COMSOL MULTIPHYSICS®

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# CFD in COMSOL Multiphysics

Christian Wollblad

Program manager, CFD

COMSOL



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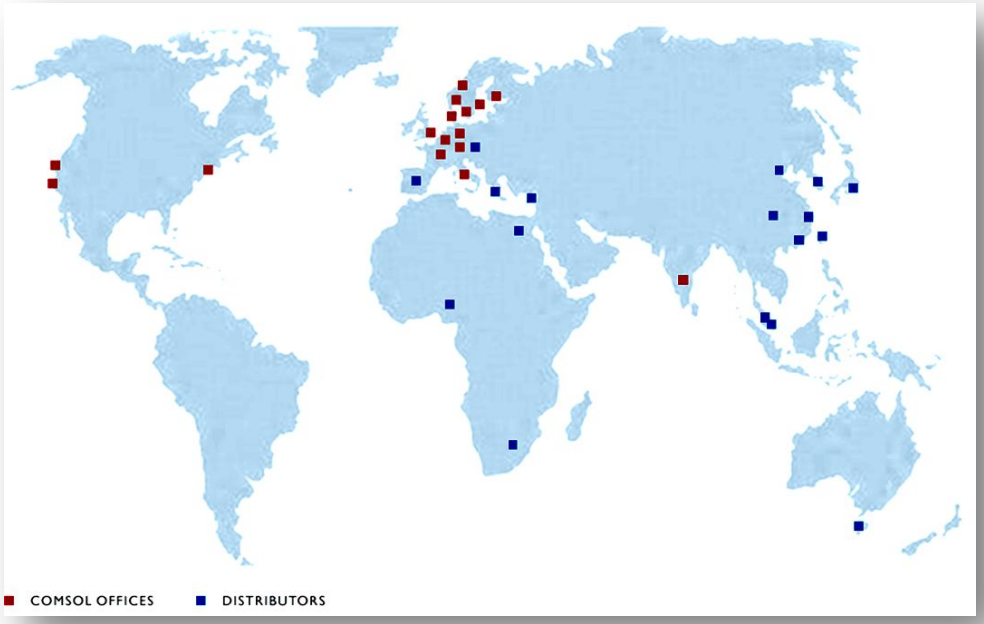
# World leader in multiphysics simulations

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

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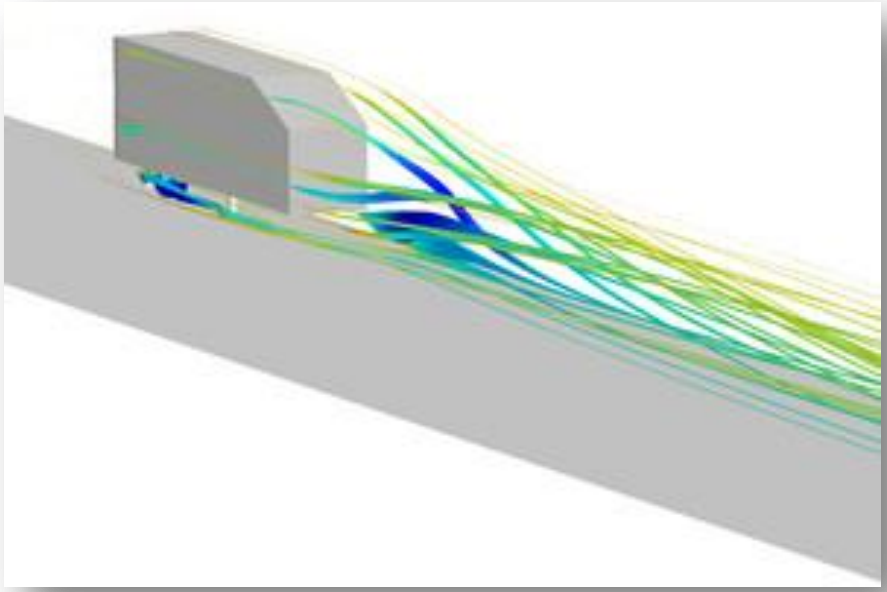
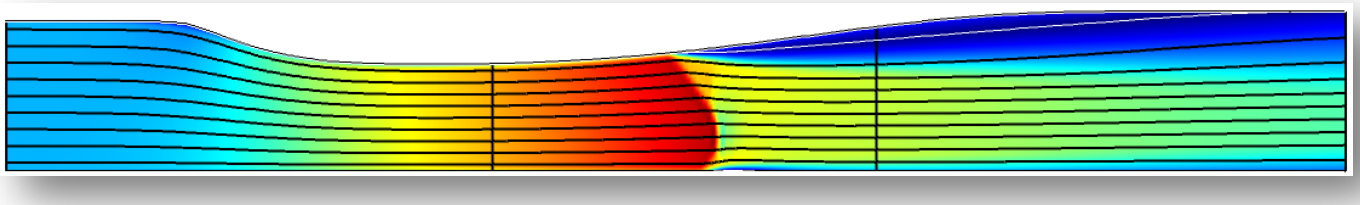
# CFD – The Classical View

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



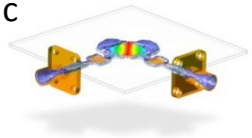
Flow over an Ahmed Body



Flow in a Sajben diffuser

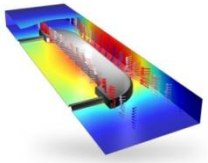
# Traditional approach to modeling

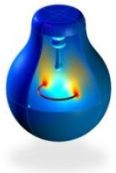
Electromagnetic Fields



Acoustics

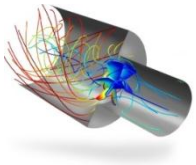
Chemical Reactions

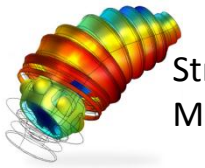




Heat Transfer

Fluid Flow





Structural Mechanics

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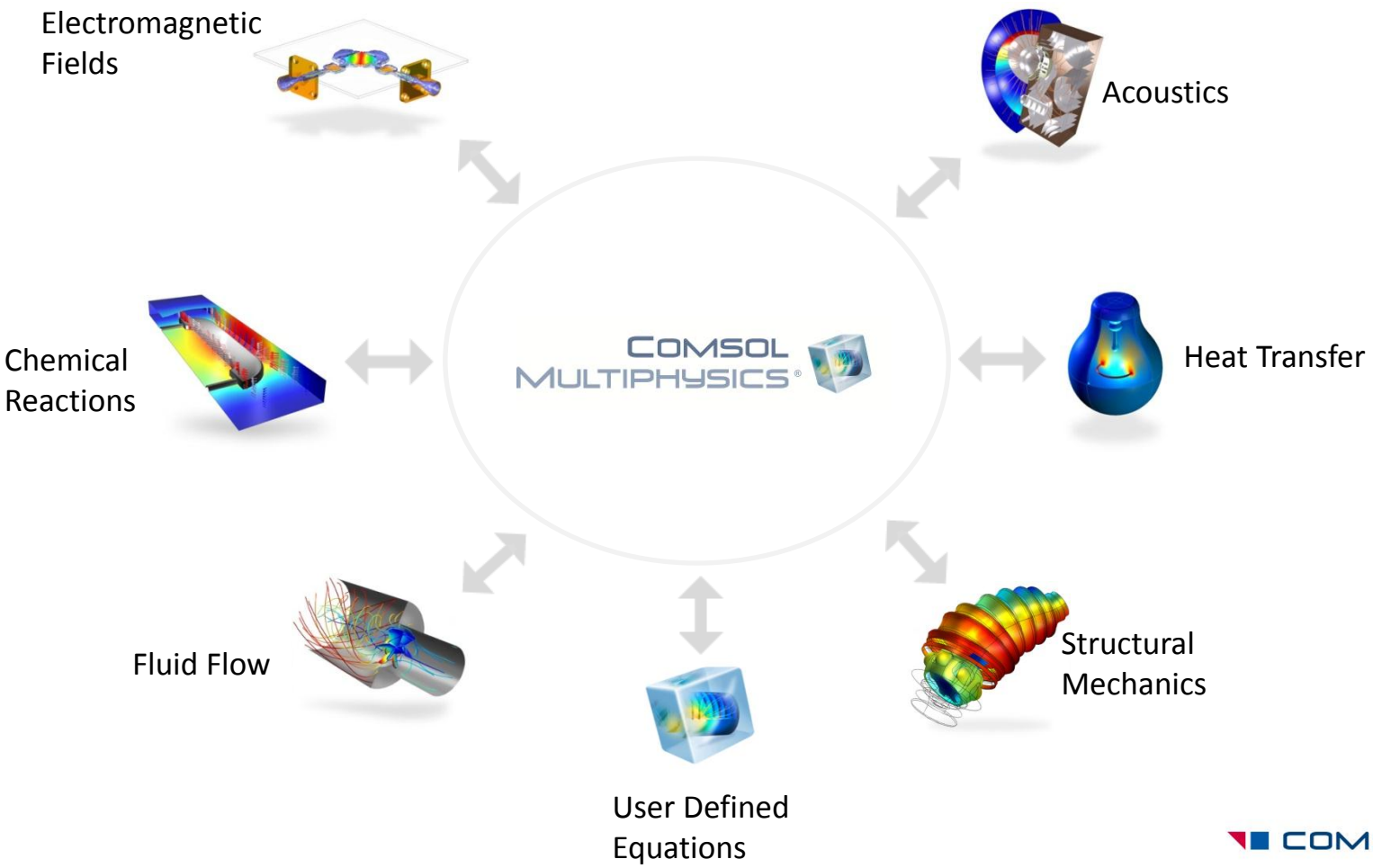
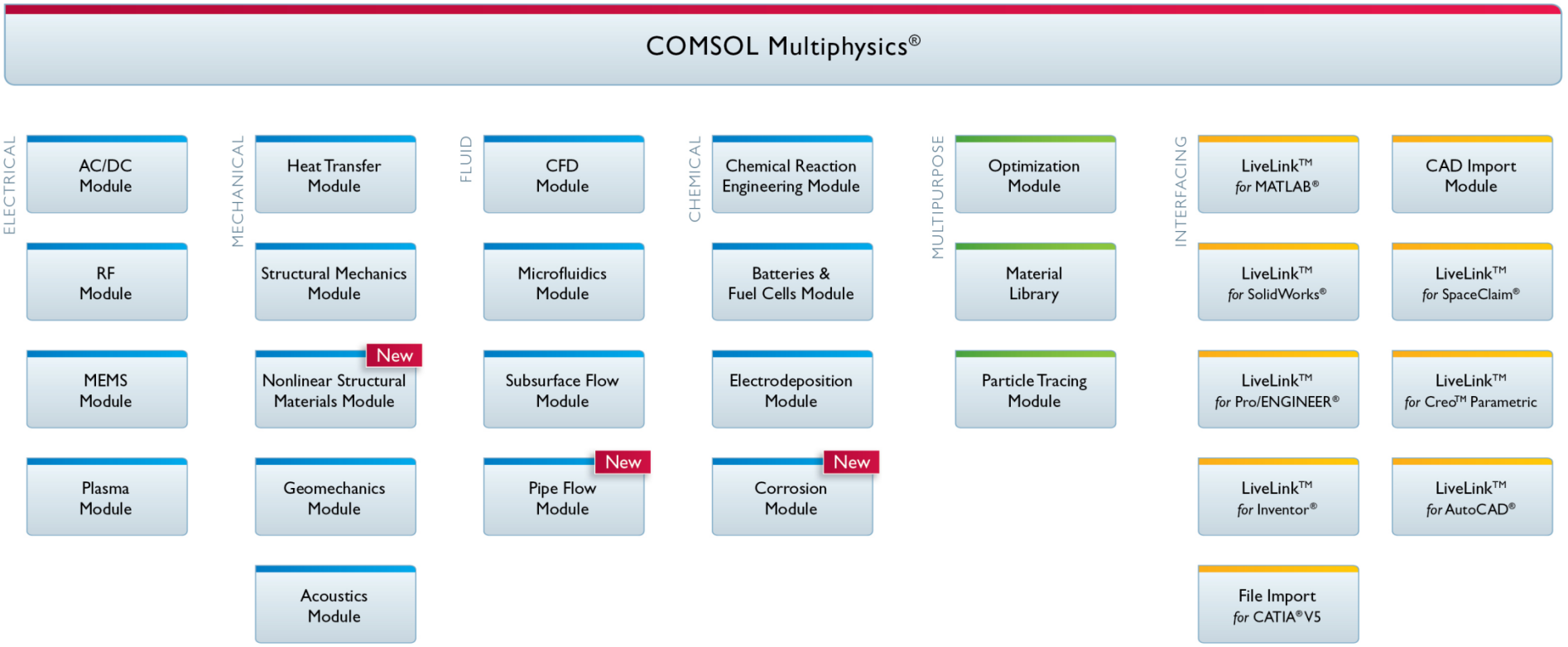
# The COMSOL Multiphysics approach



