical efficiency and lower noise outputs.



Bosch Rexroth - Radial Piston Motor

- Leicester University – Validation Exercise
 - Department of Mechanical Engineering - Dr Shian Gao.
 - Final year's thesis project – Kane Osborne
 - Motor selected with extensive experimental data available for comparison purposes.
 - Full Transient 3D simulation 8 pistons, CAM
 - Fixed Motor speed and Flow Driven simulations
 - Pressure readings within Piston Bore, Inlet and Outlet

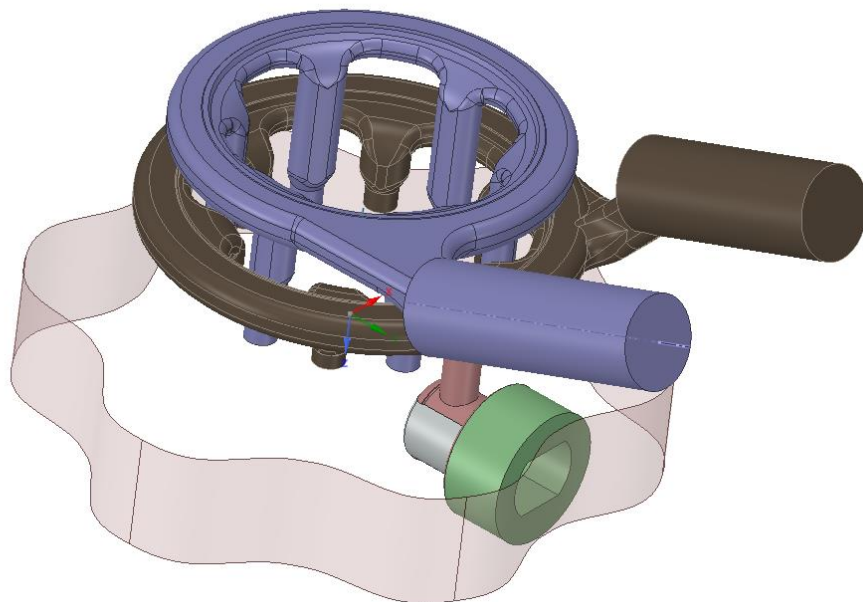


Bosch Rexroth - Radial Piston Motor



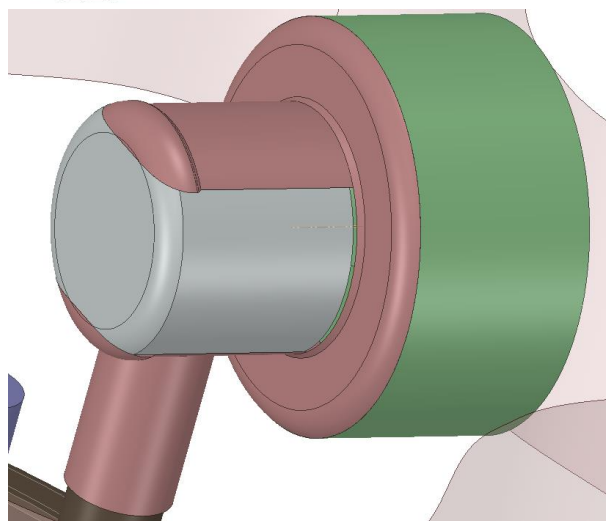


Bosch Rexroth - Radial Piston Motor



Flow volume extracted from mechanical geometry and then split into mesh regions: -

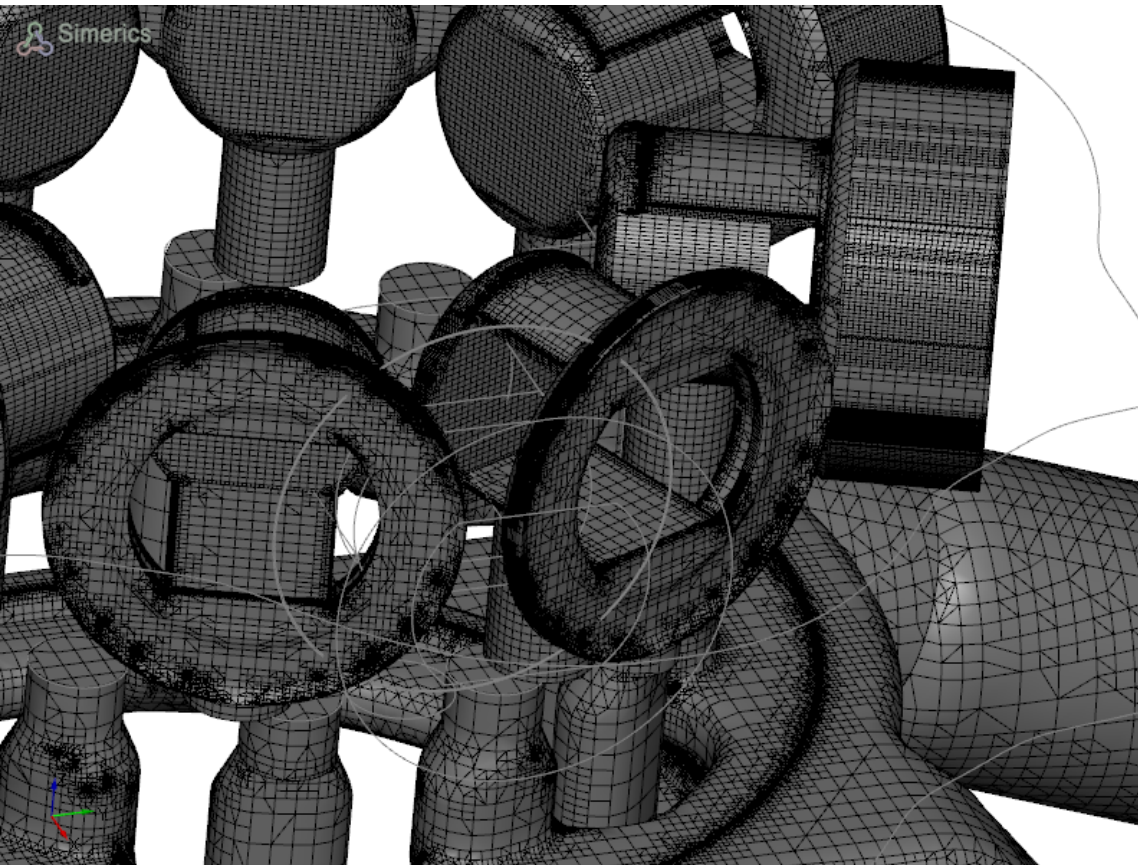
1. Inlet Port
2. Outlet Port
3. Rotating Connector
4. Inner Radial Piston
5. Outer Radial Piston



