



Capture the Concept™

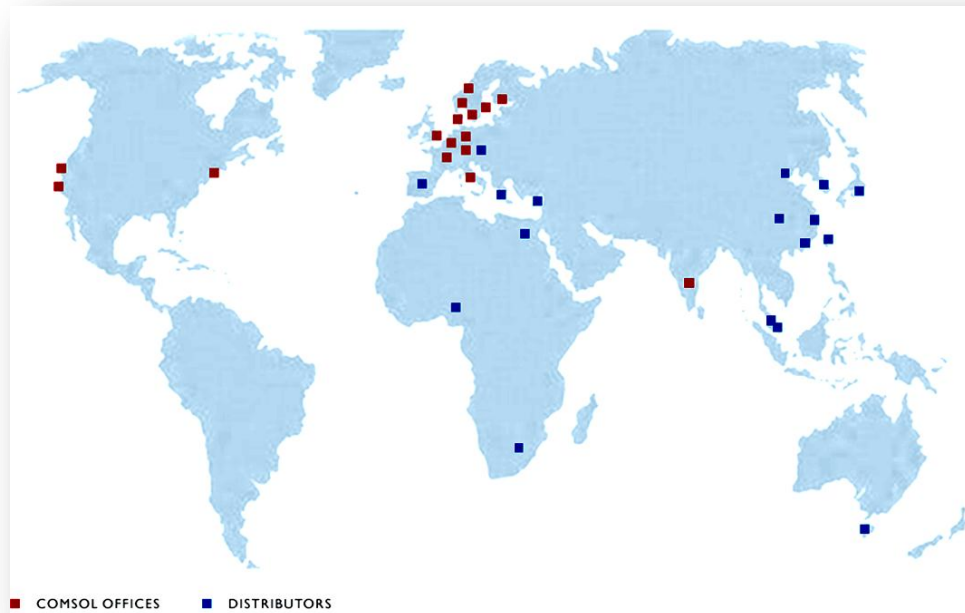
CFD in COMSOL Multiphysics



Christian Wollblad
Program manager, CFD
COMSOL

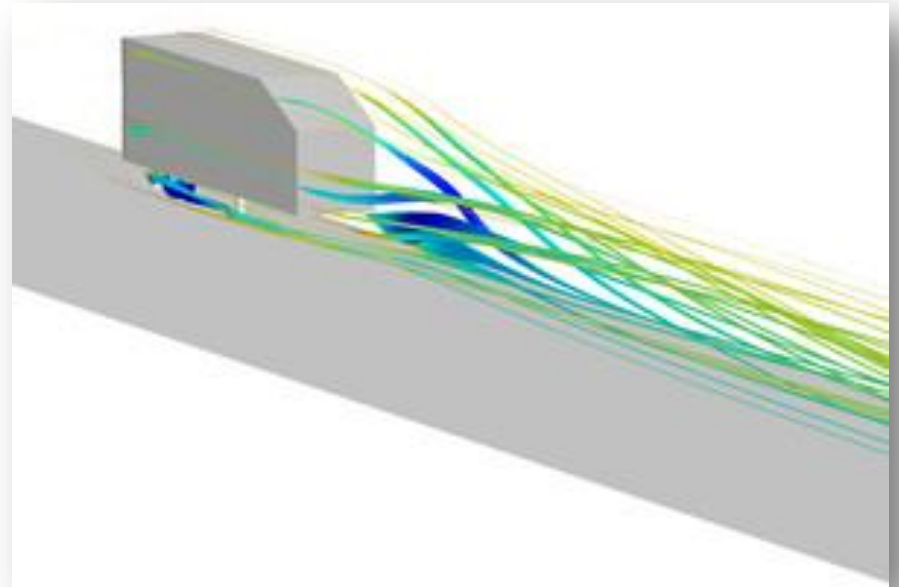
World leader in multiphysics simulations

- HQ in Stockholm.
- 16 offices worldwide.
- 250+ employees.
- 14 000 licenses, 60 000 users.

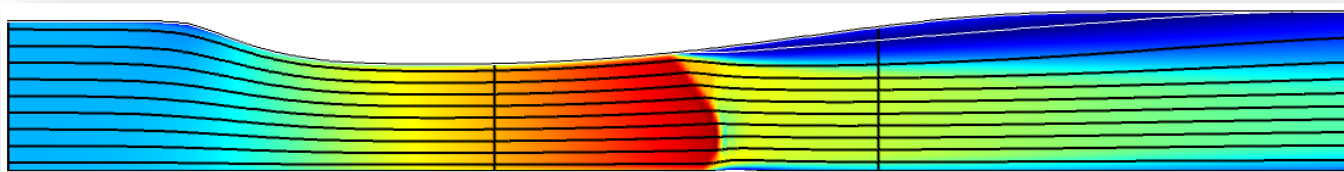


CFD – The Classical View

- Laminar
- Turbulent
 - RANS
 - LES
 -
- Incompressible
- Compressible
 - Mach number effects



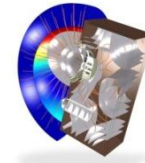
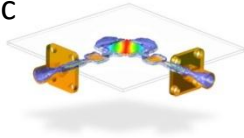
Flow over an Ahmed Body



Flow in a Sajben diffuser

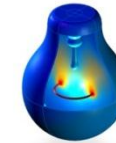
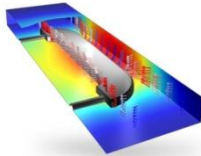
Traditional approach to modeling

Electromagnetic
Fields



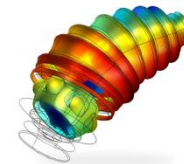
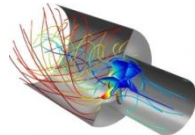
Acoustics