# COMSOL Multiphysics 4.3 Product Suite

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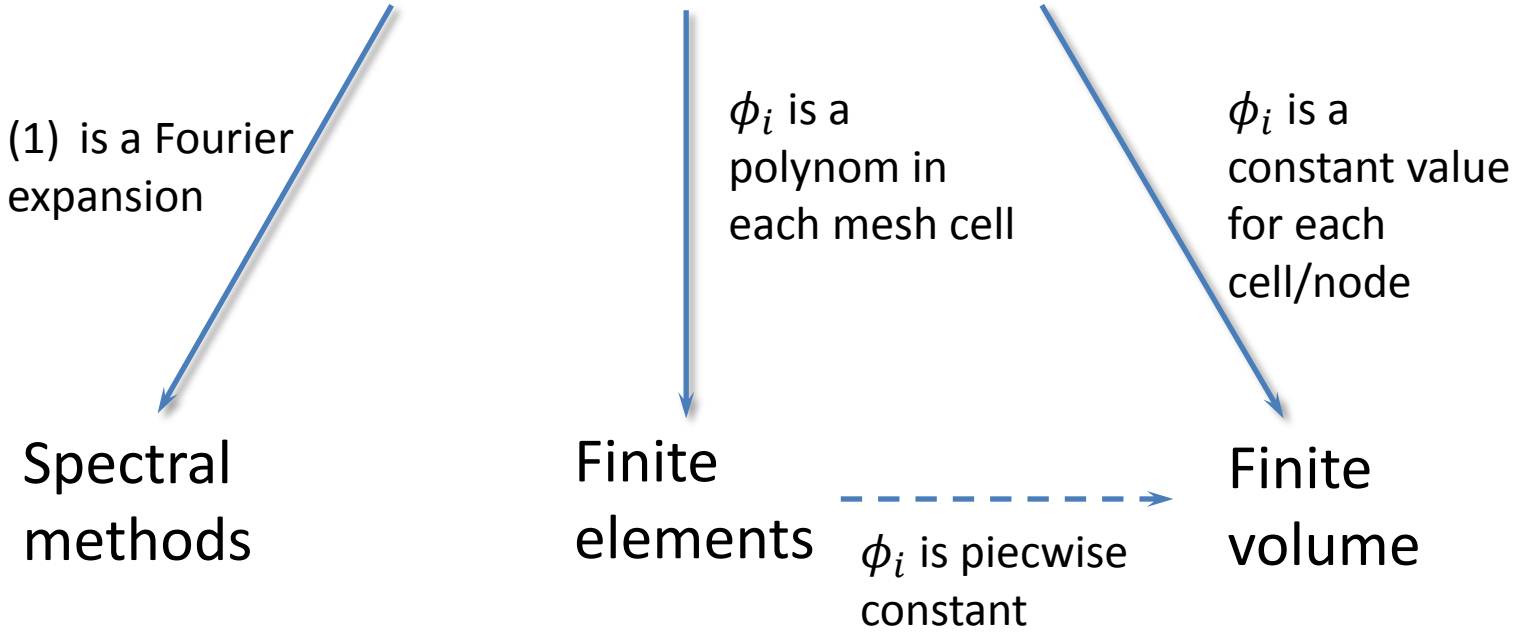
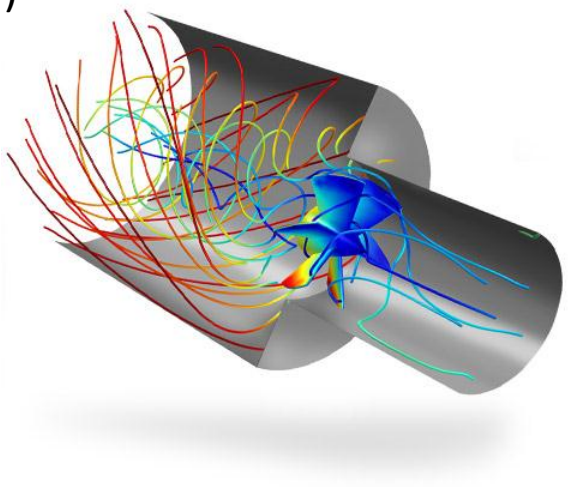
# The Finite Element Method