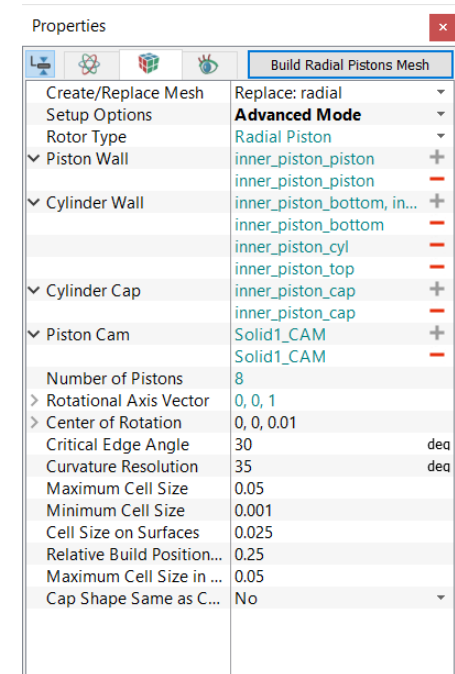
Only one instance of the pumping geometry is transferred to PumpLinX as the meshing templates will duplicate the mesh for this the required number of times.



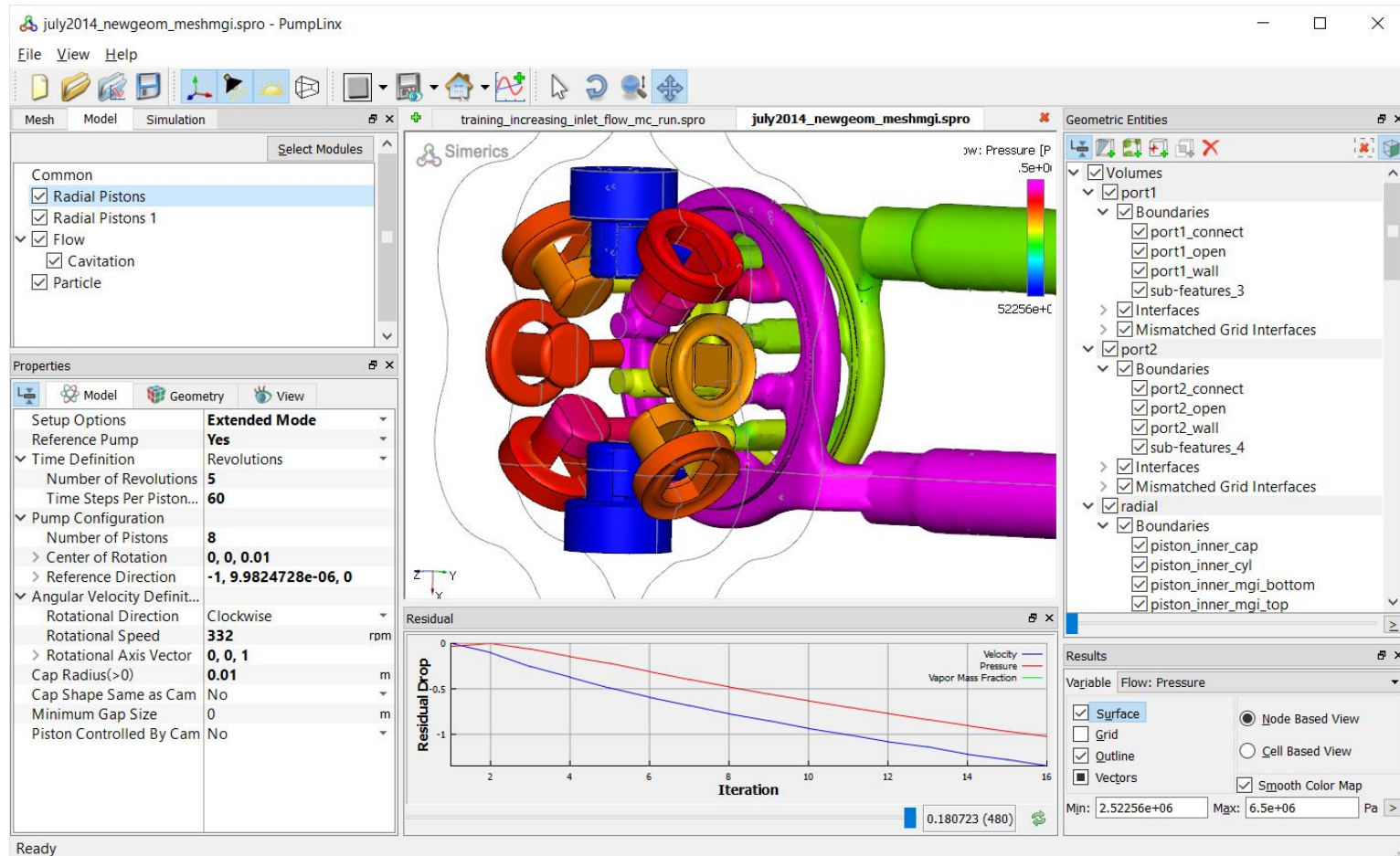
Bosch Rexroth - Radial Piston Motor



Binary Adaptive Tree mesh used for ports and connecting regions. Mesh templates used for inner and outer Radial Pistons. Mesh illustrated contains 3.3 million cells.