Chemical
Reactions



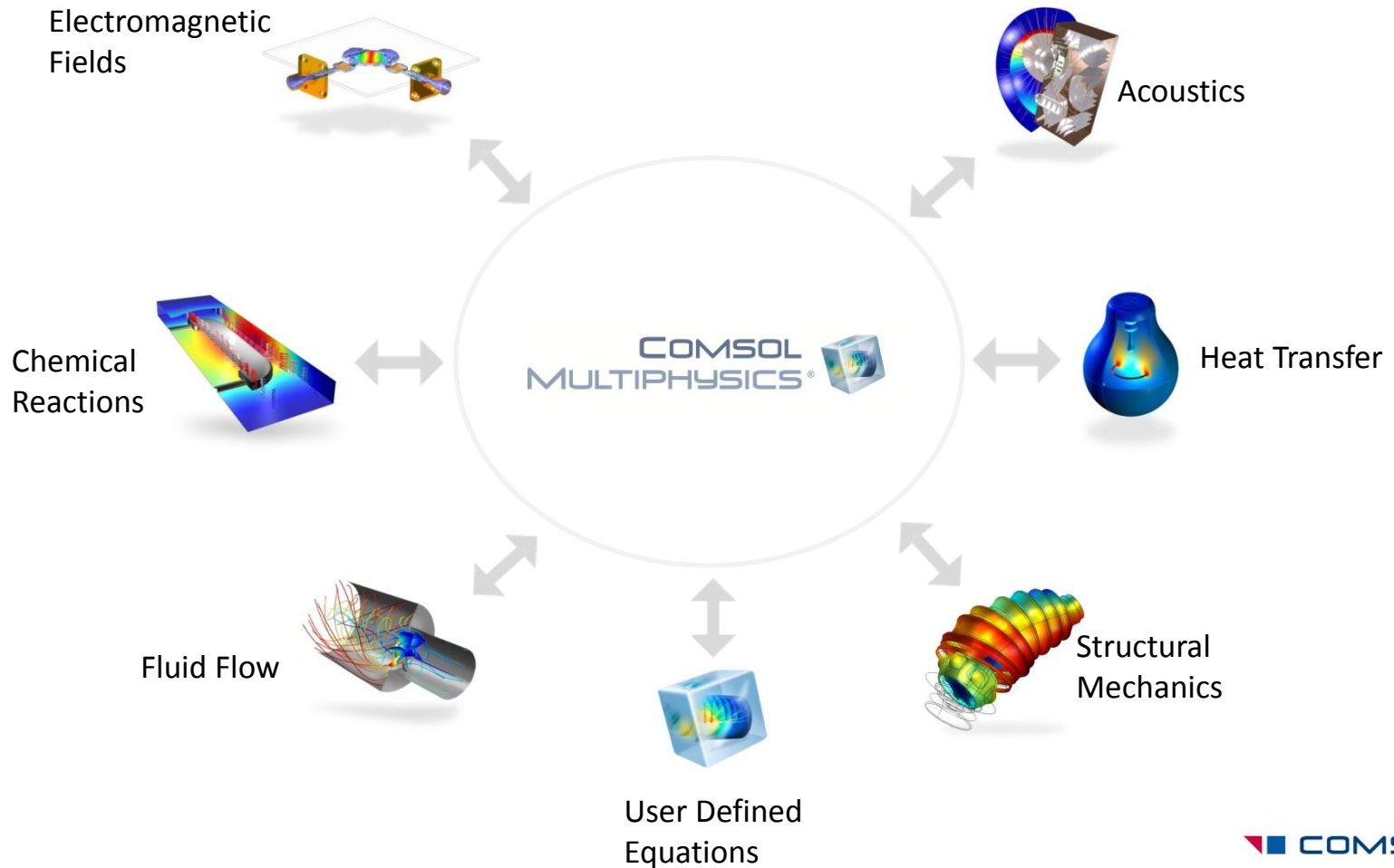
Heat Transfer

Fluid Flow



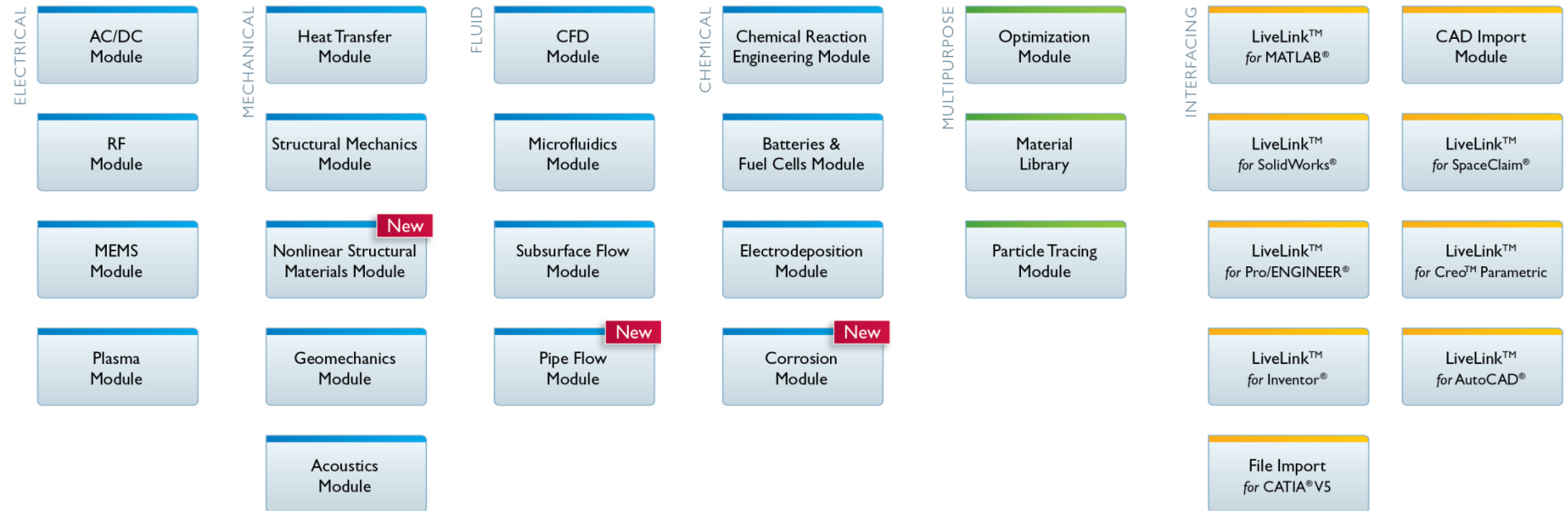
Structural
Mechanics

The COMSOL Multiphysics approach



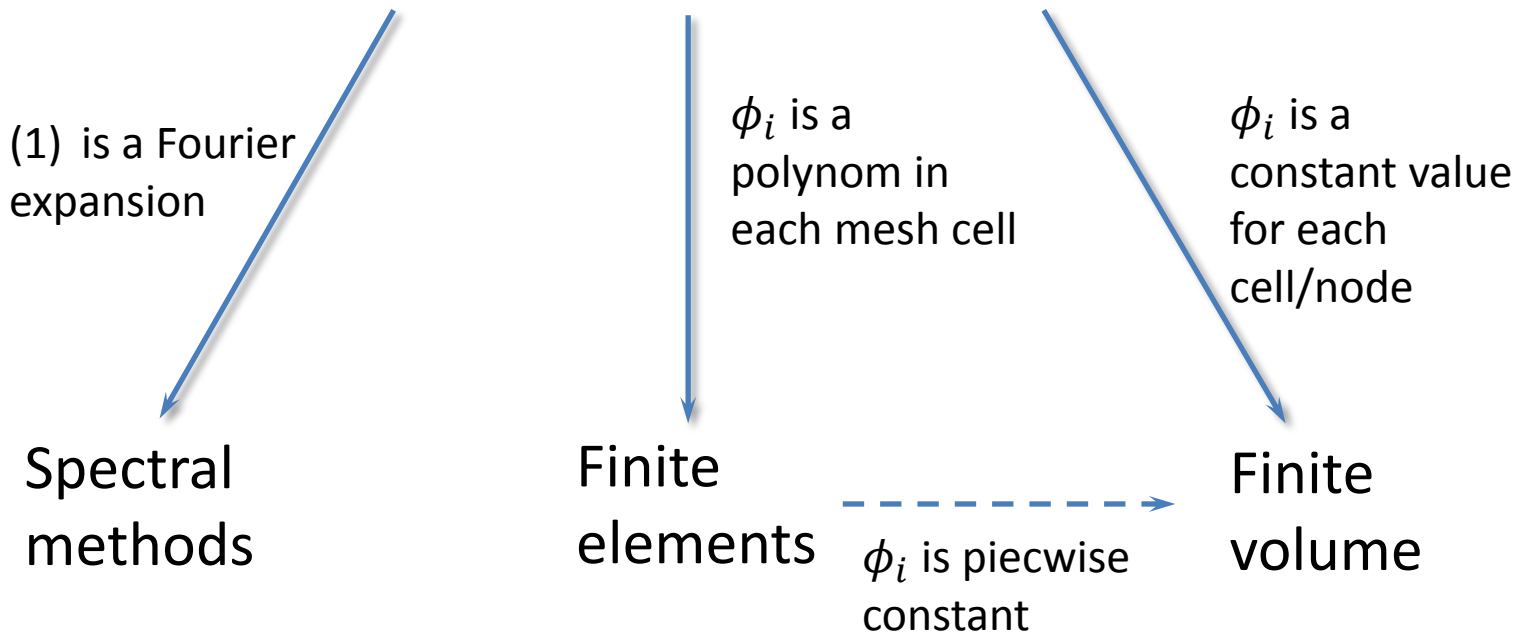
COMSOL Multiphysics 4.3 Product Suite

COMSOL Multiphysics®



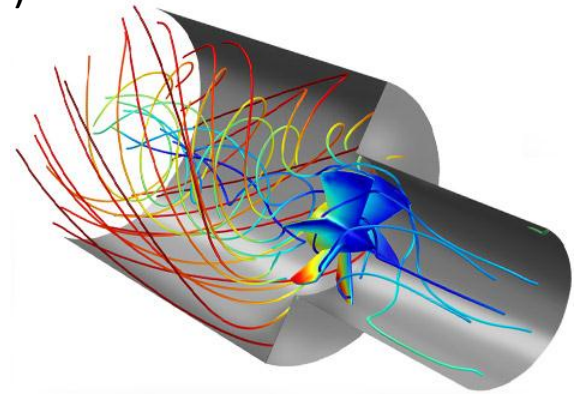
The Finite Element Method

- General PDE: $L(u) - f = 0$
- Assume that $u \approx \tilde{u} = \sum_i u_i \phi_i$ (1)
Where ϕ_i is a set of basis functions.



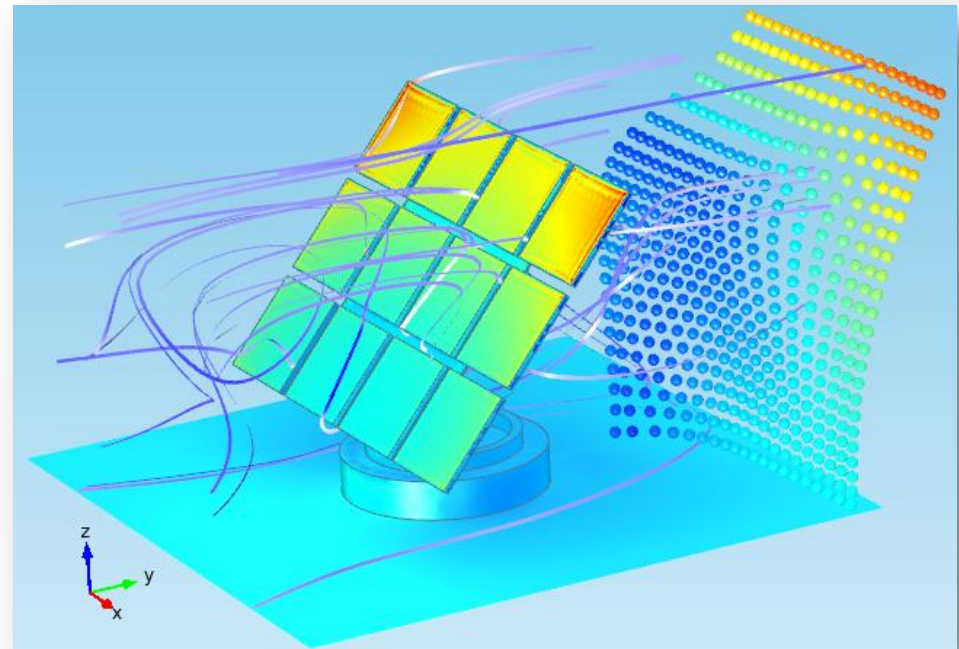
Typical Multiphysics Couplings

- Flow and heat: Forced or natural convection
- Flow and mass-flux, (and heat): Chemical & Diffusion problems
- Flow and structures: Fluid-solid interaction (FSI)
- Flow and EM: Biological RF heating



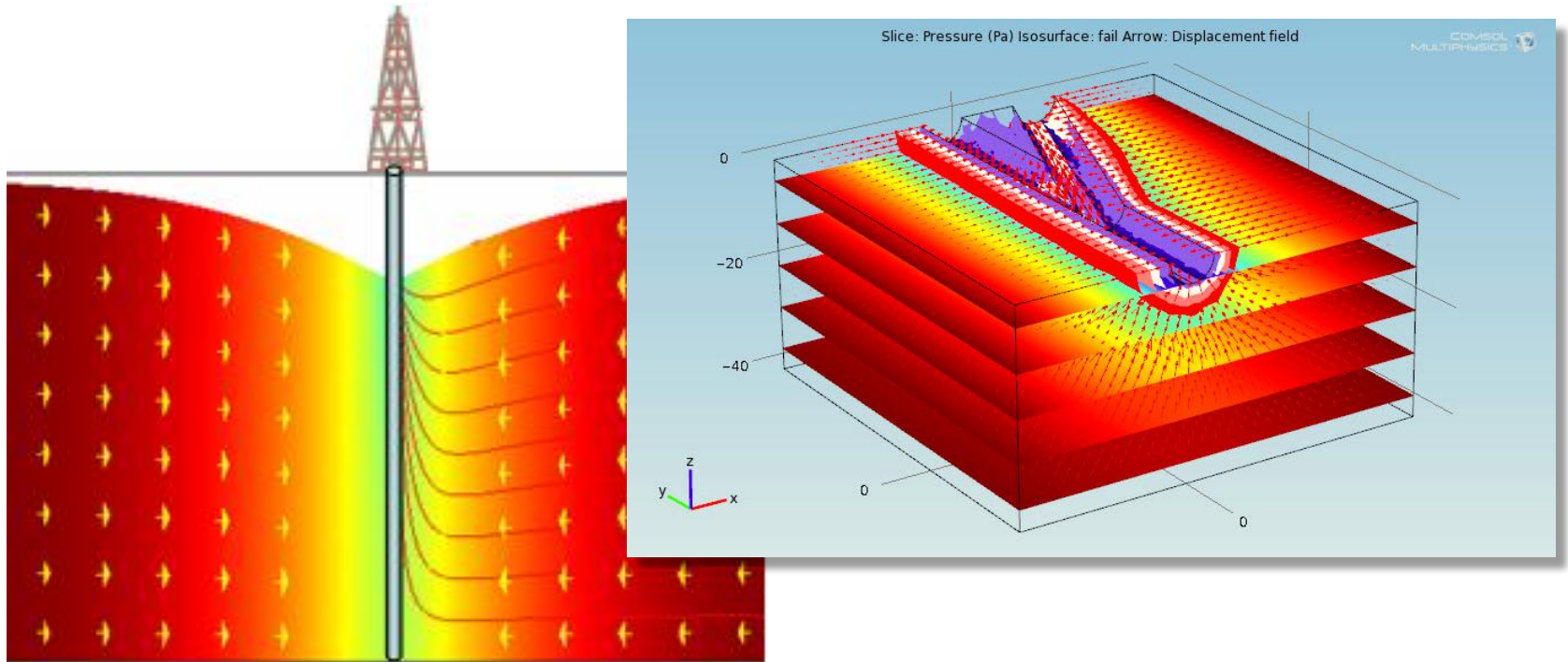
Fluid-Structure Interaction

- No data transfer between solid and fluid
- One solver machinery
- One post-processing framework