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



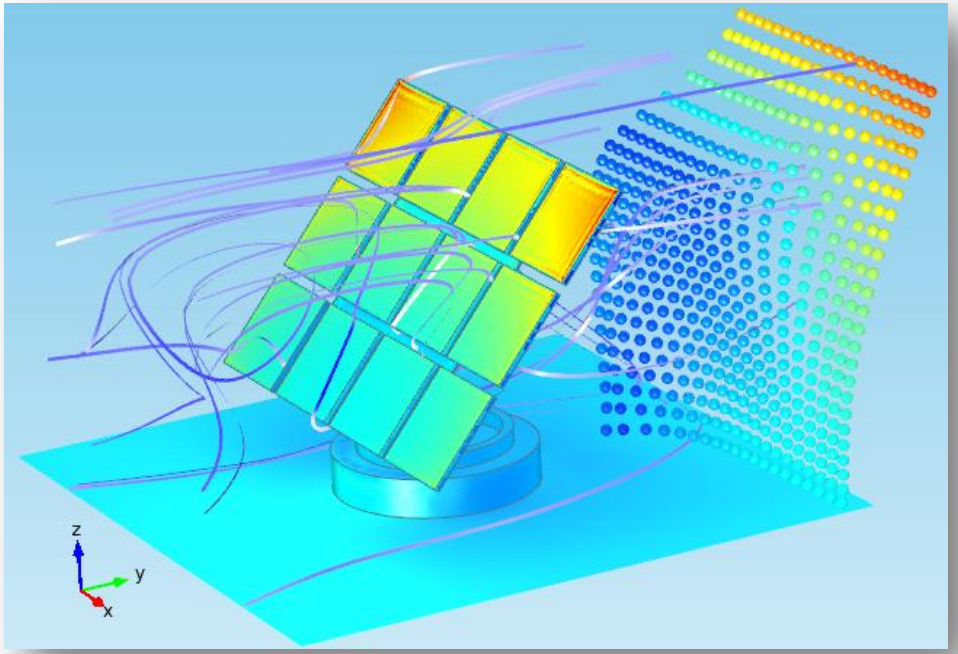
# Typical Multiphysics Couplings

- 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



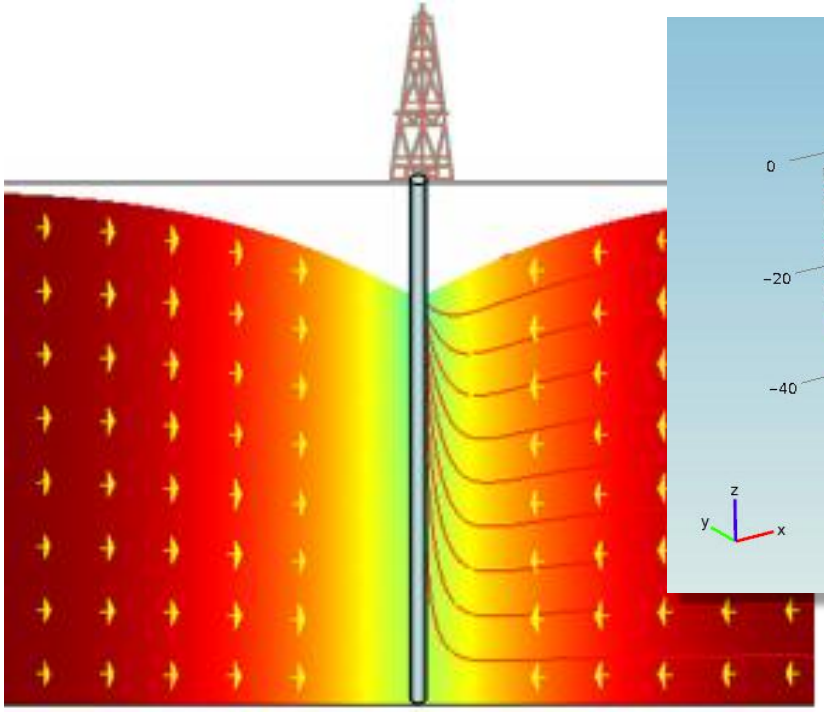
# Fluid-Structure Interaction

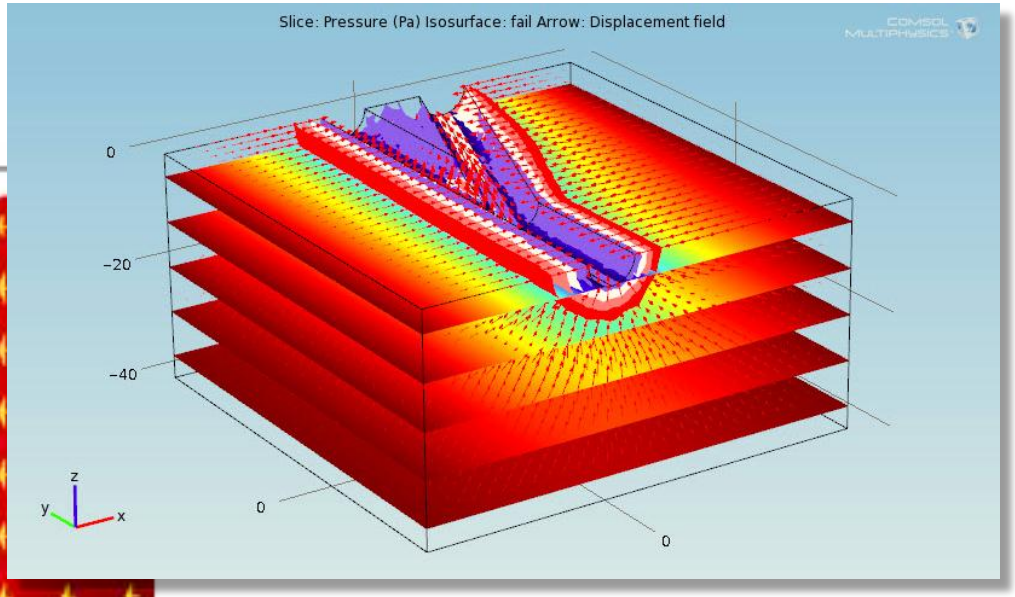
- No data transfer between solid and fluid
- One solver machinery
- One post-processing framework




Fluid load on a solar panel

# FSI Examples – Poroelasticity

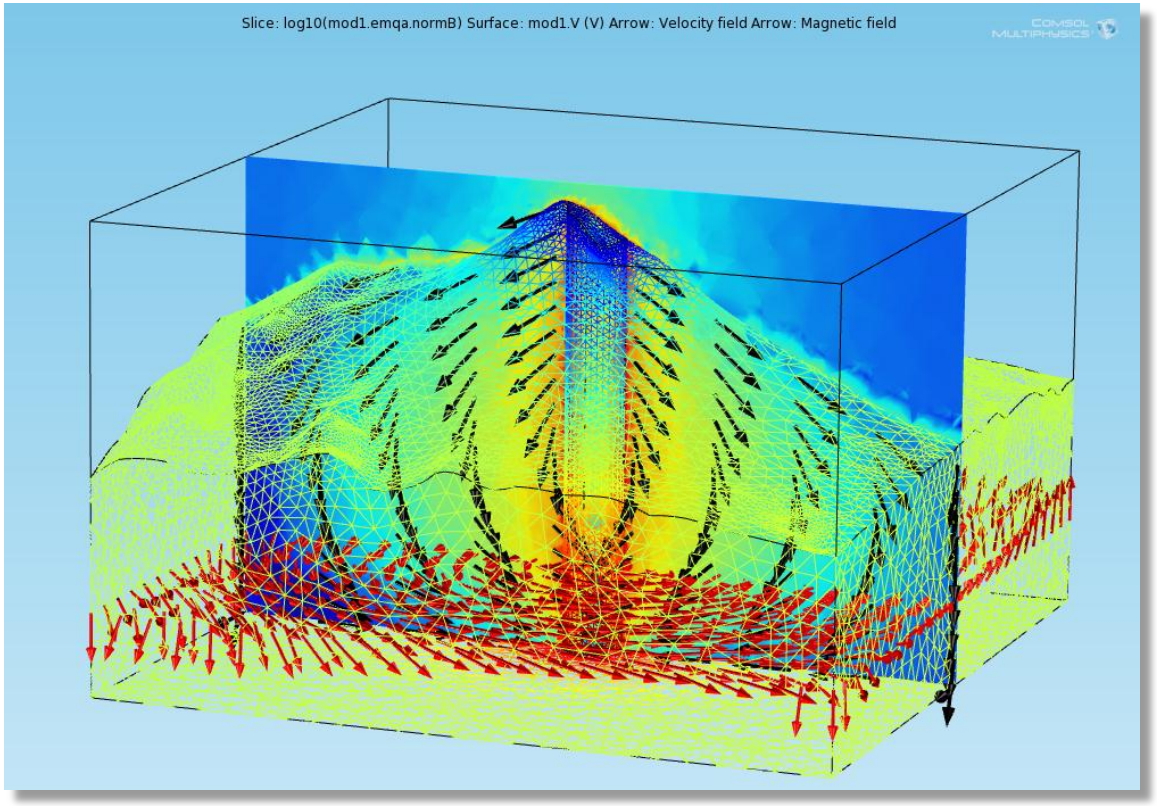





- Fluid Pressure & Structural Support Load
- Collapsing Structure  & Slows Flow Rate

# Flow Coupled to Electrical

- Electromagnetic Field from  percolating charged rainwater

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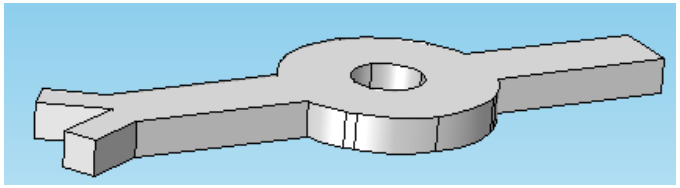
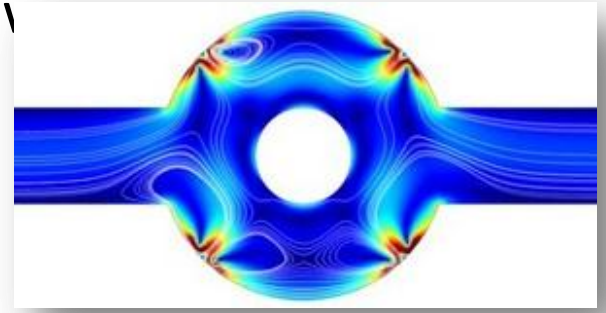
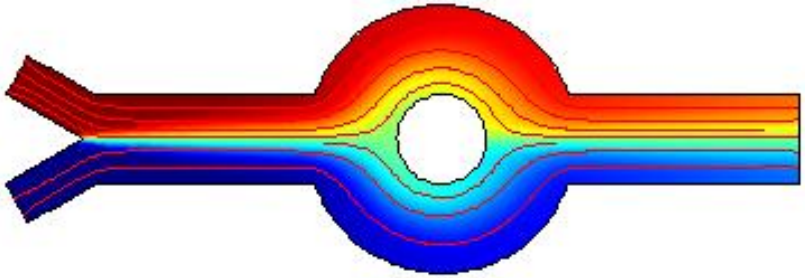
# ElectroOsmotic Mixer

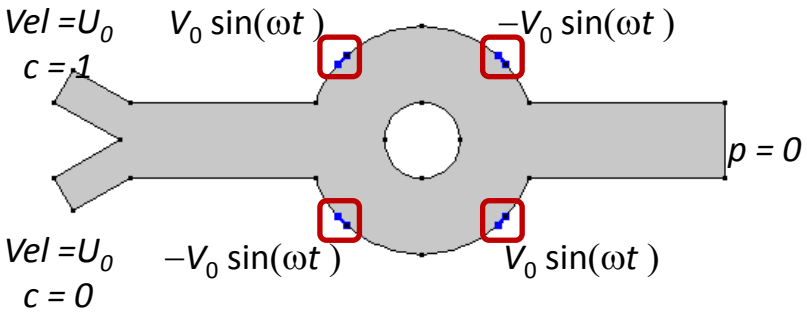


- Pressure Driven & ElectroOsmotic Flo
- Coupled Flow and Diffusion
- Goal: Improve Microfluidic Mixing