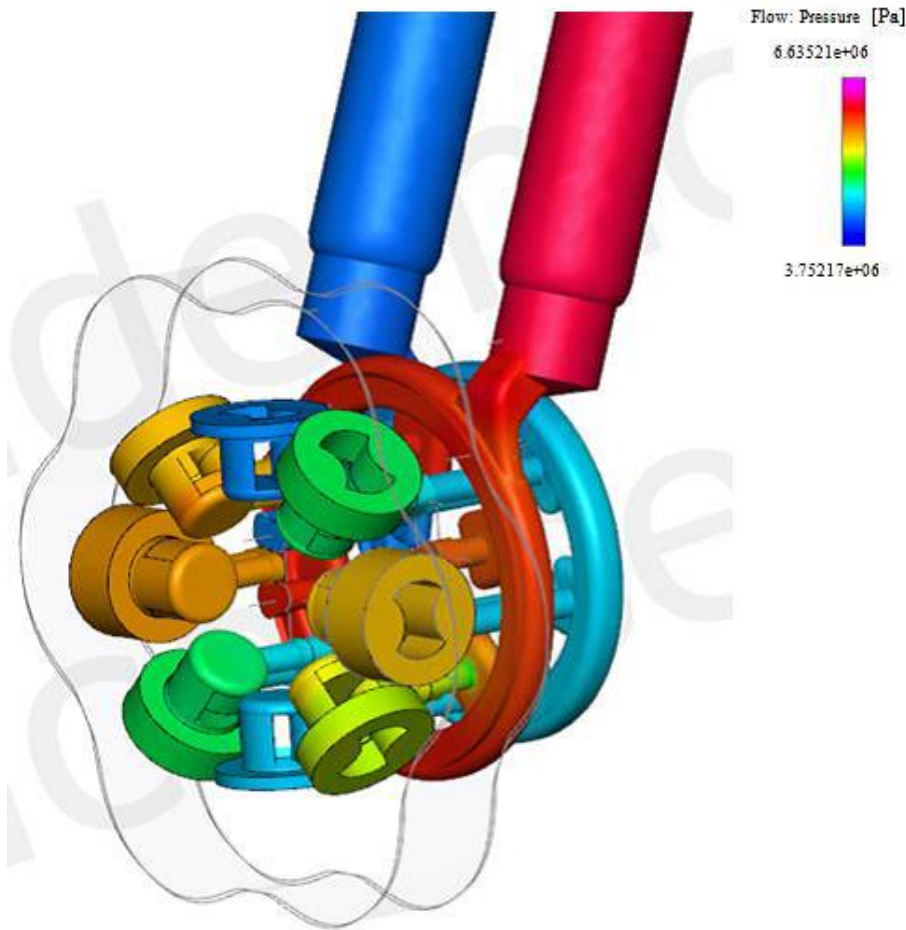
Bosch Rexroth - Radial Piston Motor



Initial models were run at constant RPM using Radial Piston template.
Cavitation/Aeration model used to allow for compressibility of Oil.
Run-time approximately 4 hours for one full revolution on i7 Laptop.