Fluid load on a solar panel

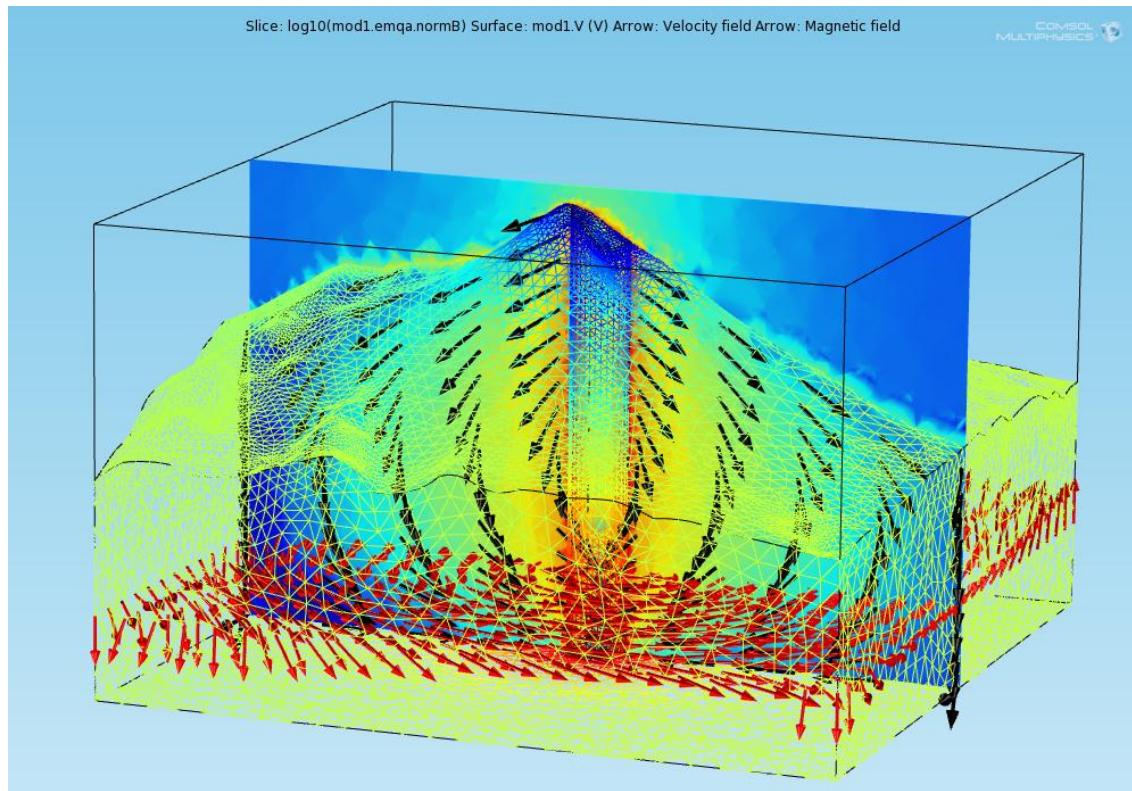
FSI Examples – Poroelasticity



- Fluid Pressure & Structural Support Load
- Collapsing Structure & Slows Flow Rate

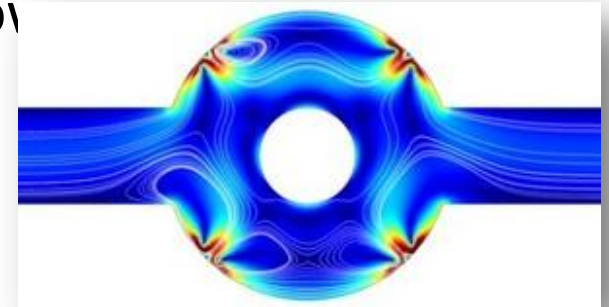
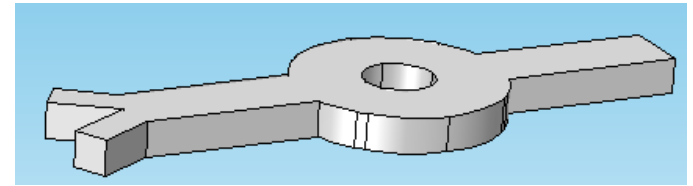
Flow Coupled to Electrical

- Electromagnetic Field from percolating charged rainwater

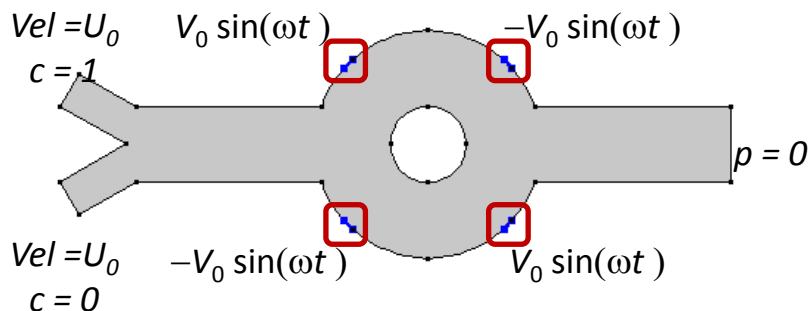
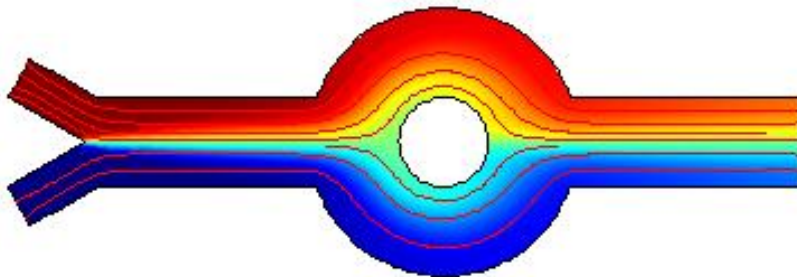


ElectroOsmotic Mixer

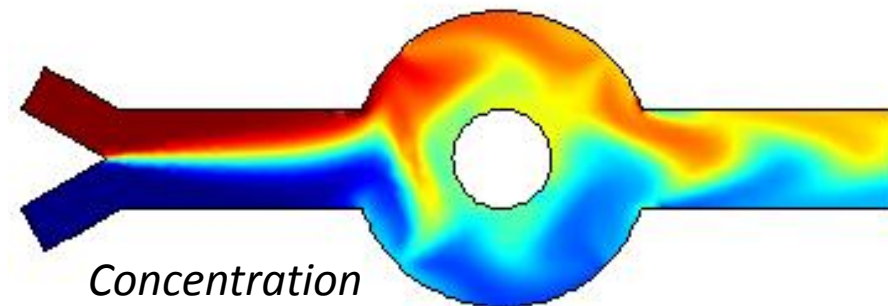
- Pressure Driven & ElectroOsmotic Flow
- Coupled Flow and Diffusion
- Goal: Improve Microfluidic Mixing



No Mixing

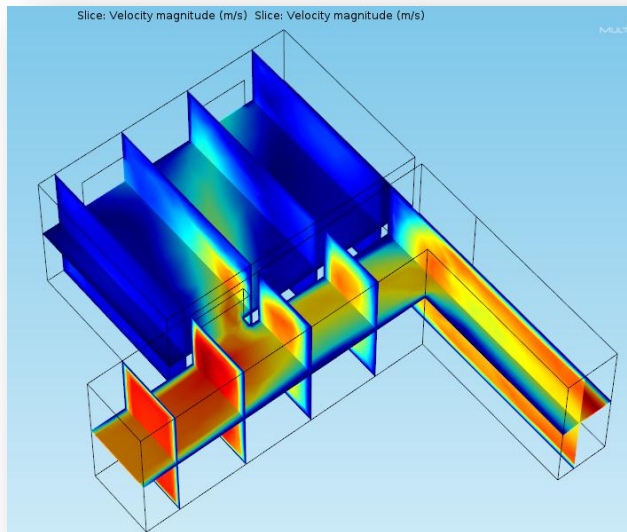


ElectroOsmotic Mixing

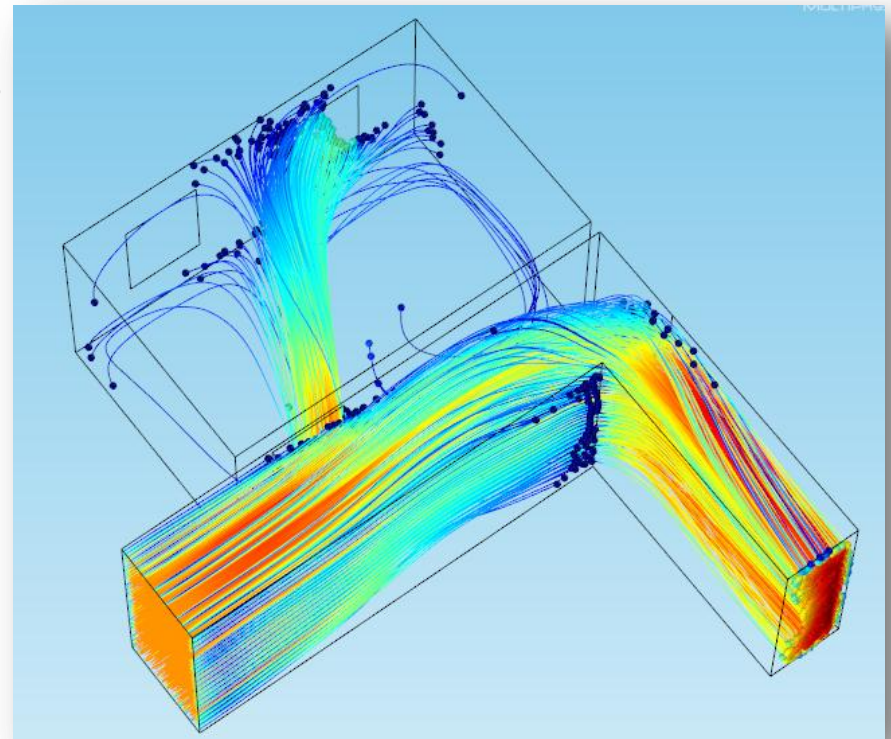


Particle Tracing - Room Contamination

- Particle Release in Hallway
- How much gets into office?