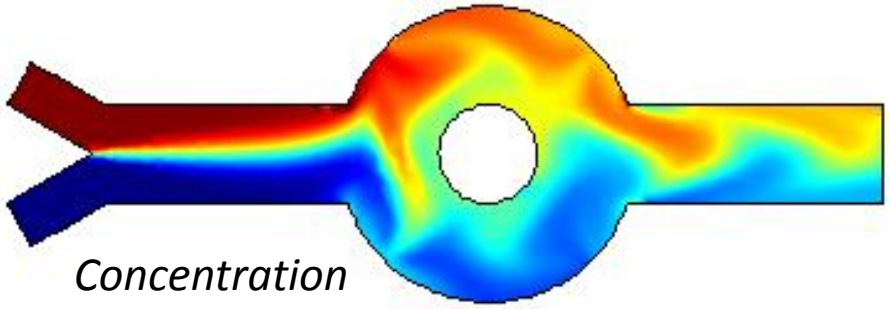


*No Mixing*






*ElectroOsmotic Mixing*

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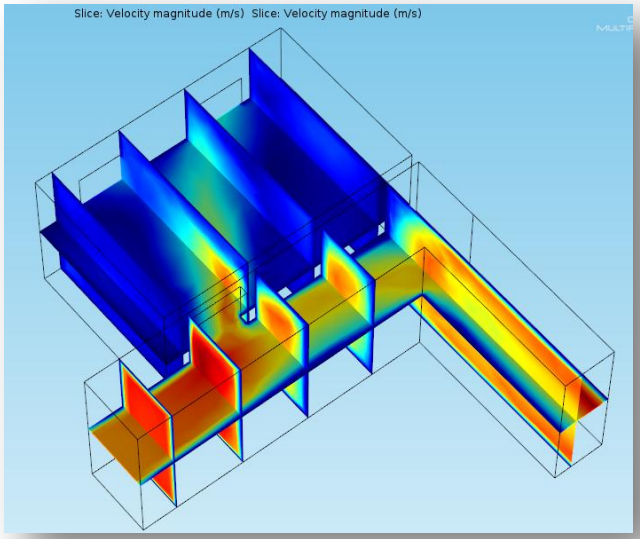
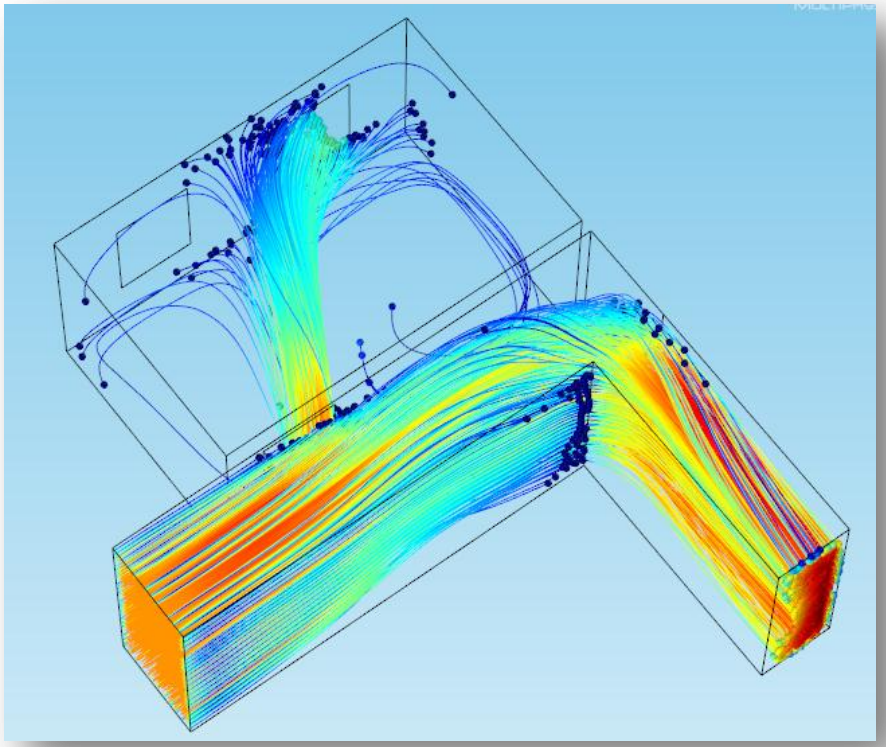
# Particle Tracing - Room Contamination

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




Air Velocity

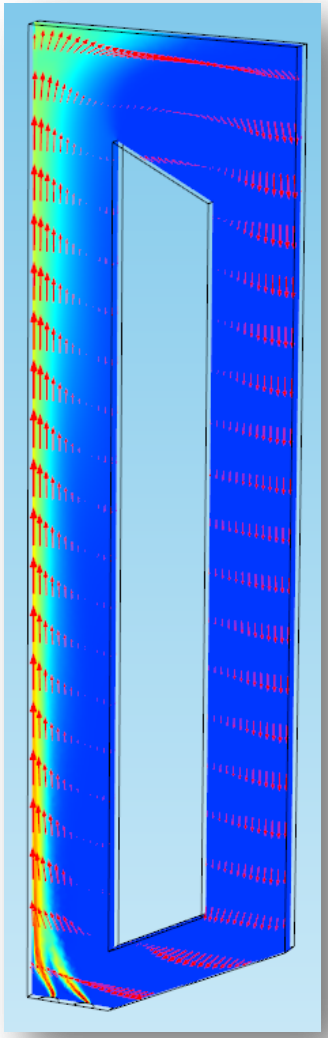


10 micron Particles

# 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



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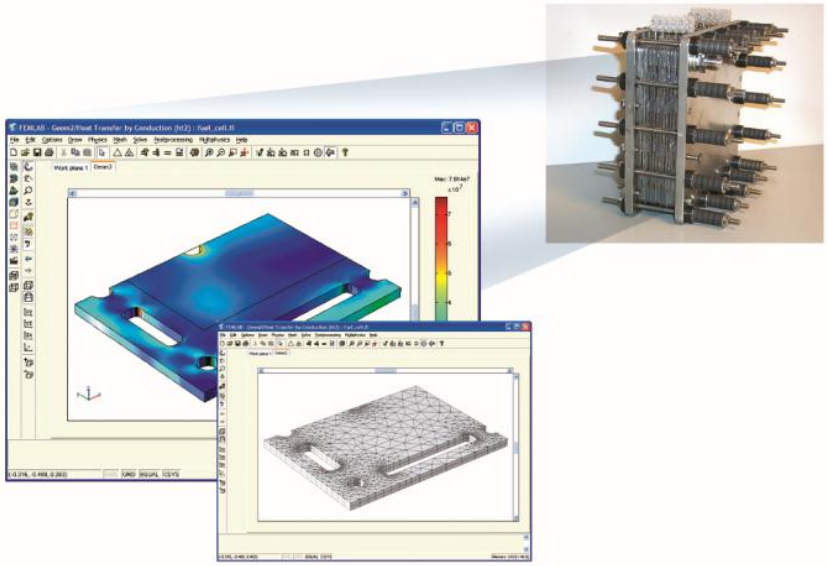
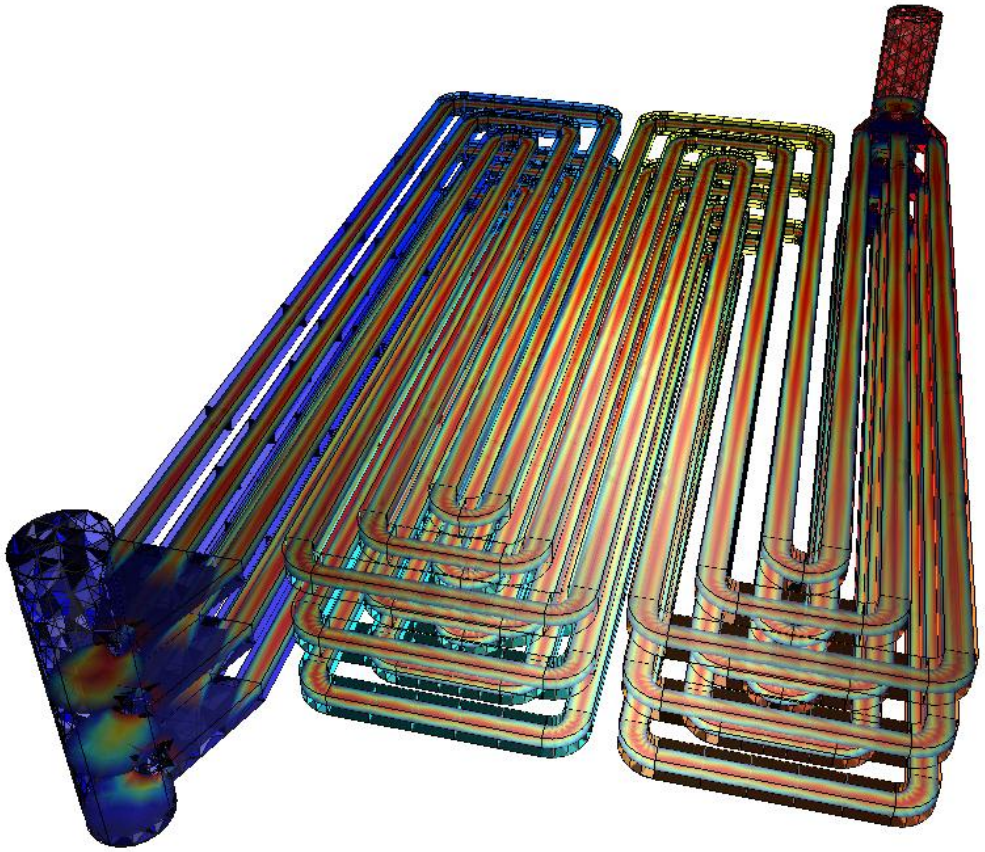
# Fuel Cells – Multiphysics by Nature