Bosch Rexroth - Radial Piston Motor

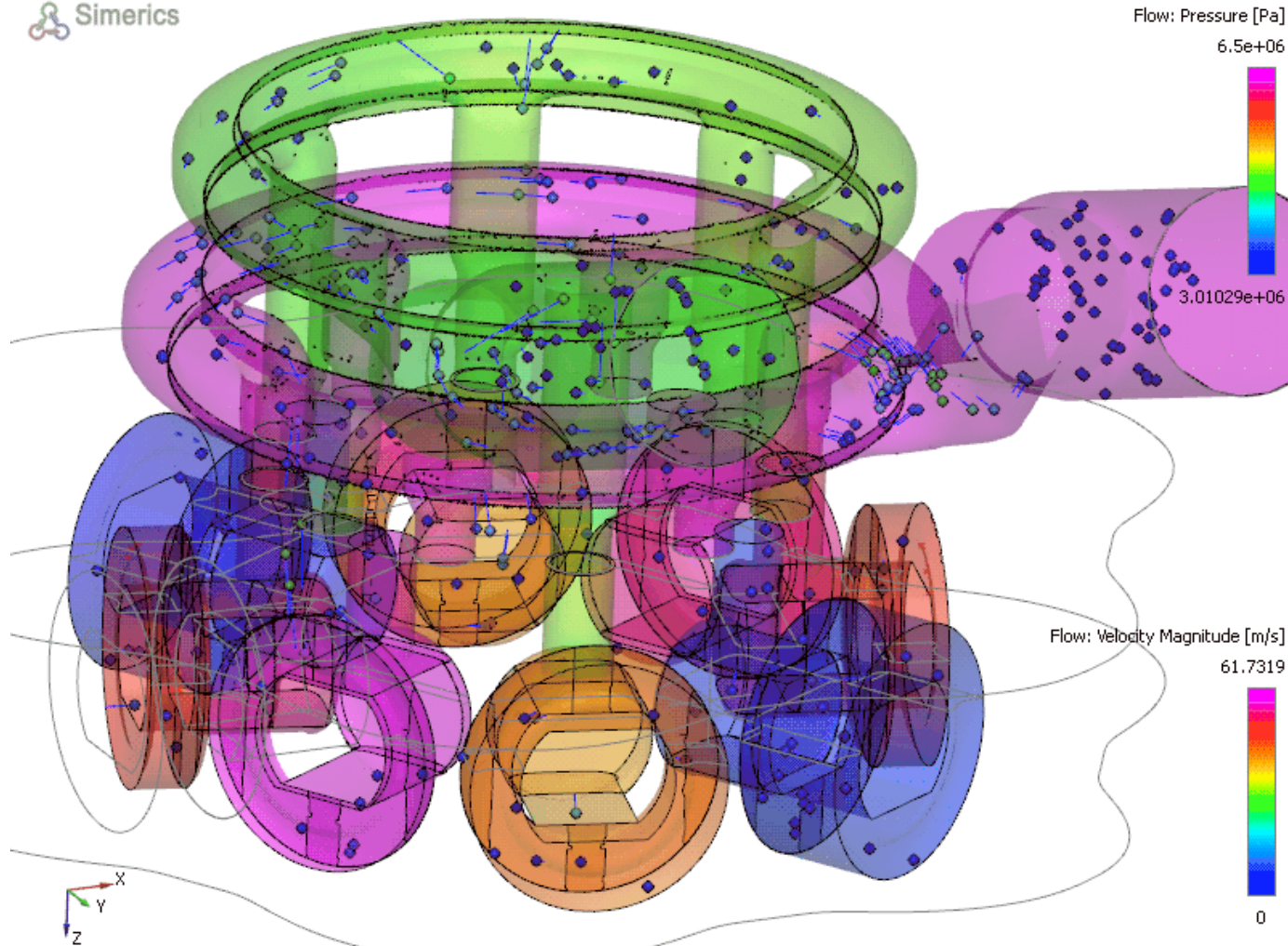


- 3D Pressure Distribution snapshot on exterior surfaces of Fluid domain
- 8 pistons being driven by a CAM simultaneously
- Substantial Delta P, large forces.
- Detailed study done on sensitivity to CAM shape.
- CFD is now in regular use at Bosch Rexroth in Scotland



Bosch Rexroth - Radial Piston Motor

 Simetrics



Compressor Simulations

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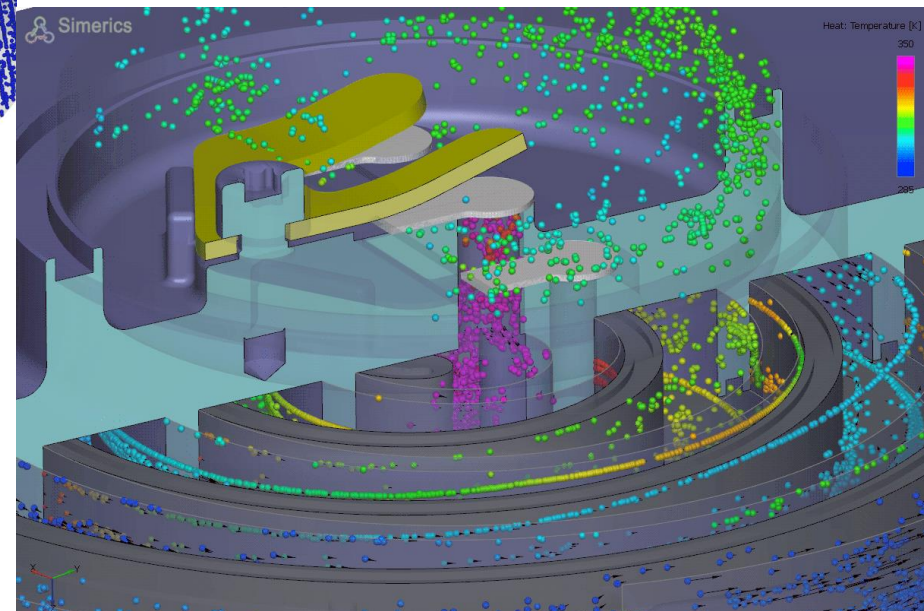
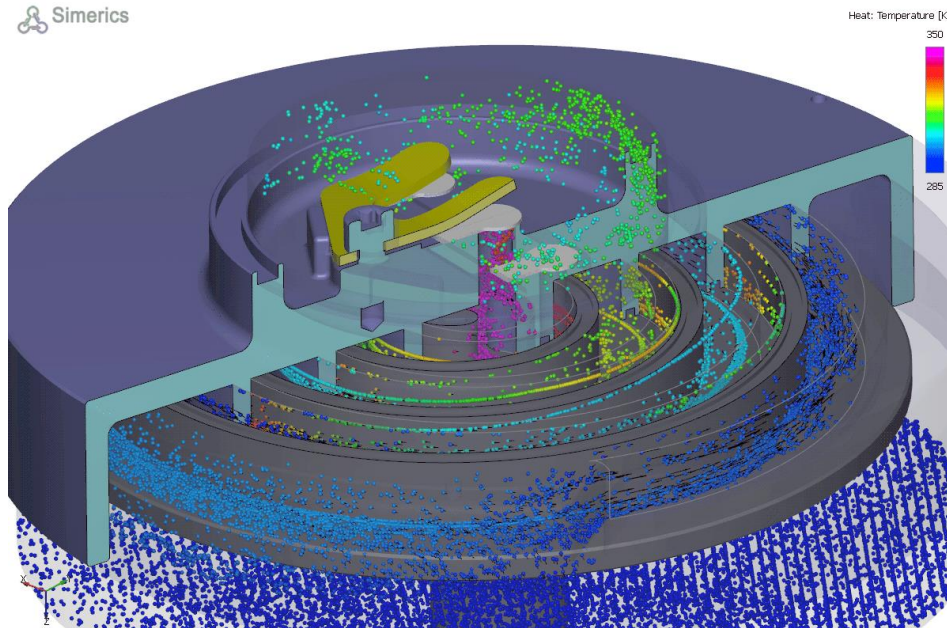
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Scroll, Rolling/Piston and Twin-Screw Examples
Particularly Challenging Positive Displacement
Machinery