Air Velocity

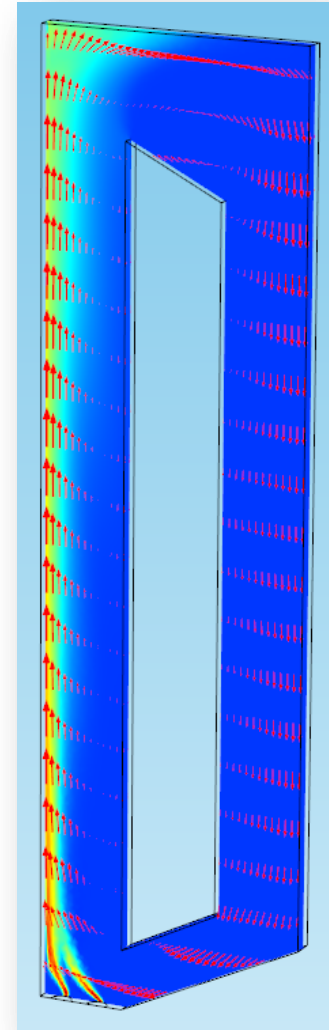


10 micron Particles

Reactions in Multiphase Flow

- Bubbles introduced at the bottom makes the flow turbulent
- The mixing is done by the gas sparging and it requires less energy than mechanical stirring
- Wet oxidation
- Bioreactor

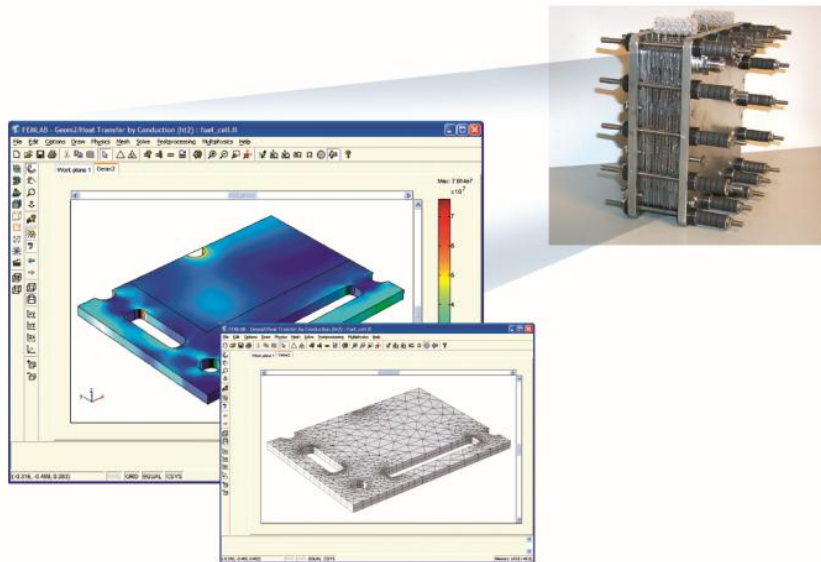
Bubble column



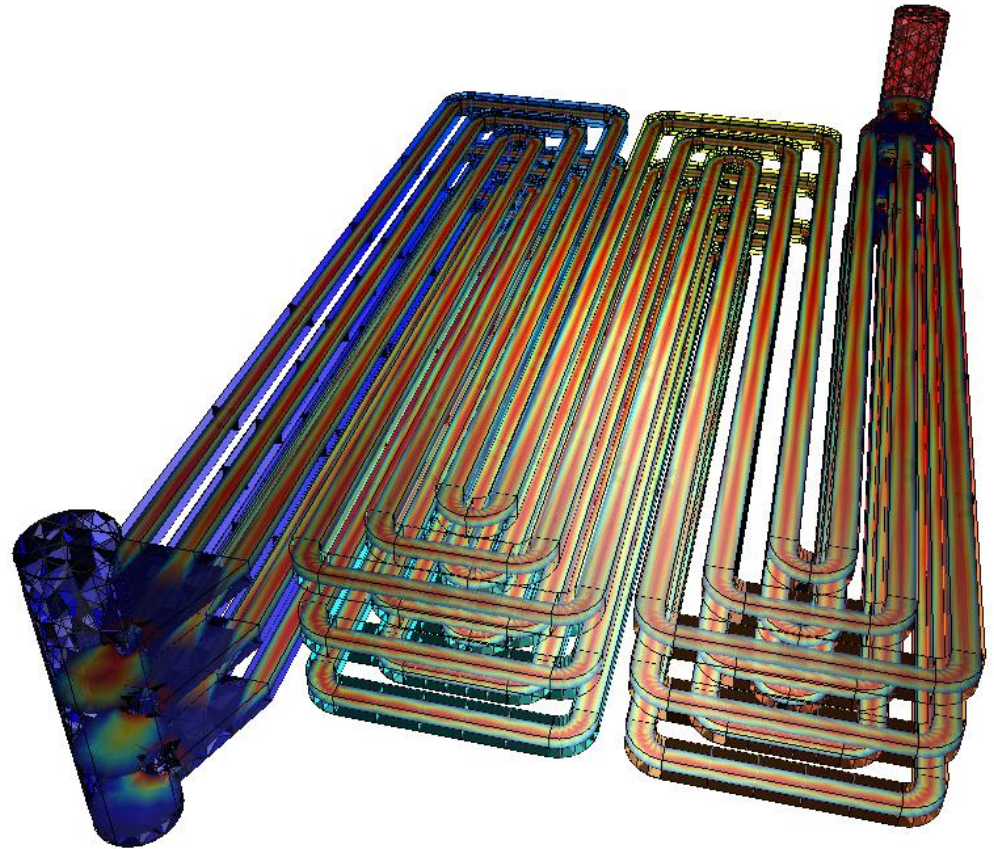
Fuel Cells – Multiphysics by Nature

Fuel Cells in General

- Electro Chemistry
- Heat + Flow



Stress from Thermal & External Loading

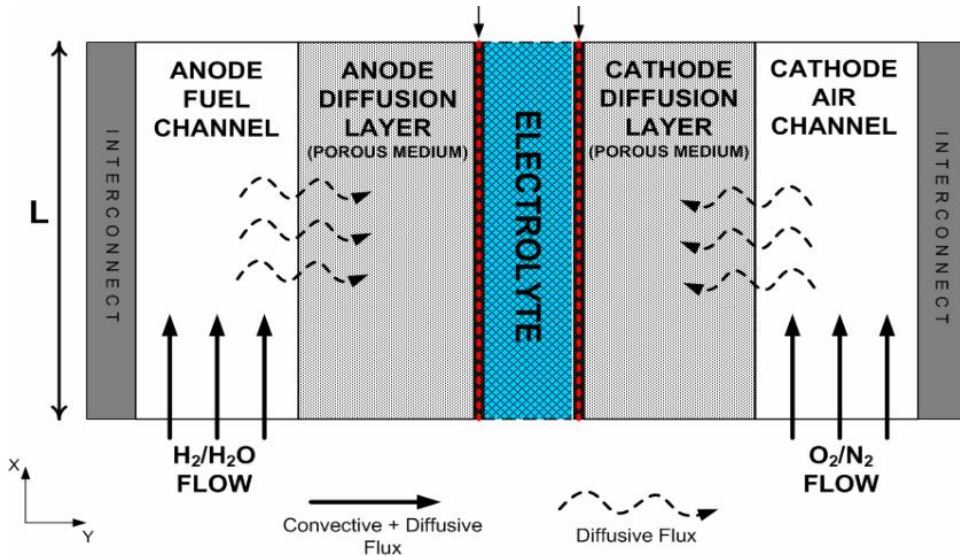


Slice Plots of Velocity through Transparent Boundary Plot of Concentration in Fuel Cell Stack

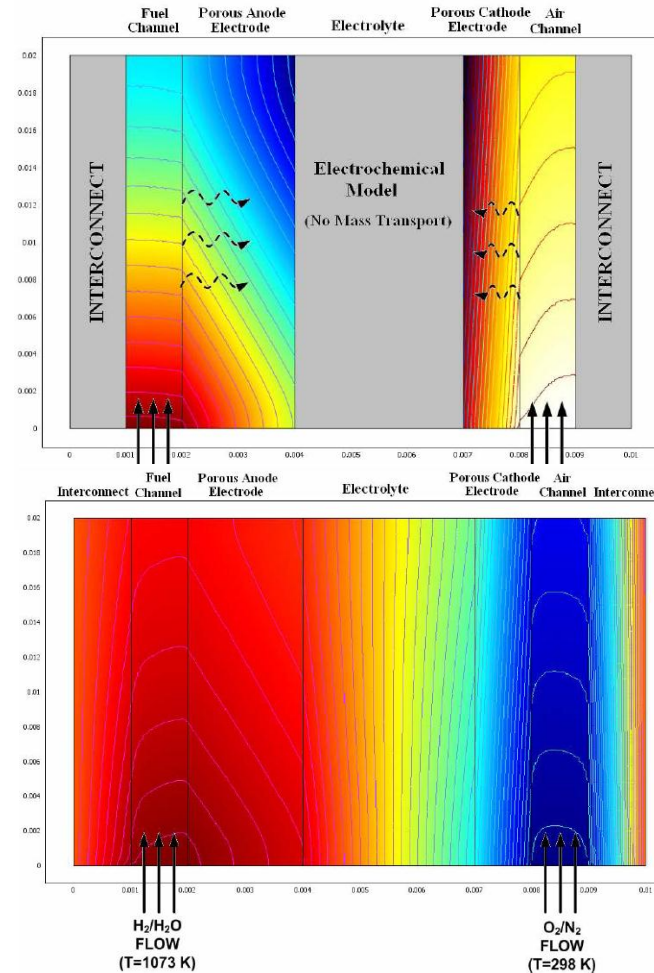
Fuel Cell Electrochemistry

Solid Oxide Fuel Cell

- Electro Chemistry
- Convection & Diffusion
- Heat & Flow



Excerpted from "Modelling and Design of Solid Oxide Fuel Cell Anode",
Tseronis, Kookos, and Theodoropoulos COMSOL Conference 2006