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

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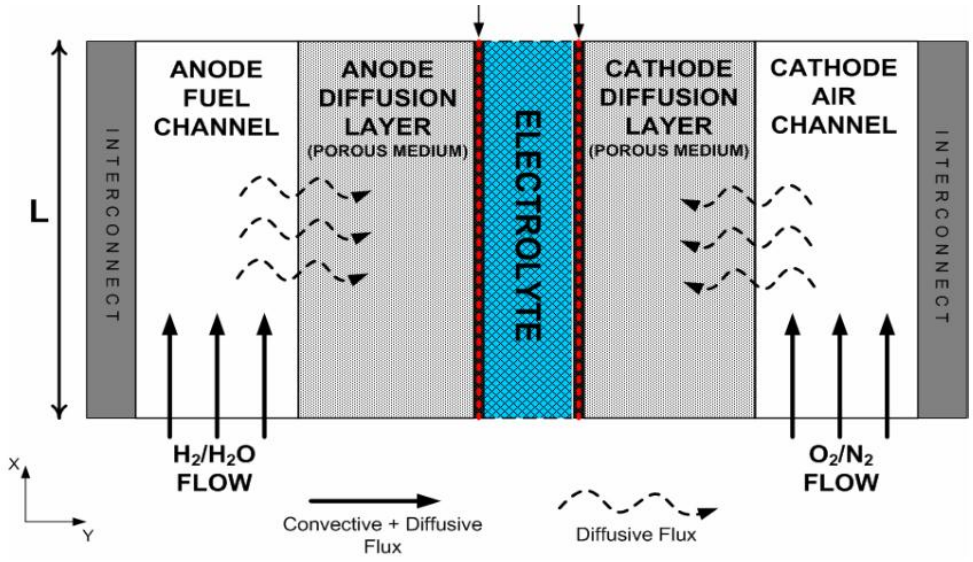
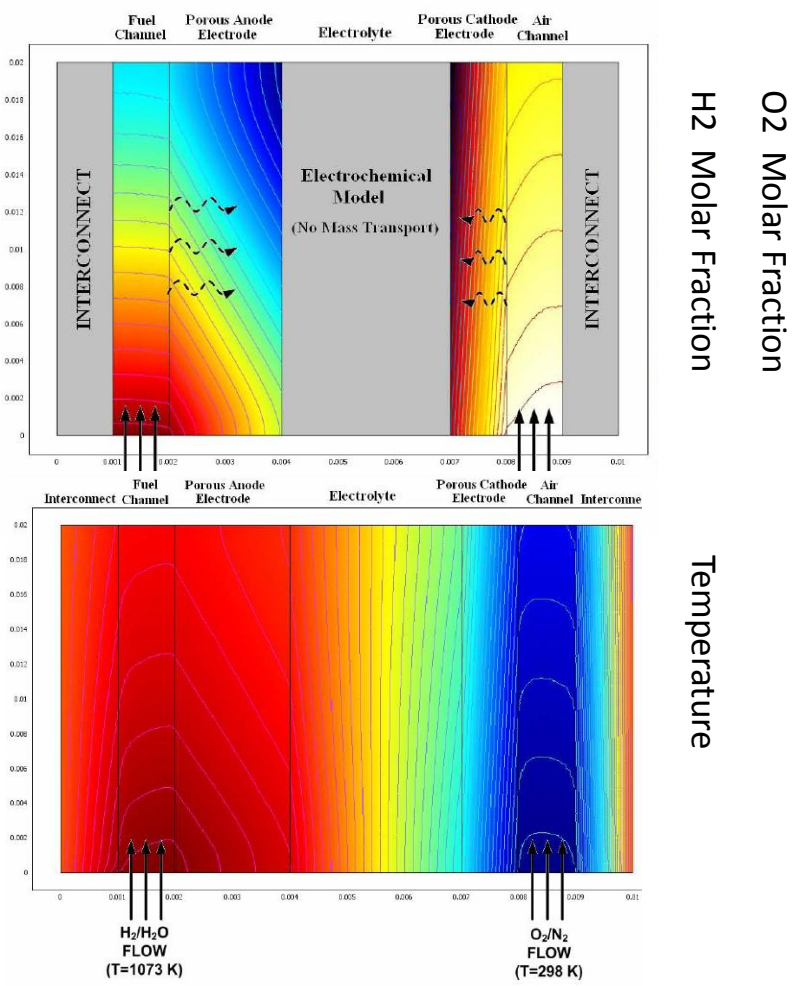
# Fuel Cell Electrochemistry

Solid Oxide Fuel Cell

- Electro Chemistry
- Convection & Diffusion
- Heat & Flow




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

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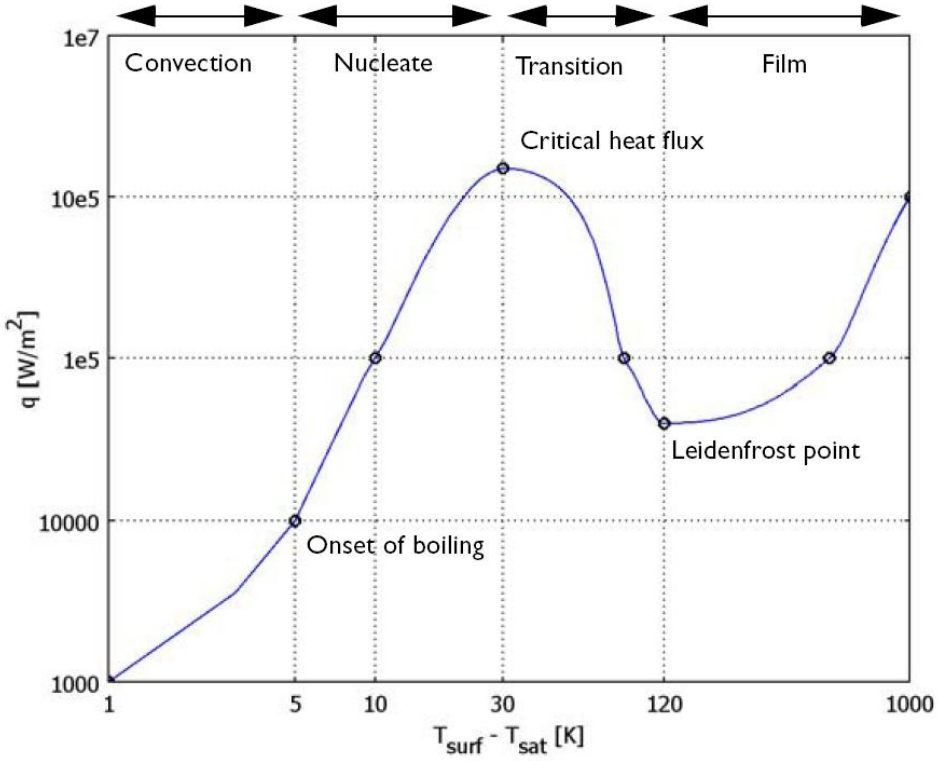
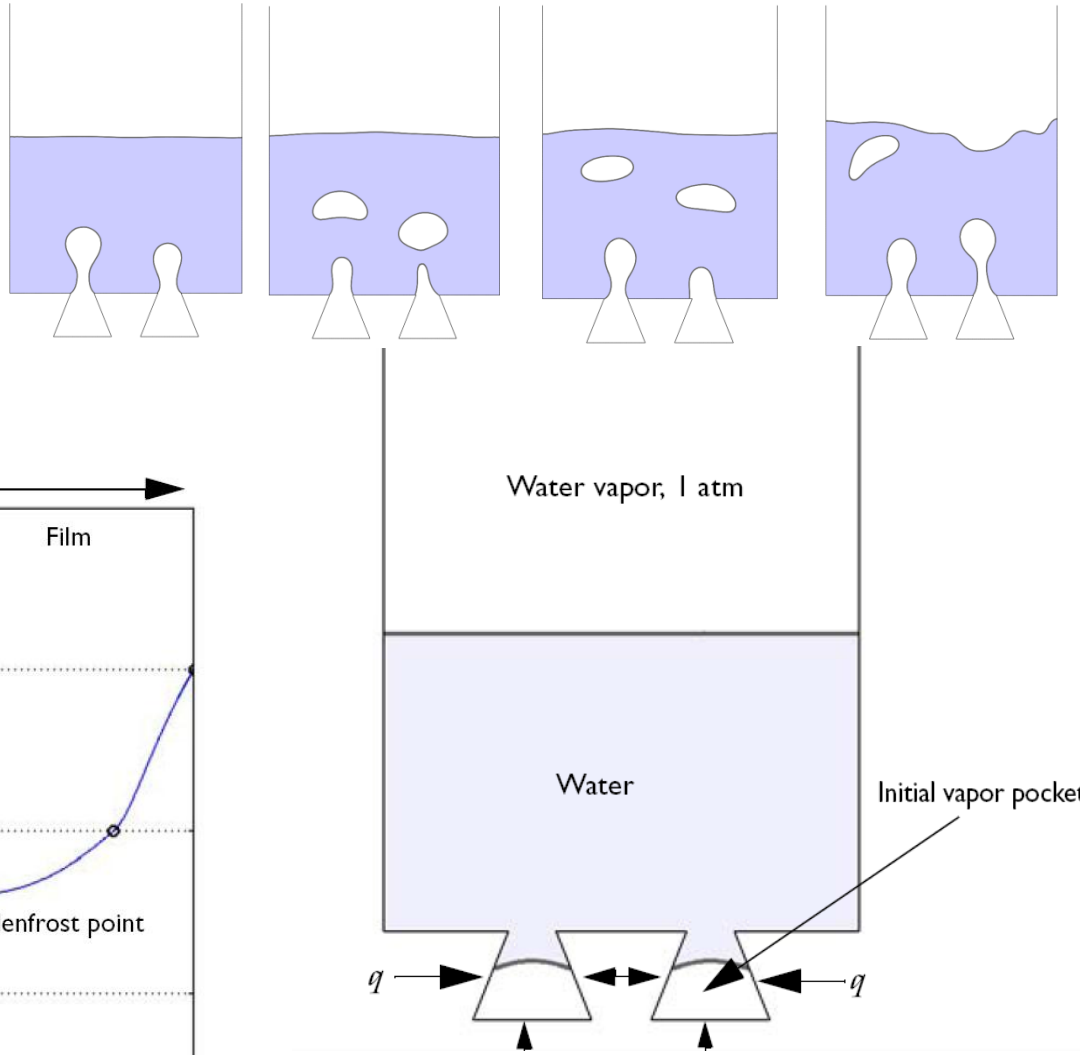
# Boiling