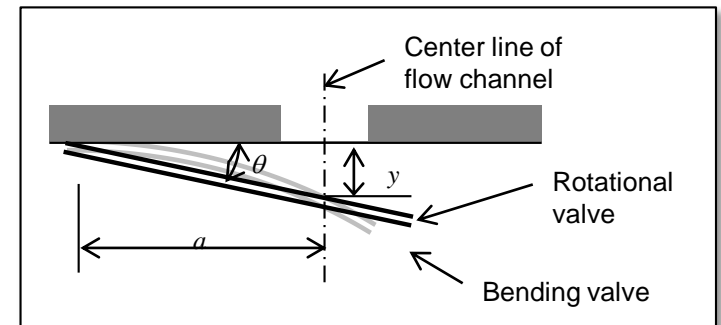
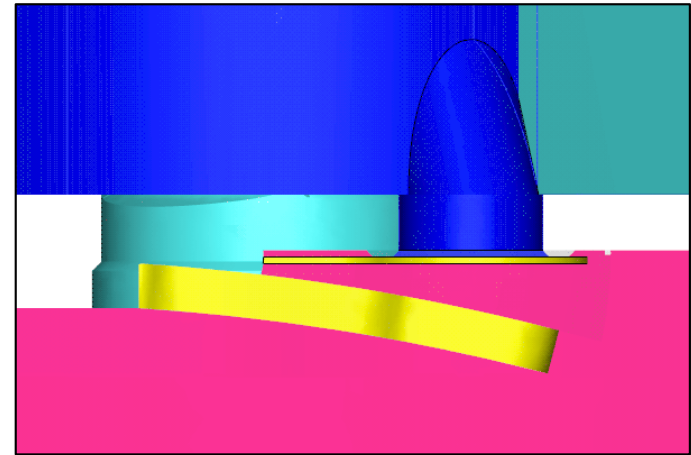
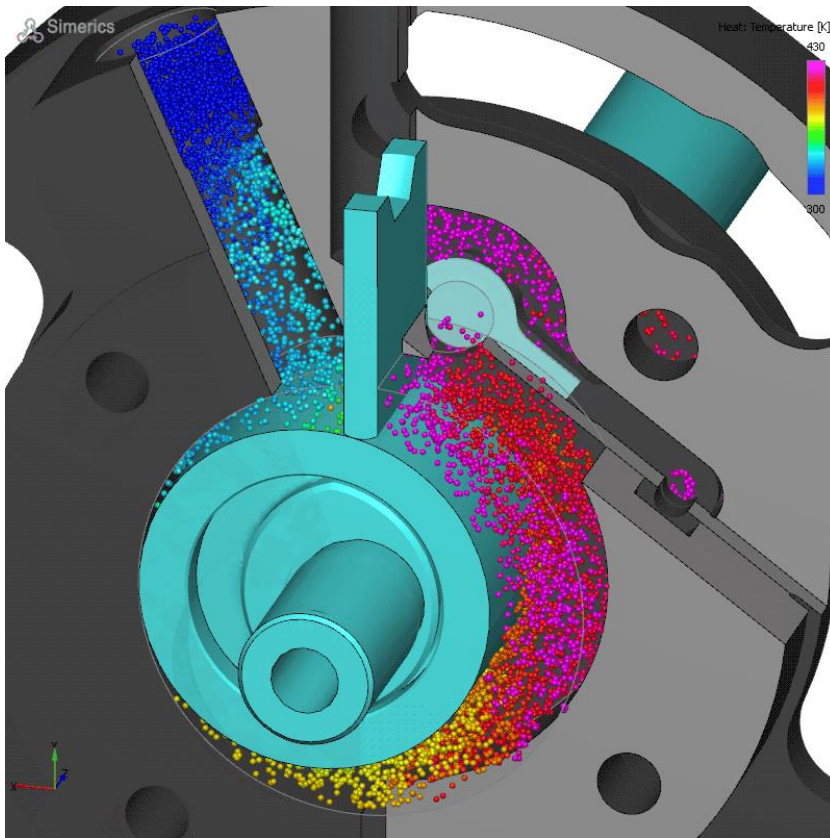
Compressor: Scroll Compressor