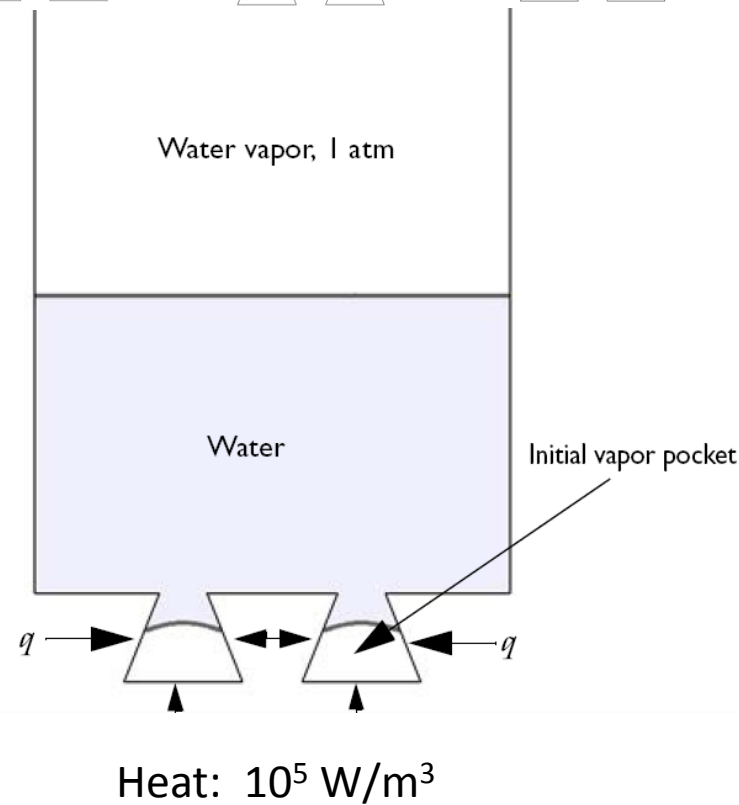
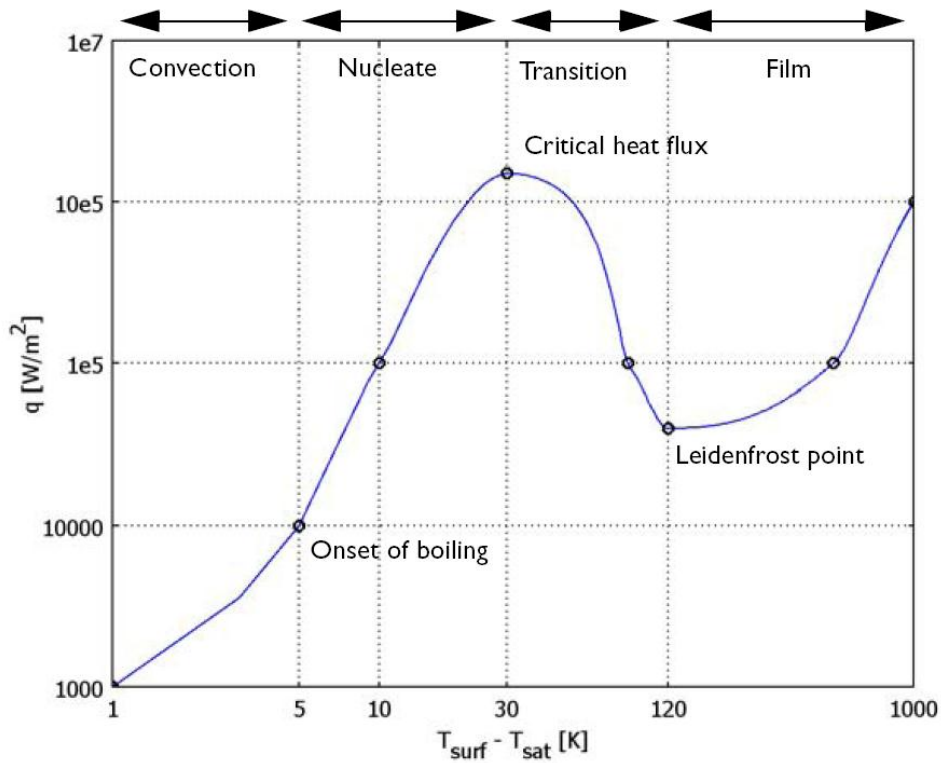
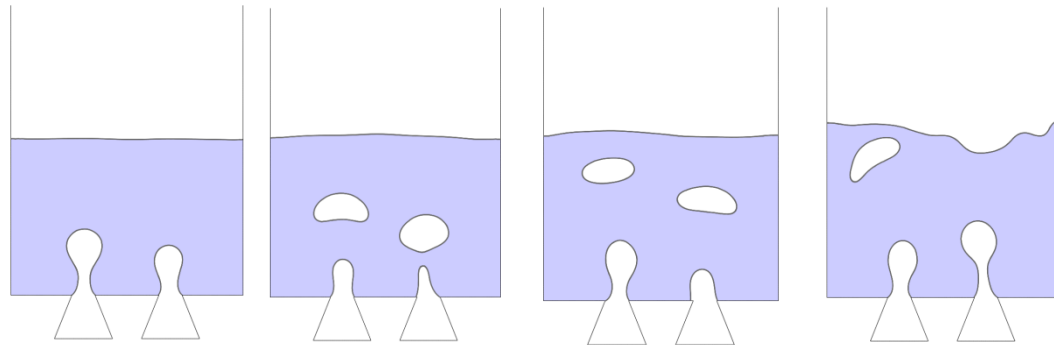


O₂ Molar Fraction
H₂ Molar Fraction

Temperature

Boiling

- 2-Phase Linked to Heat
- Boiling Curve for Water



COMSOL NEWS

A TECHNICAL COMPUTING MAGAZINE

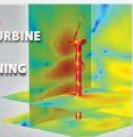


Lithium-Ion Battery Simulation for Greener Ford Vehicles

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WIND TURBINE
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DAMPENING

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ATTITUDE CONTROL
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 COMSOL

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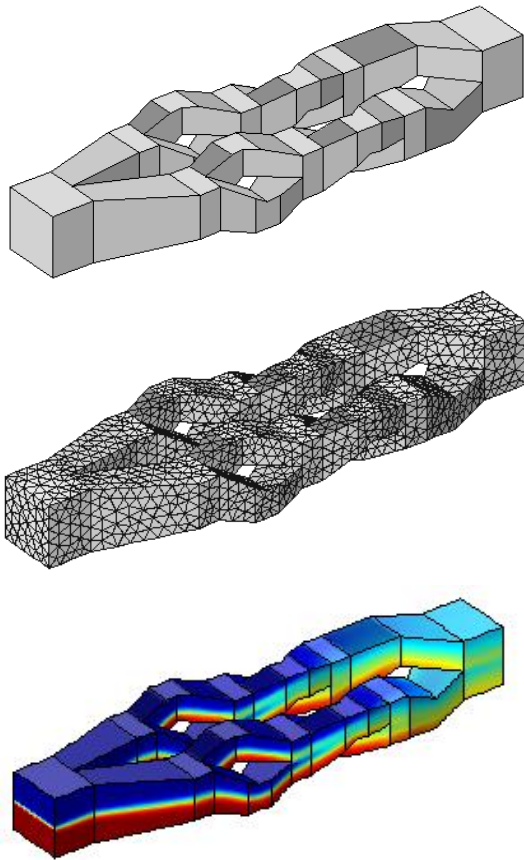
GUEST EDITORIAL

- 64 3D Direct Modeling: Removing Bottlenecks in Multiphysics Simulation

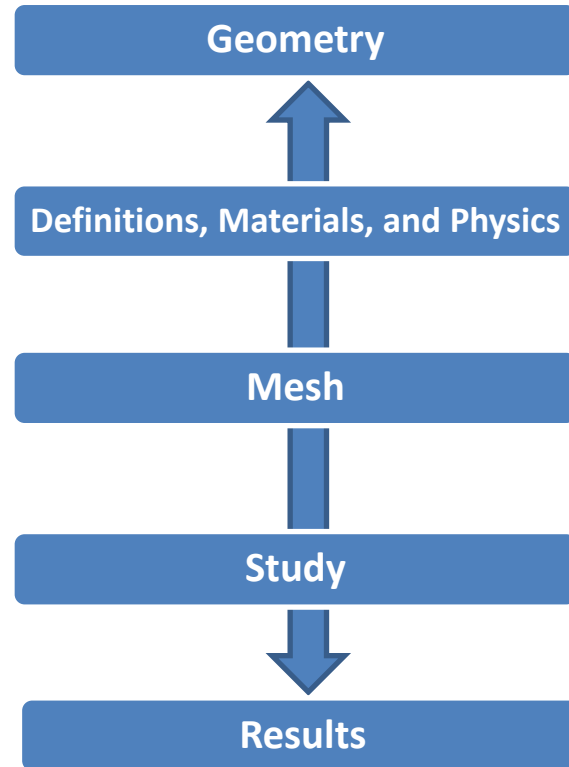
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Ford Motor Company	MatWeb	Ritsumeikan University	VSG
German Federal Institute for Materials Research and Testing	Microvisk	SB Microsystems	Xi Engineering Consultants
		Scientific & Biomedical Microsystems LLC	

COMSOL Multiphysics Workflow



Micromixer



User Friendly Interface

The screenshot displays the COMSOL Multiphysics software interface, divided into three main panes:

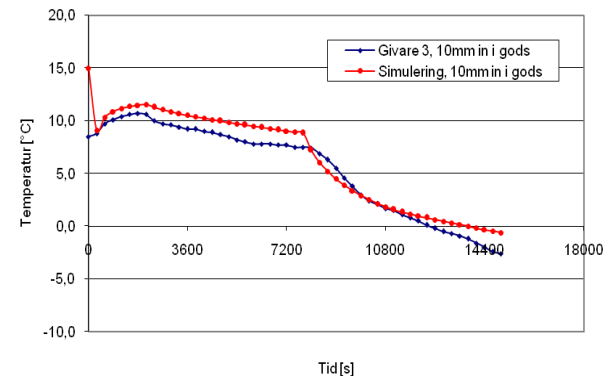
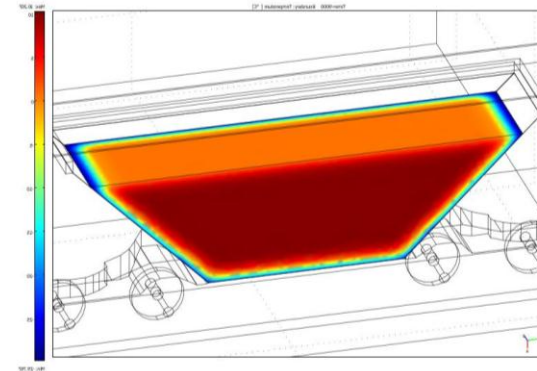
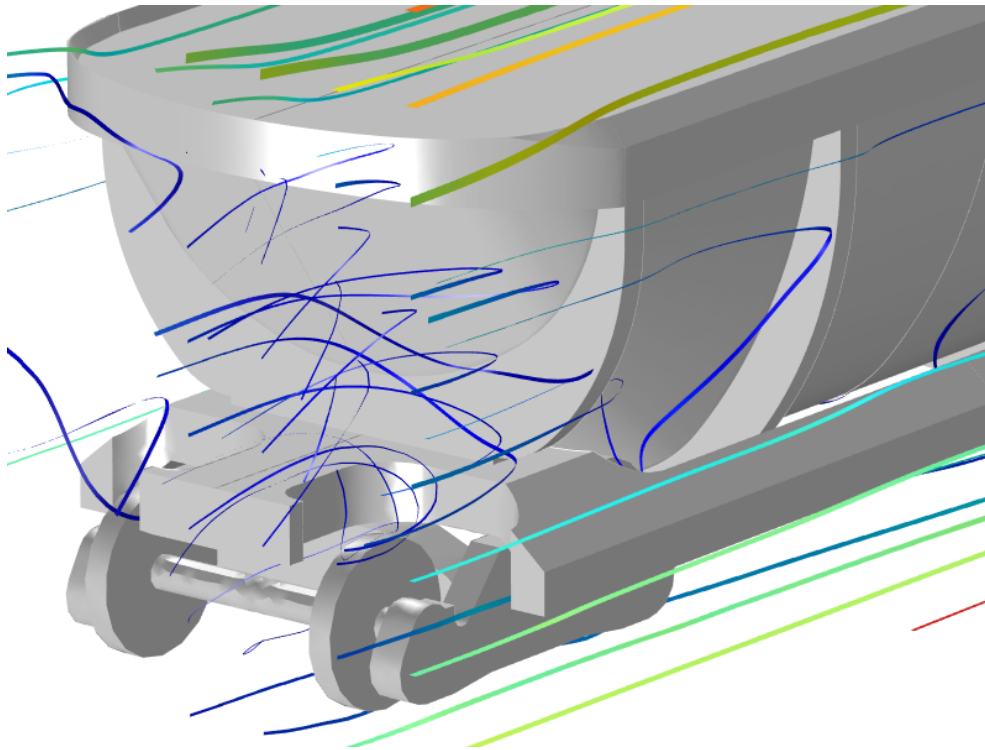
- Model Builder:** Shows a hierarchical tree structure for a model named "micromixer.mph". The tree includes "Global Definitions", "Model 1 (mod1)", "Definitions" (with sub-items like "Step 1 (step1)", "Variables 1", "Average 1 (aveop_inlet)", "Average 2 (aveop_outlet)", "Boundary System 1 (sys1)", and "View 1"), "Geometry 1", "Materials", "Laminar Flow (spf)", "Transport of Diluted Species (chds)" (with sub-items like "Convection and Diffusion 1", "No Flux 1", "Initial Values 1", "Inflow 1", and "Outflow 1"), "Meshes", "Study 1", and "Results" (with sub-items like "Data Sets", "Derived Values", "Global Evaluation 1", "Tables", "Velocity (spf)", and "Pressure (spf)").
- Settings:** Shows the configuration for the "Inflow" boundary condition. The "Boundary Selection" is set to "Manual" and lists "1". The "Concentration" section is expanded, showing the equation $c_{0,c} = c0 * \text{step1}(-z[1/m])$ with units of mol/m^3 . Other sections like "Override and Contribution" and "Equation" are collapsed.
- Graphics:** Shows a 3D visualization of a blue cube. The axes are labeled with values: 50, 0, -50 on the vertical axis (scaled by $\times 10^{-5}$), and 10, 0 on the horizontal axes. A black arrow points from the equation input field in the Settings pane to the cube in the Graphics pane.

Everything is Equation Based

The screenshot displays the COMSOL Multiphysics software interface, illustrating the equation-based modeling process. The interface is divided into three main panes:

- Model Builder:** Shows the hierarchical structure of the model, including Global Definitions, Model 1 (mod1), Geometry 1 (geom1), Materials, Rotating Machinery, Turbulent Flow, Domains, Fluid Properties 1 (fp1), Initial Values 1 (init1), Rotating Domain 1 (rd1), Boundaries, Points, Mesh 1 (mesh1), Study 1 (std1), and Results. The Results section is expanded to show Data Sets (Solution 1 (dset1), Surface 1 (surf1), Surface 2 (surf2)), Derived Values, Tables, Velocity (rmspf) (pg1), Pressure (rmspf) (pg2), Wall Resolution (rmspf) (pg3), Export, and Reports.
- Equation View:** Displays the mathematical equations used in the model, organized into three sections:
 - Variables:** A table listing variables, their expressions, units, and descriptions.
 - Shape Functions:** A table listing shape functions, their units, and descriptions.
 - Weak Expressions:** A list of weak expressions used in the model.
- Graphics:** Shows a 3D visualization of the model, a cylindrical reactor with a central stirrer. The reactor is filled with a fluid, and the visualization shows the velocity field (color-coded from blue to red) and the pressure field (color-coded from blue to red). The z-axis is labeled with 0, 0.5, and 1. The x and y axes are also shown.

Relitor, Luleå

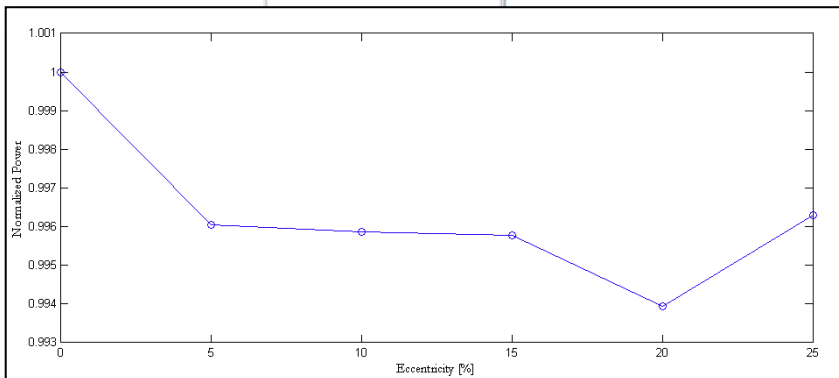
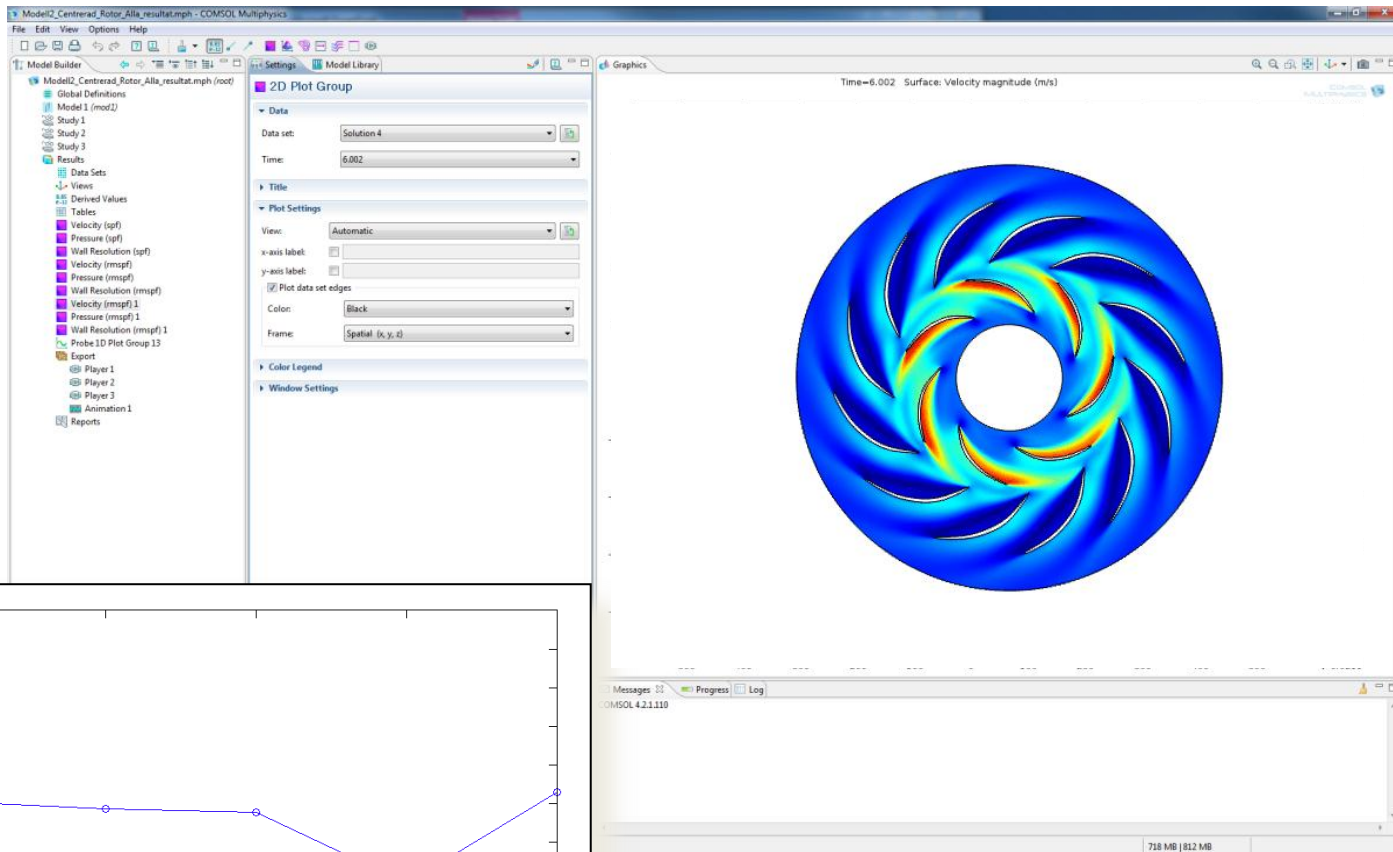


- Moisture i the gods freezes during transport and makes unloading the wagons difficult
- Simulated the freezing and investigated possible improvements such as isolating, pre-heating and melting.