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




Heat: $10^5$ W/m$^3$

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## CONTRIBUTORS

AltaSim Technologies
CEA-MINATEC
Desktop Engineering
ENEL
Ford Motor Company
German Federal Institute for Materials Research and Testing
Harvard Medical School
HCL Technologies
Massachusetts General Hospital
Massachusetts Institute of Technology
MatWeb
Microvisk
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Nofima
OCAS
Riello Burners
Ritsumeikan University
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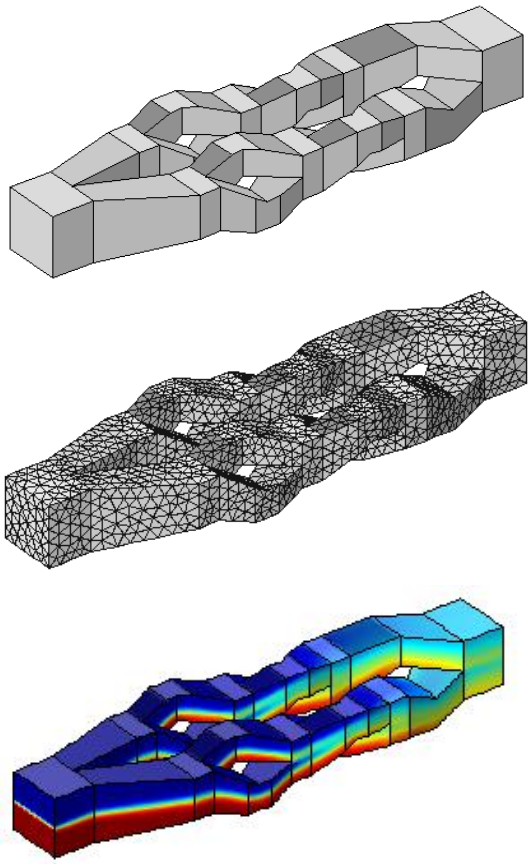
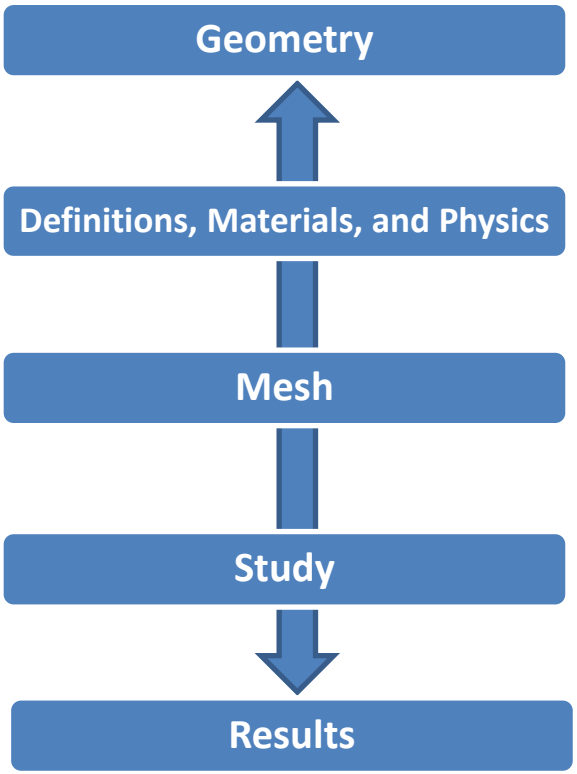
Veryst Engineering
VSG
Xi Engineering Consultants