Simetrics



Compressor: Rolling Piston

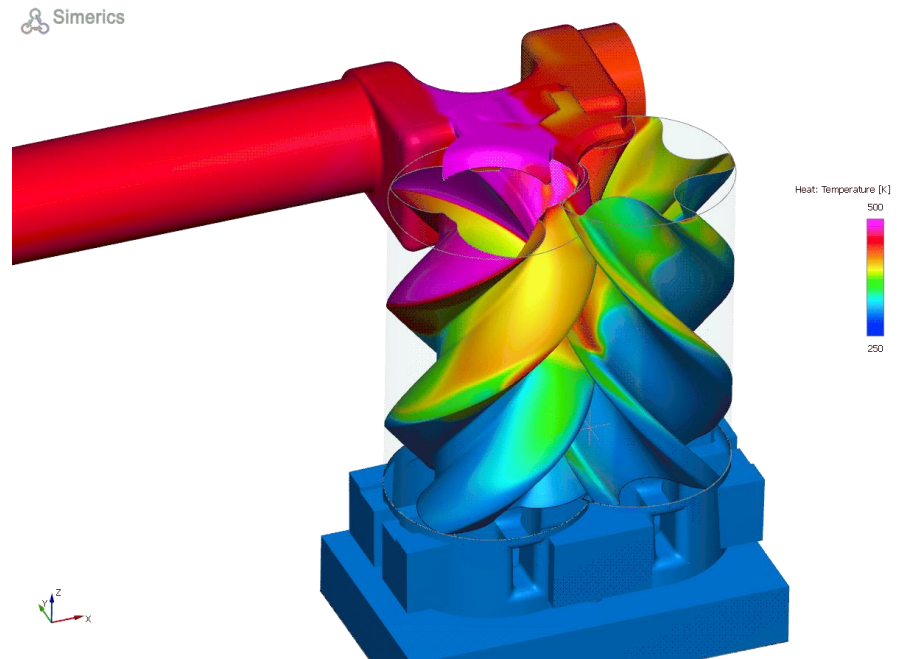
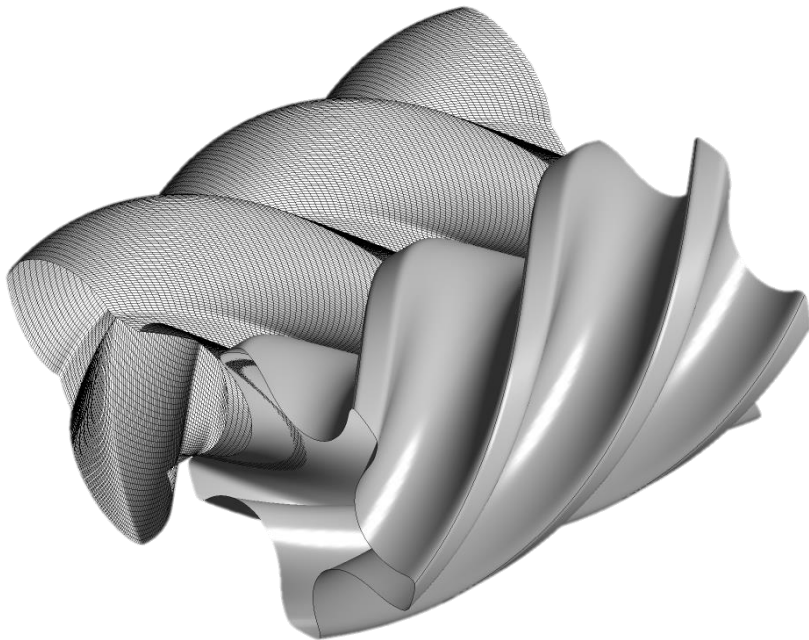
- With bending reed valve
- Real gas