ÅF, Stockholm

Centrifugal pumps

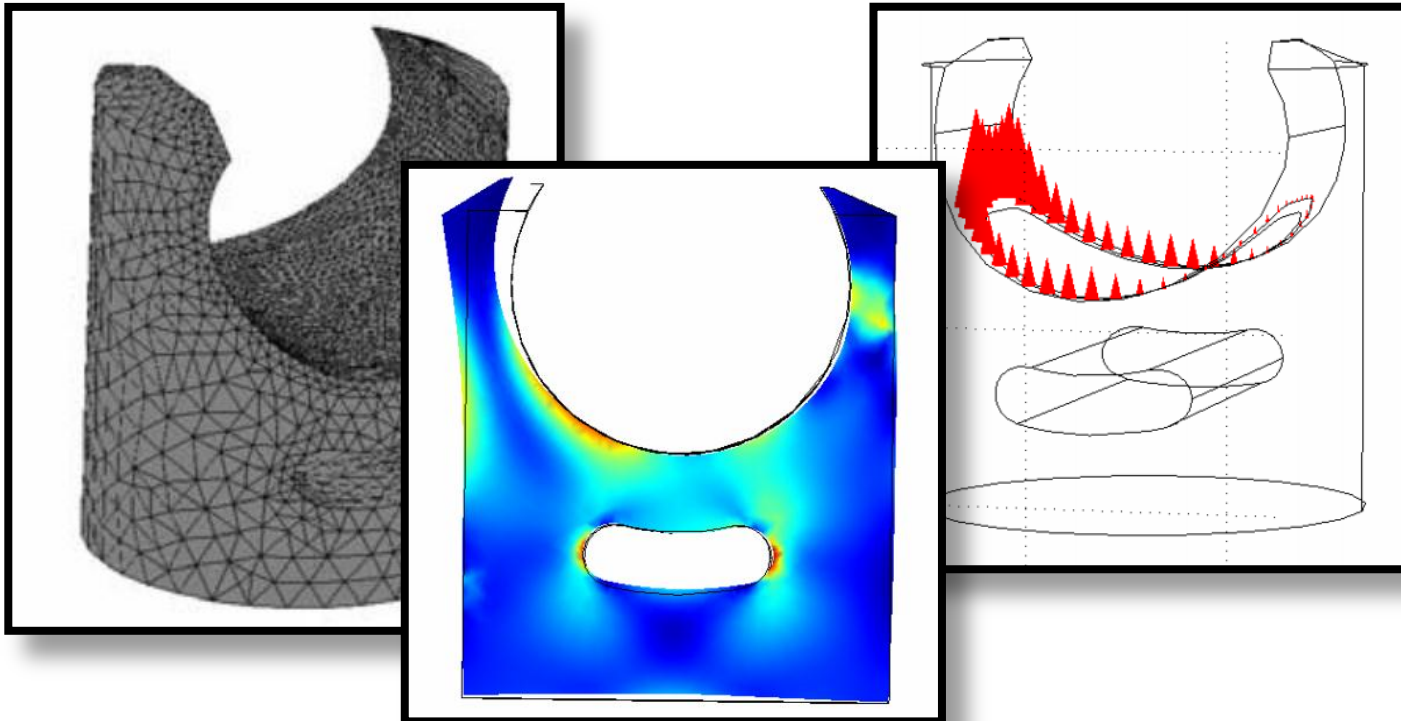
How does the effect change if the impeller is not centered?



Hägglund Drives

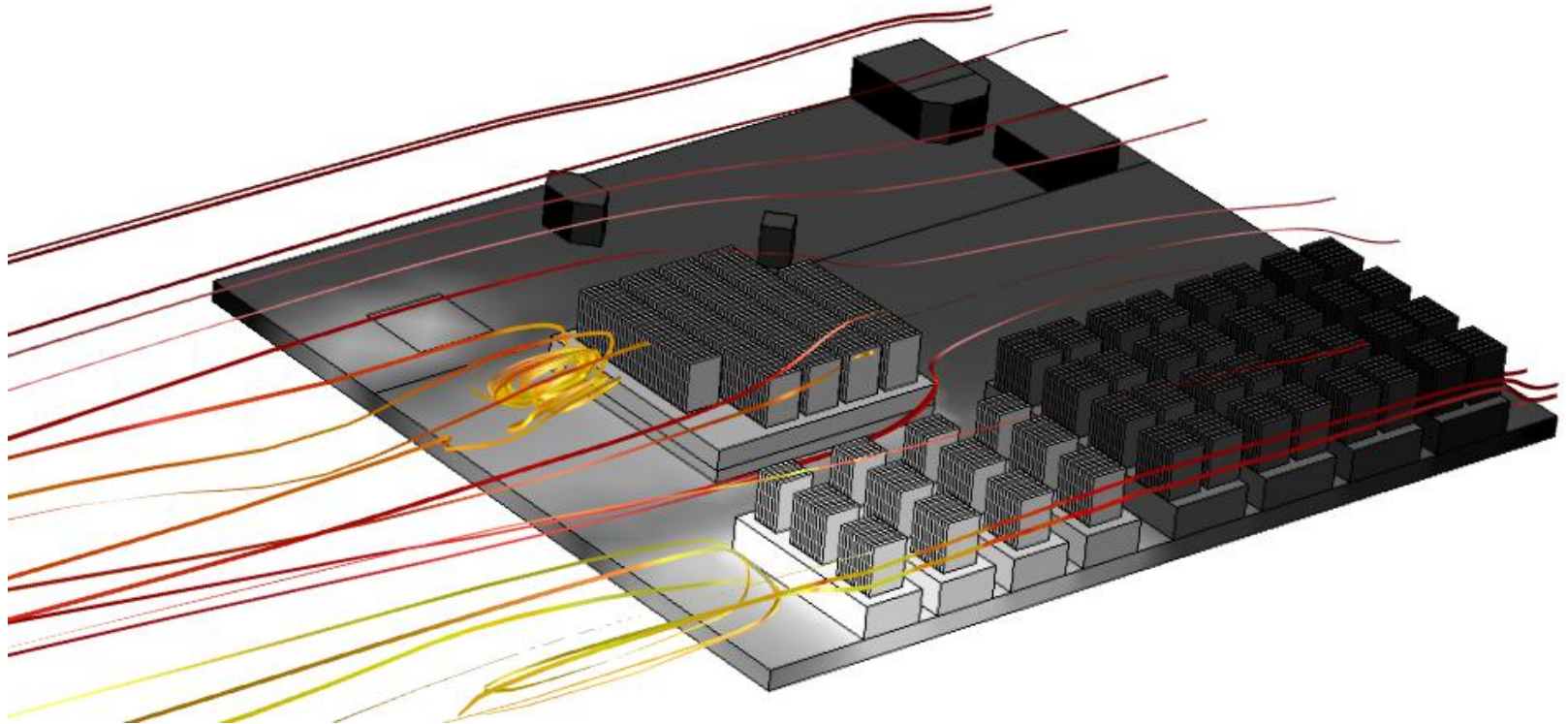
Simulation of a radial engine

- How thick is the lubrication film?
- How large is the friction?
- Can deformation of the piston cause leakage



Model Reduction

- Extension of the model
- Representation of components
- What is possible to investigate?



Turbulent or Laminar?