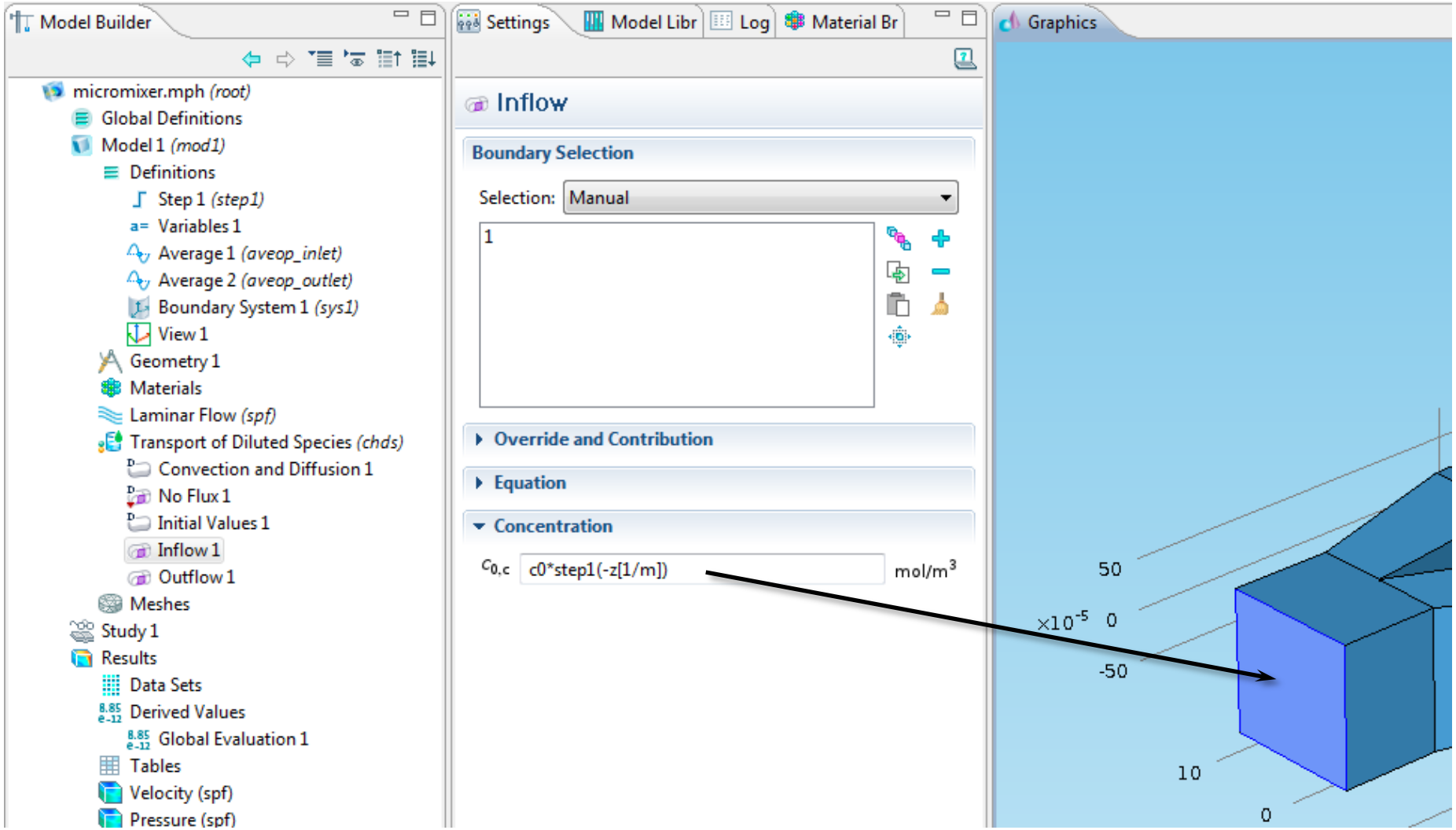
# COMSOL Multiphysics Workflow



Micromixer



# User Friendly Interface

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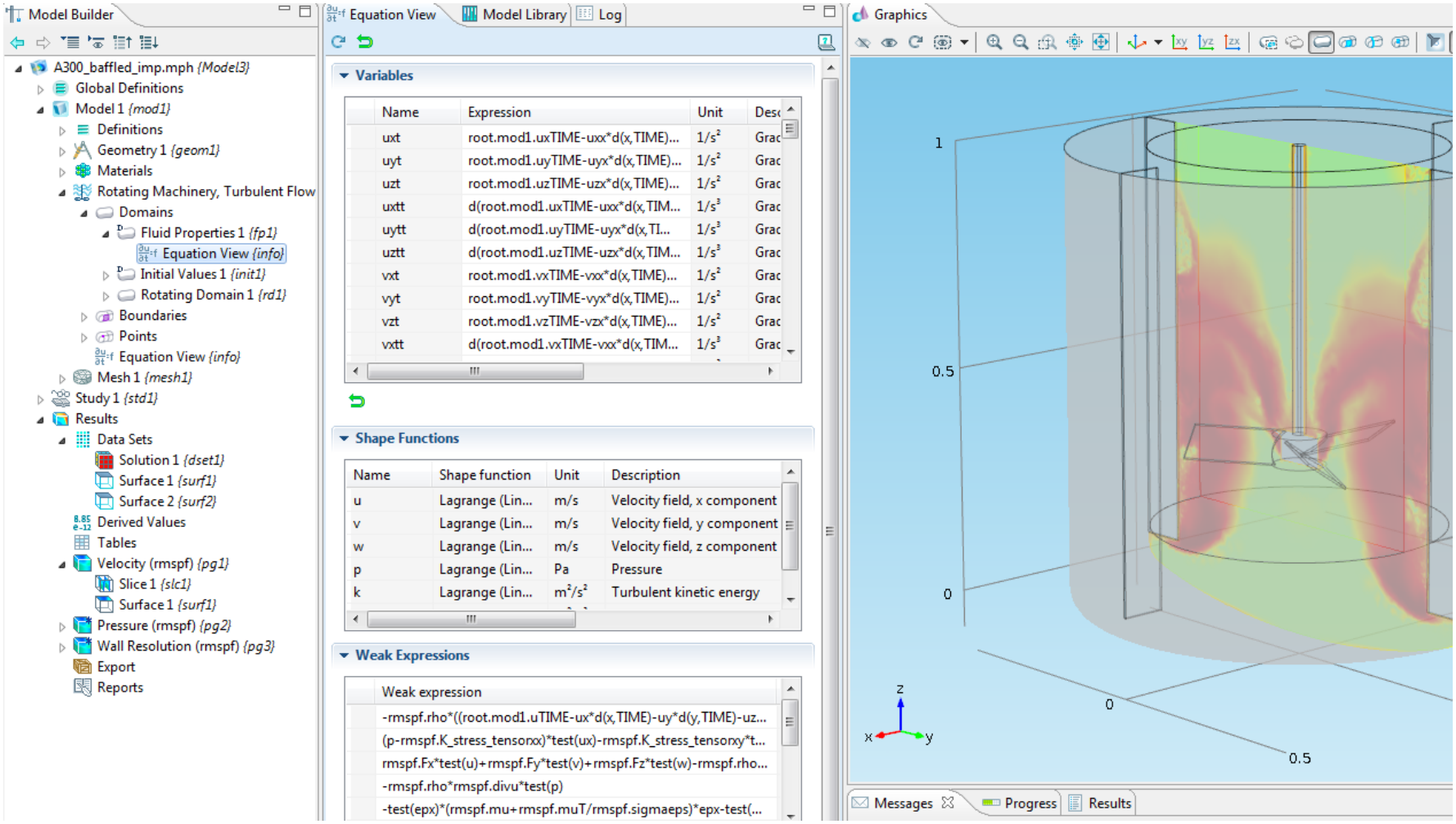
# Everything is Equation Based

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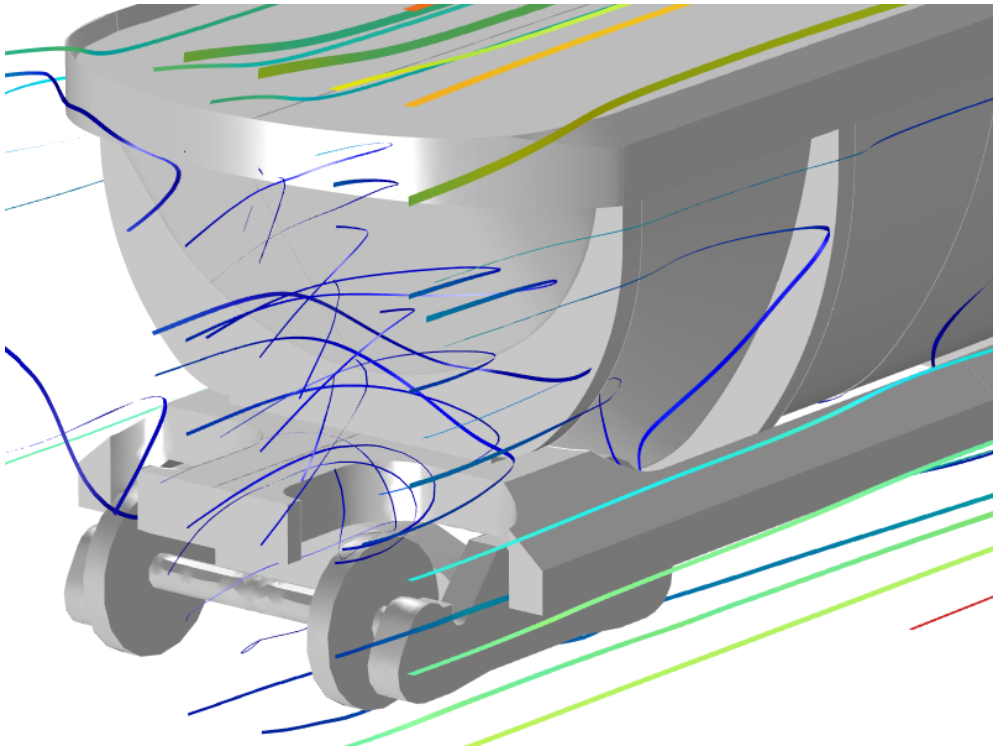
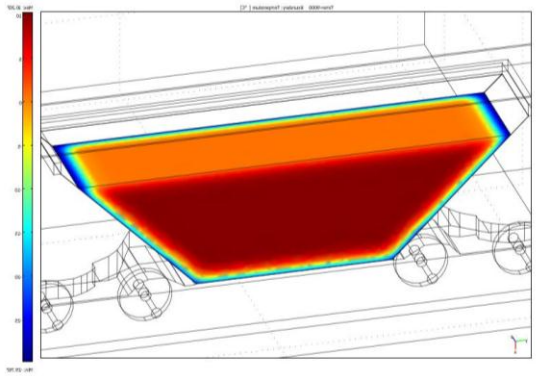
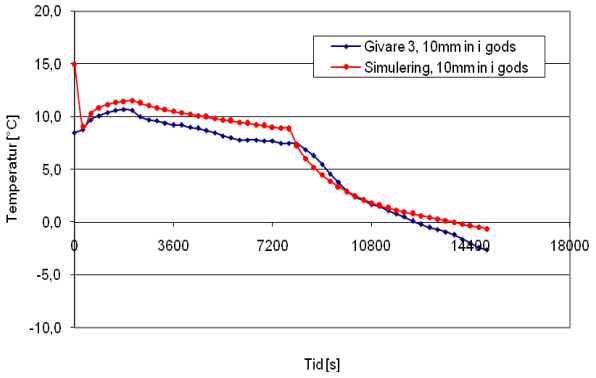
# Relitor, Luleå








- 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.

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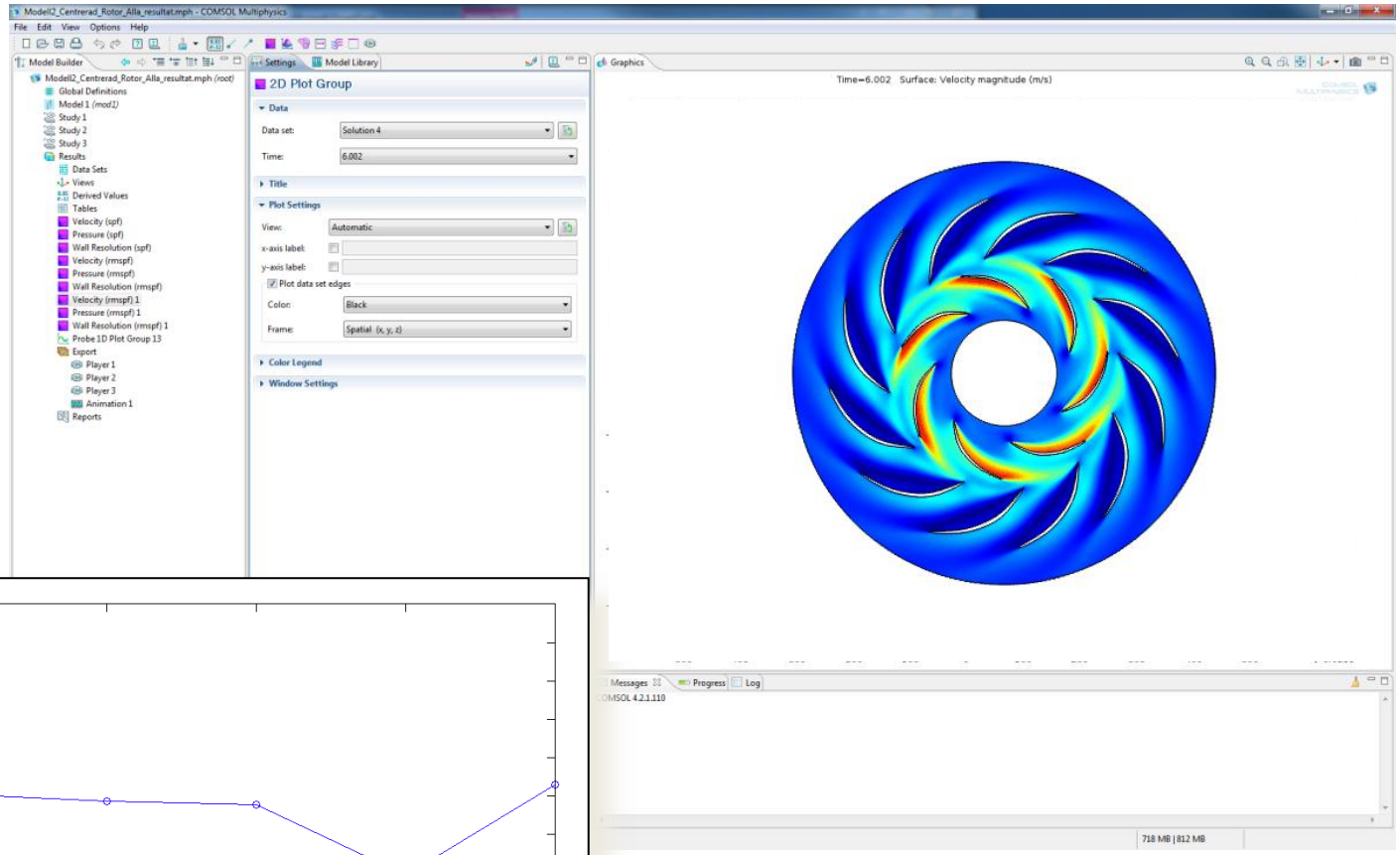
# ÅF, Stockholm