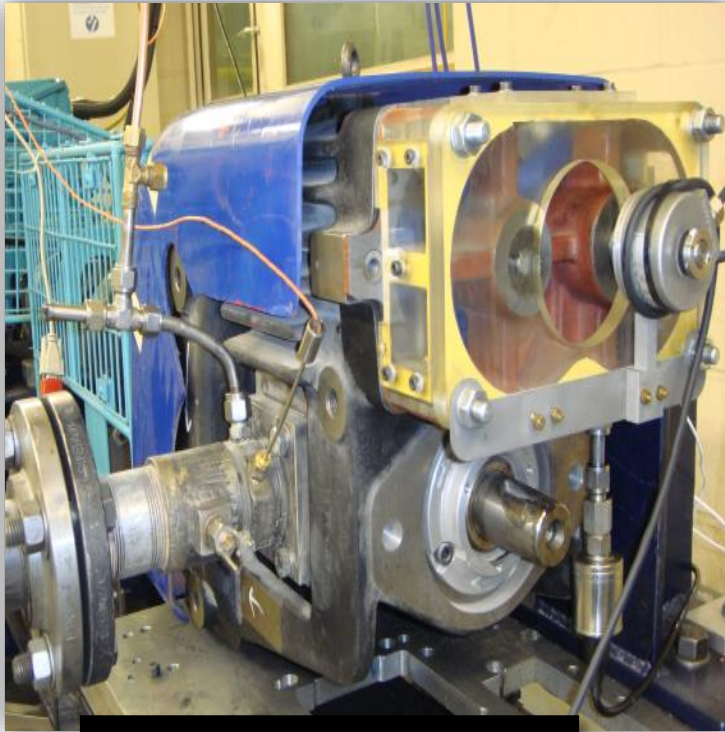


Analysis of leakage and multiphase flows in screw compressors using

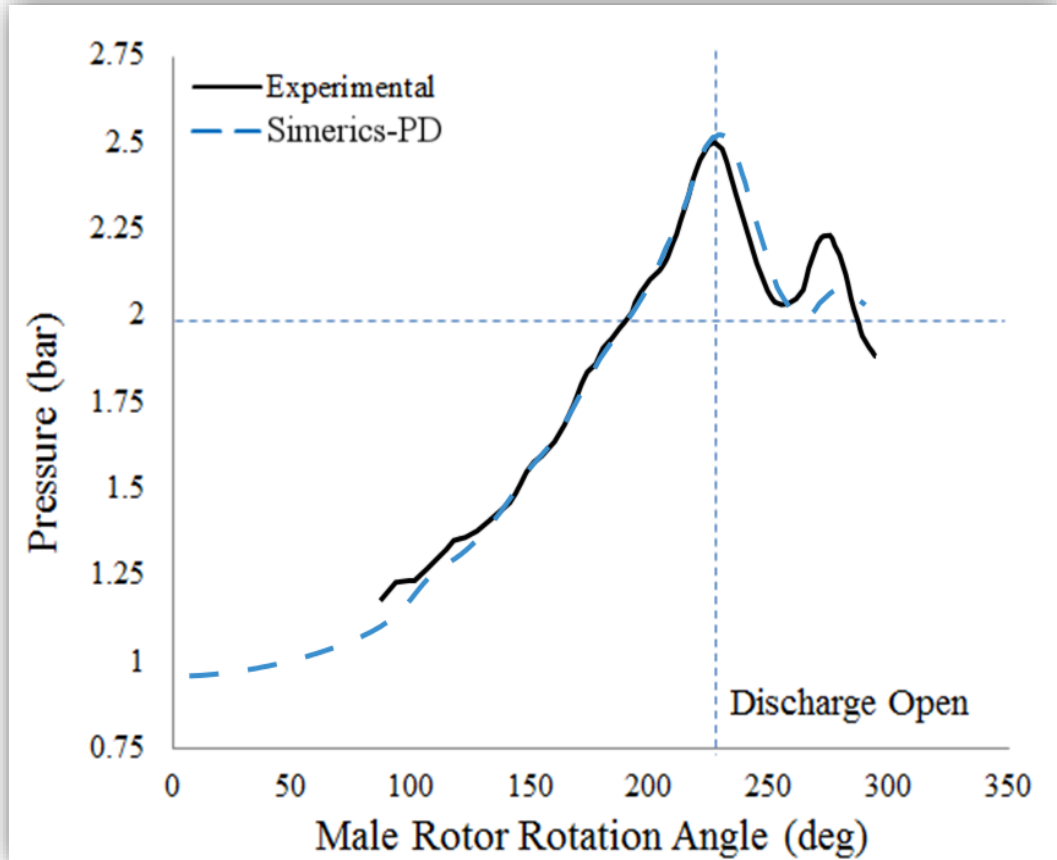
SCORG™ and Simerics-PD®



Results: Pressure vs. Male Rotor Angle

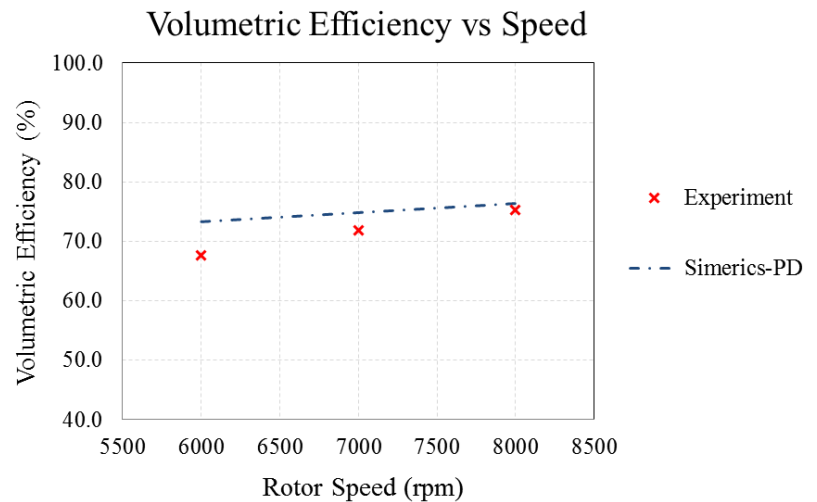
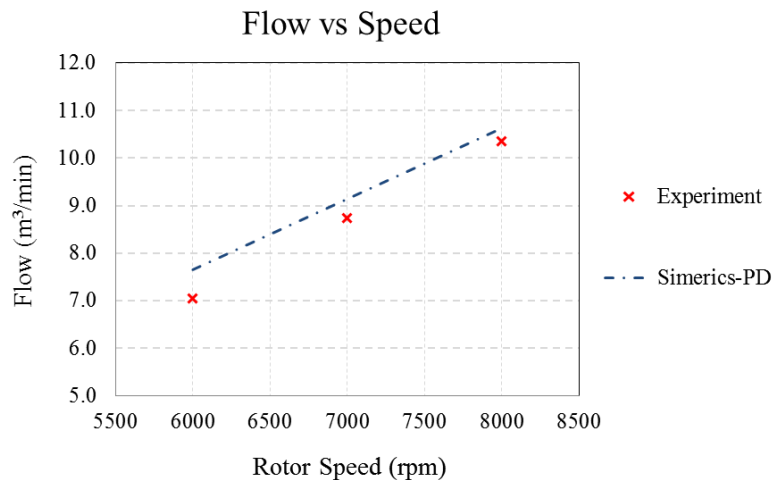
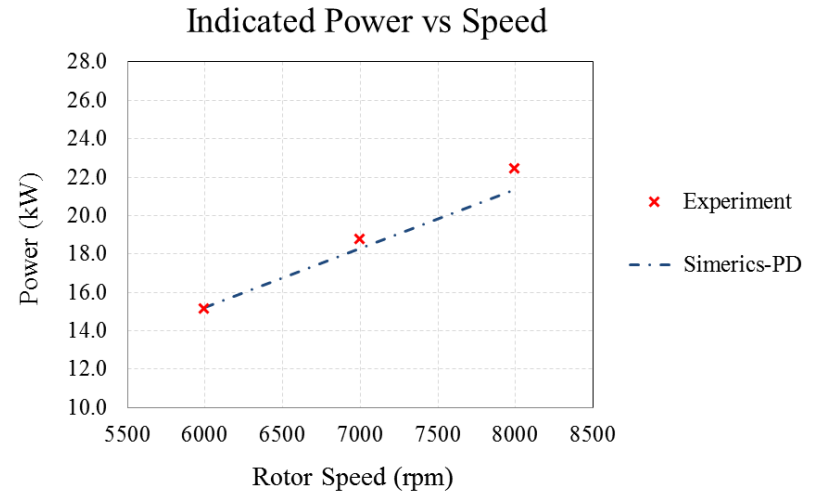
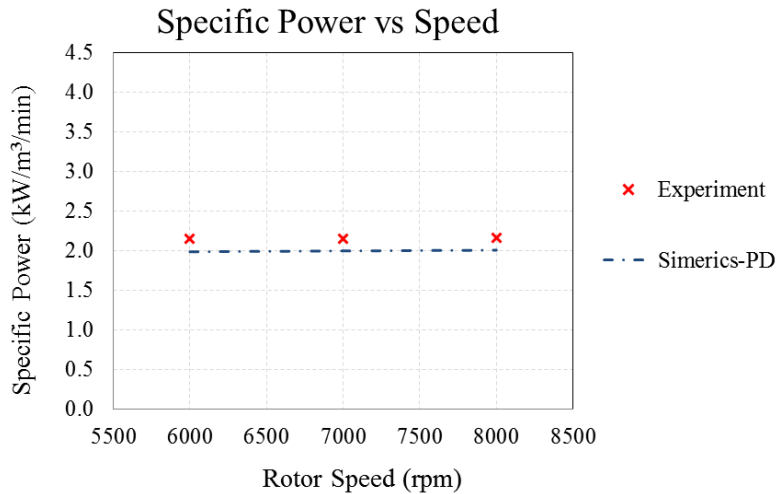