- Reynolds number

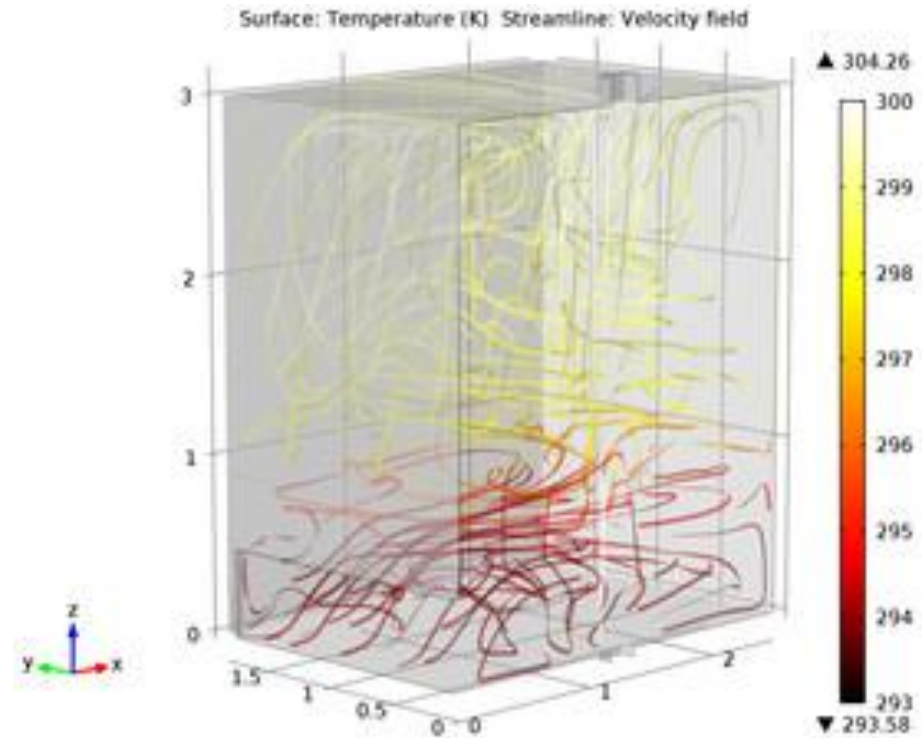
$$Re = \frac{U \cdot L}{\nu}$$

$Re \gg 1 \Rightarrow \textit{turbulent}$

- Grashof number

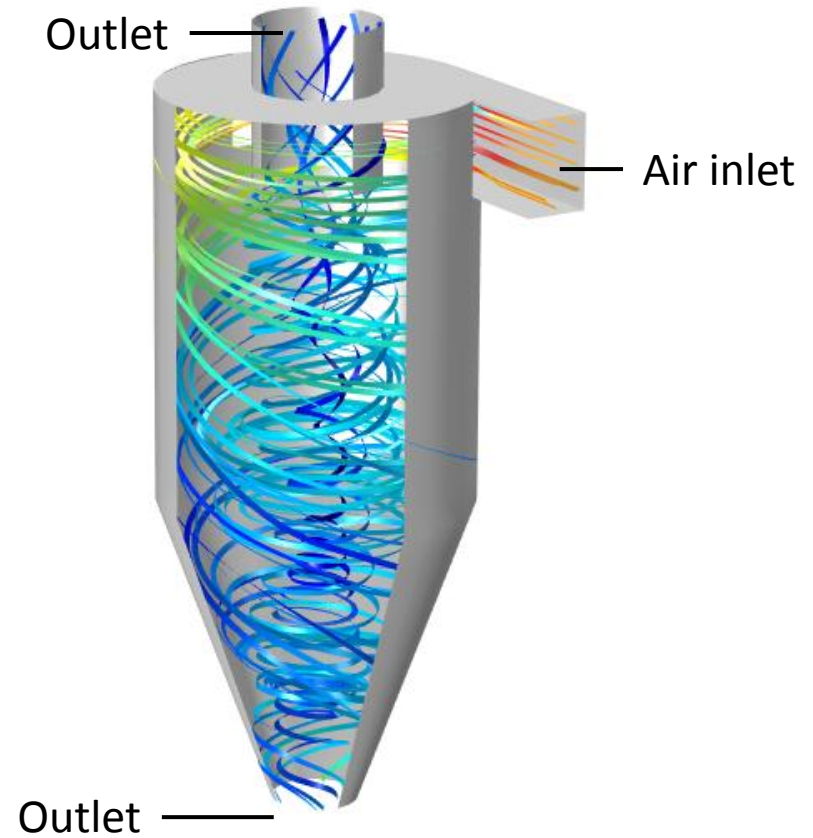
$$Gr = \frac{g \alpha \Delta T \cdot L^3}{\nu^2}$$

$Gr \gg 1 \Rightarrow \textit{turbulent}$



Which Turbulent Model

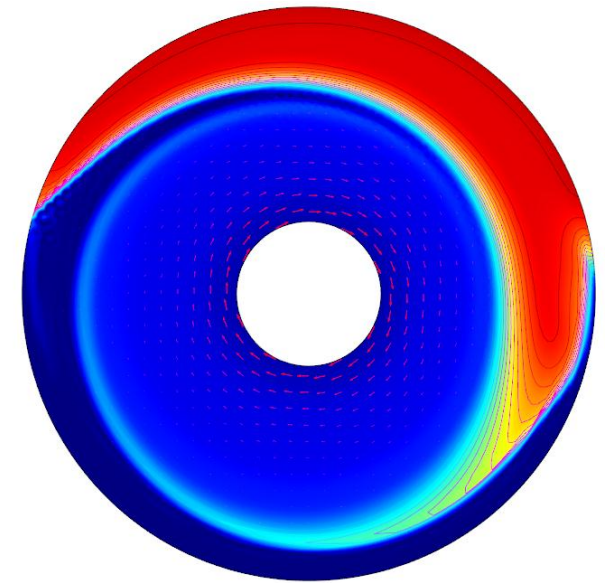
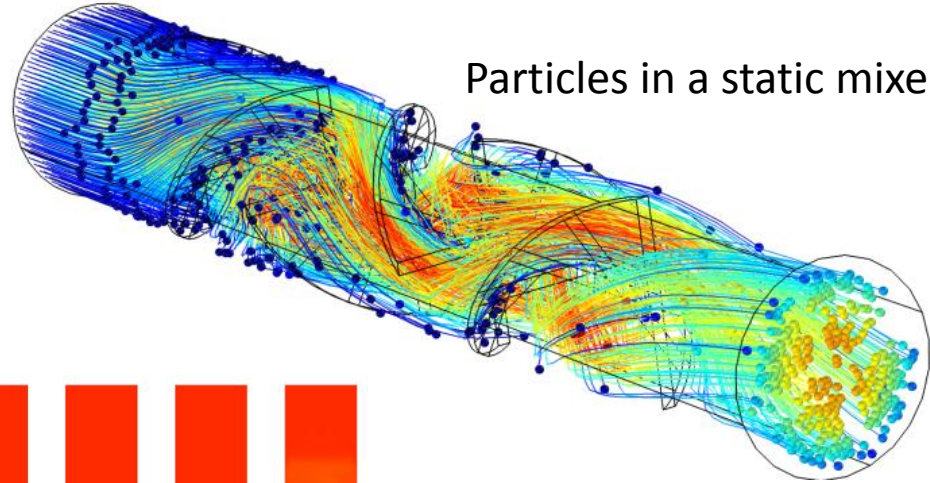
- RANS
 - One-equation model
 - Two-equation model
 - EARSM
 - Reynolds stress model
- DES/VLES
- LES
- DNS



Multiple Phases

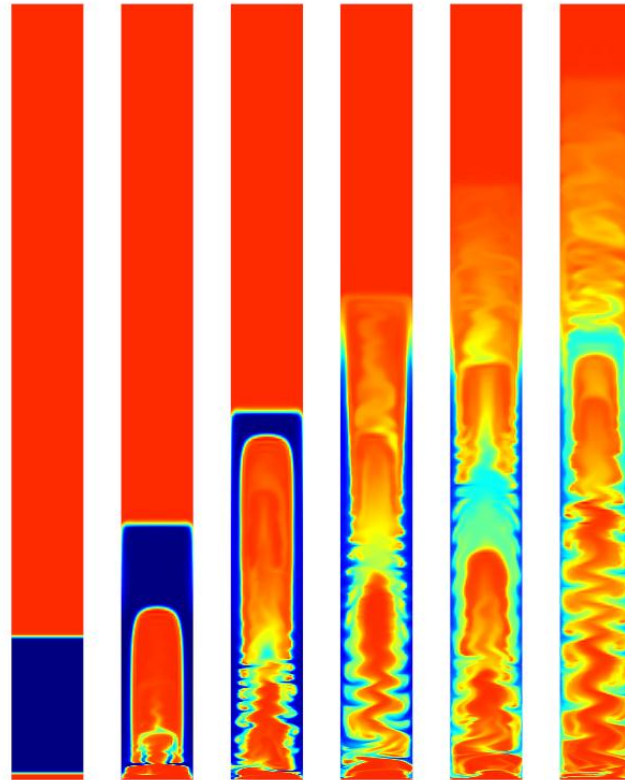
- Mixture
- Euler-Euler
- Particles

Particles in a static mixer

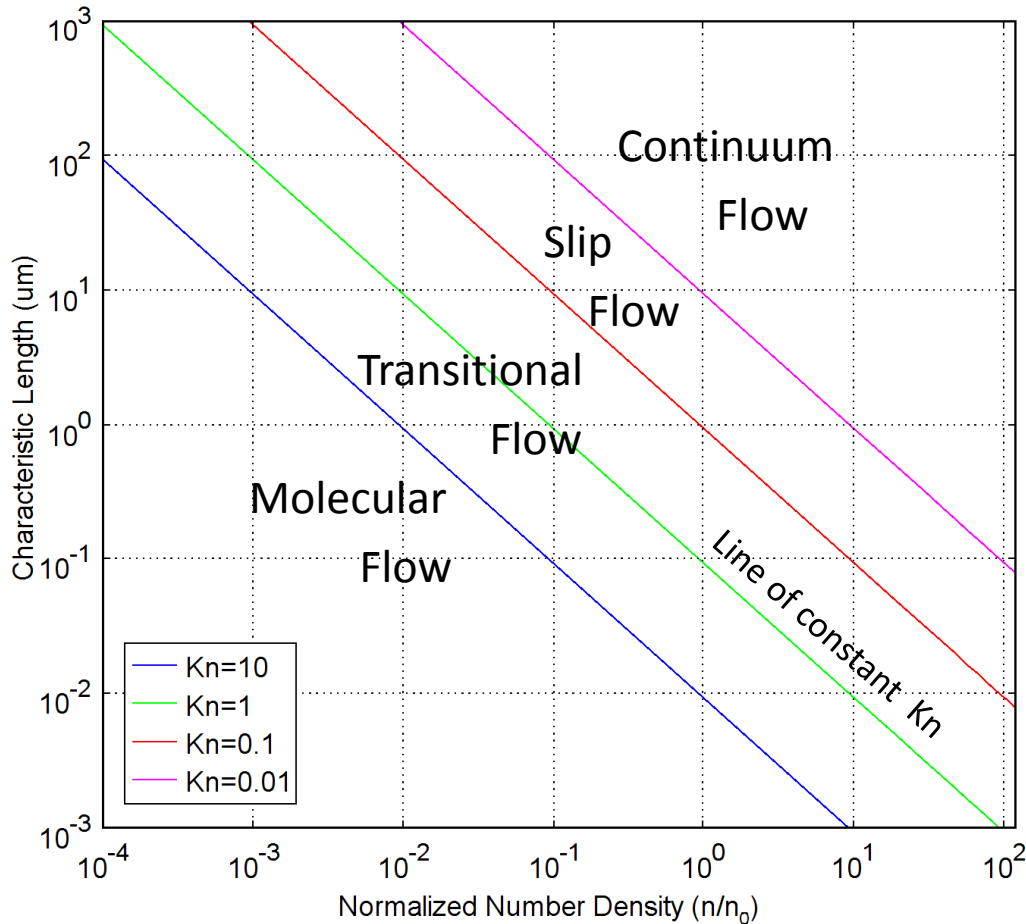


Spinning Suspension

Solid Spherical
Particles Fluidized
by Air



Rarefied Flows



Degree of rarefaction characterized by the Knudsen number, Kn :

$$Kn = \frac{\lambda}{L}$$

Rarefied Flow Interfaces:

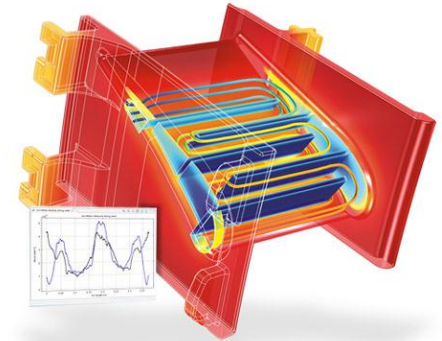
$0.01 < Kn < 0.1$: Slip Flow
(New in 4.2a)

$0.1 < Kn < 10$: Transitional Flow
(Beta version in 4.2a)

$Kn > 10$: Molecular Flow

COMSOL Multiphysics

- **True Multiphysics** – Everything can link to everything
- **Flexible** – You can model just about anything.
- **Usable** – You can keep your sanity doing it.
- **Extensible** – If its not specifically there...add it!



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Capture the Concept™