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LONDON

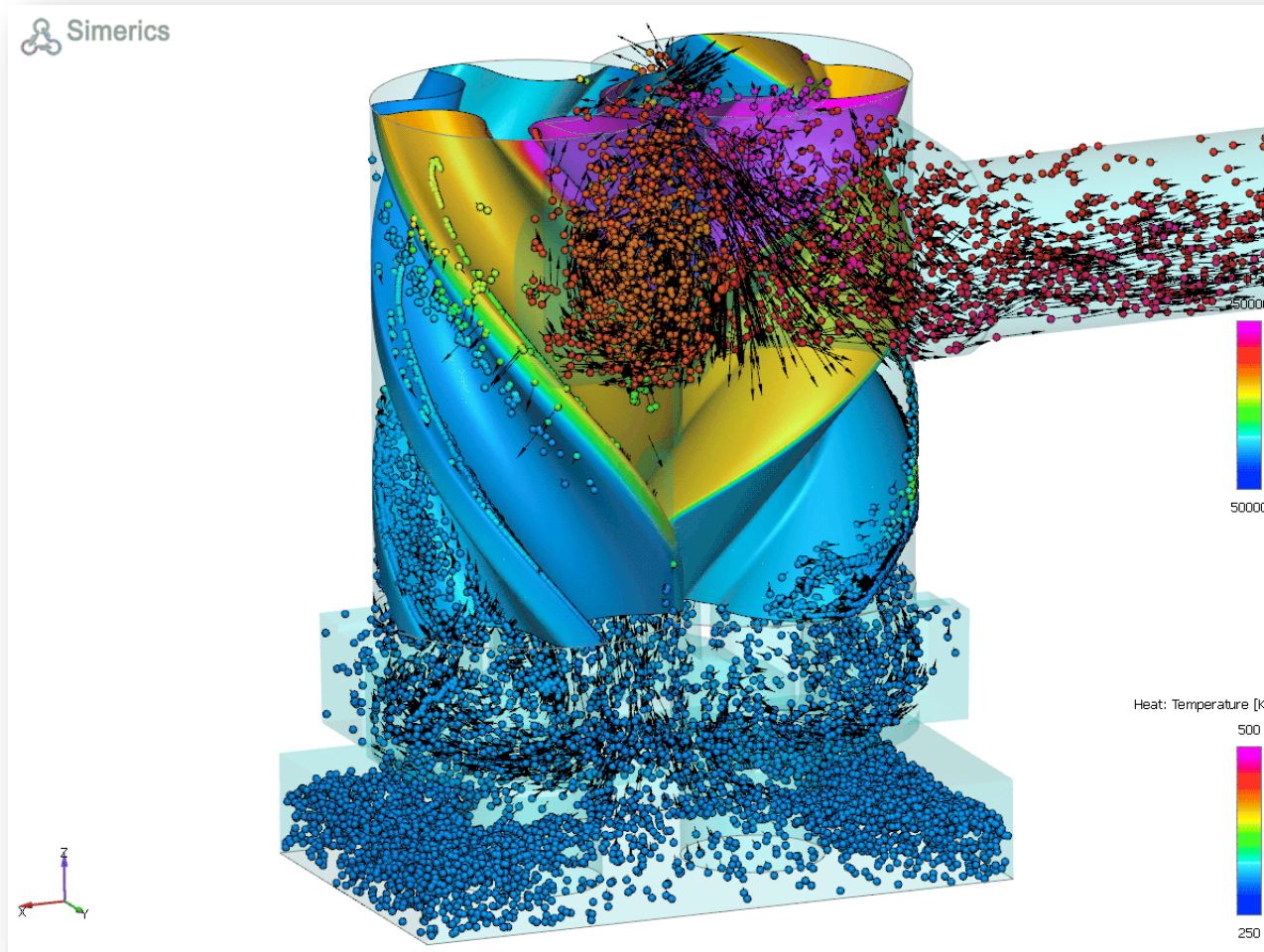




Simerics-PD Solution vs. Experimental Data



Rotor Pressure with Particles showing Temperature @ 8000 rpm





Advances in CFD Simulation of Positive Displacement Machinery

Summary Remarks

- Mesh Generation Adapted for Fluid Machinery
 - Binary Adaptive Tree
- Fluid Machinery Specific Template based Simulation
 - Many Advantages for Vertical Applications
- The Modelling of Aeration/Cavitation
 - Impacts the value of the simulation predictions
- Industrial Examples – Positive Displacement Machinery
 - Accuracy, Speed and Robustness

Questions?

www.8020engineering.com