Centrifugal pumps

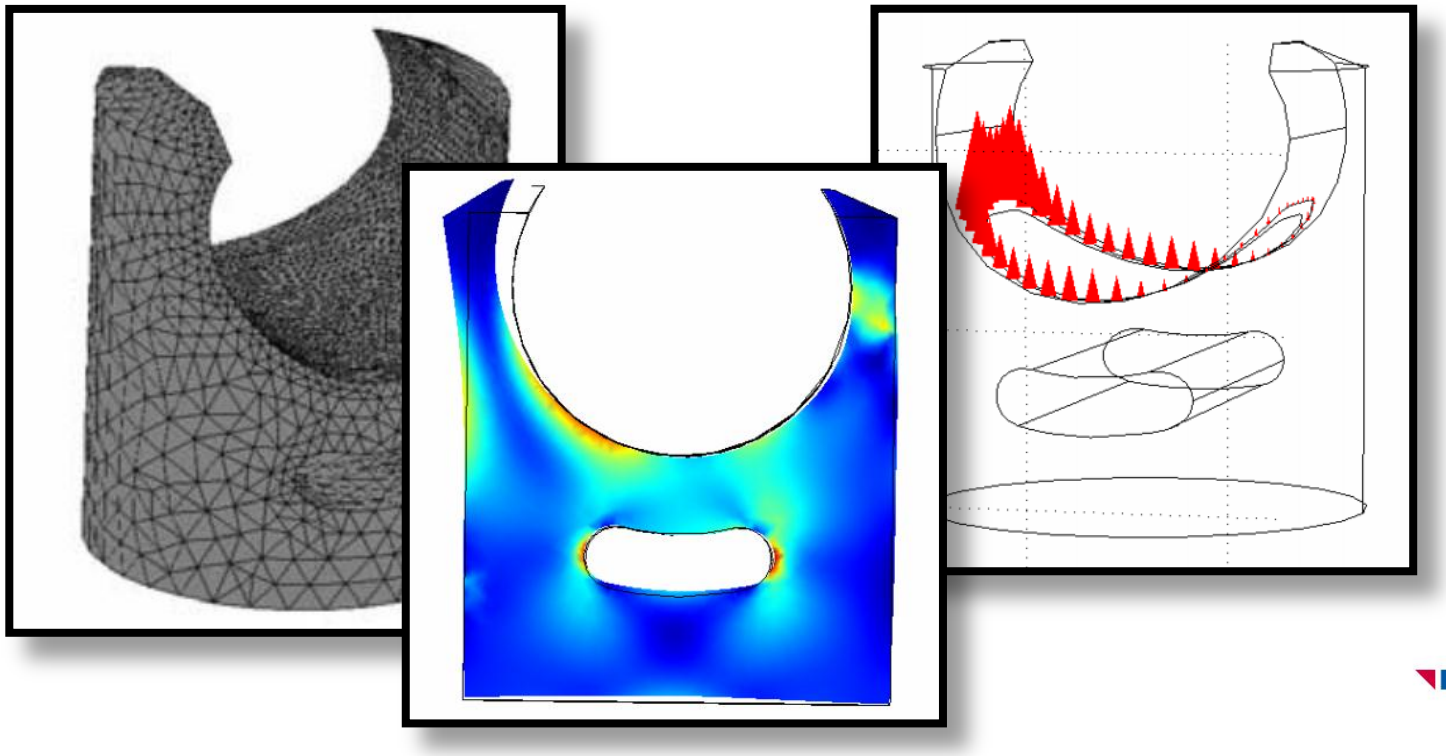
How does the effect change it the impeller is not centered?



# Hägglund Drives

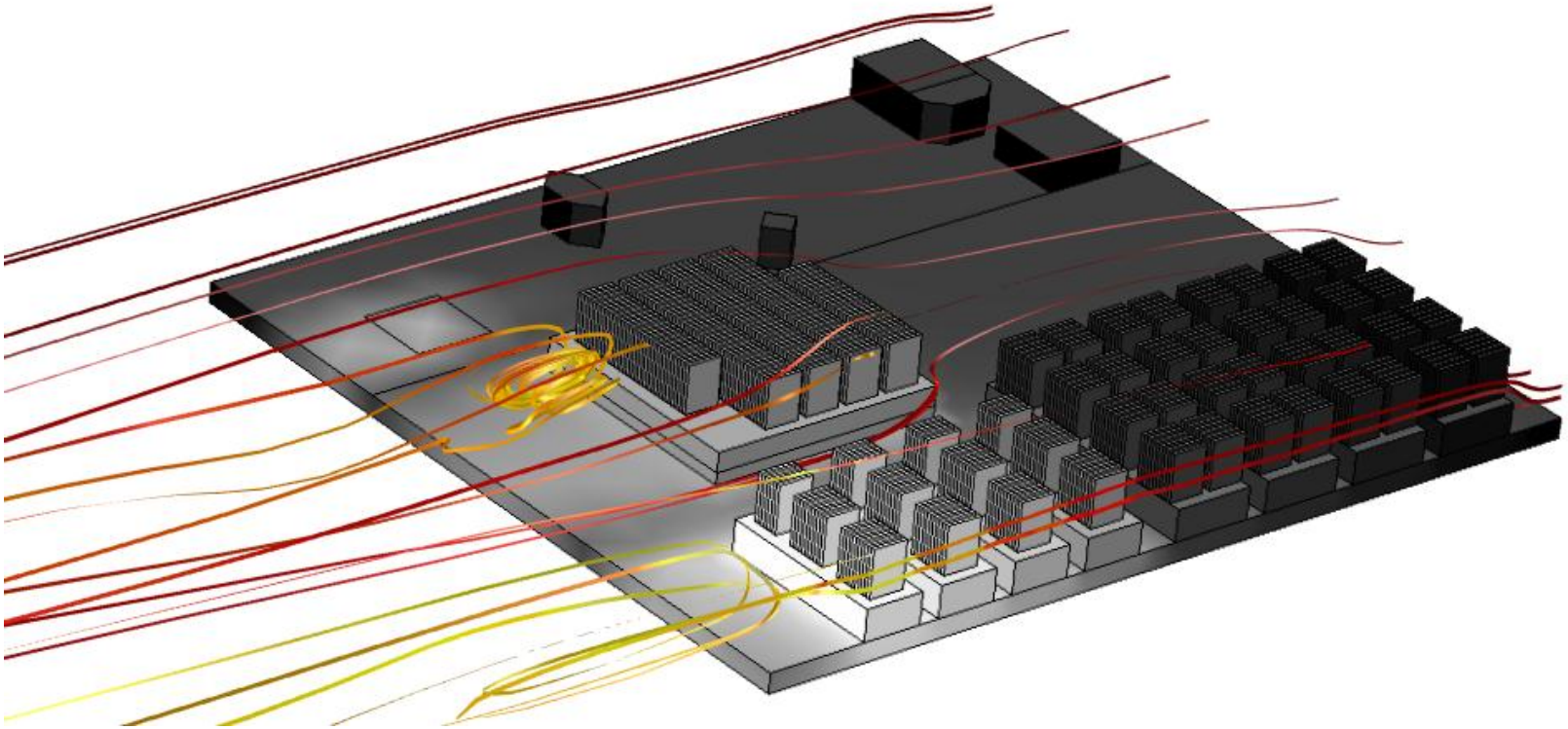
Simulation of a radial engine

- 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?



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# Turbulent or Laminar?

- Reynolds number

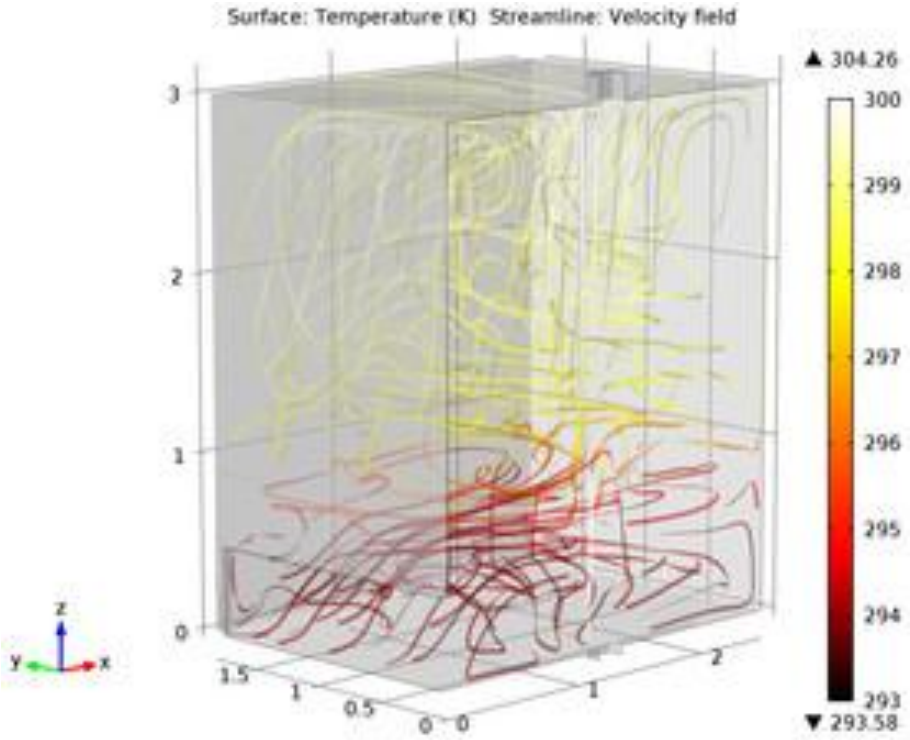
$$Re = \frac{U \cdot L}{\nu}$$

$$Re \gg 1 \Rightarrow turbulent$$

- Grashof number

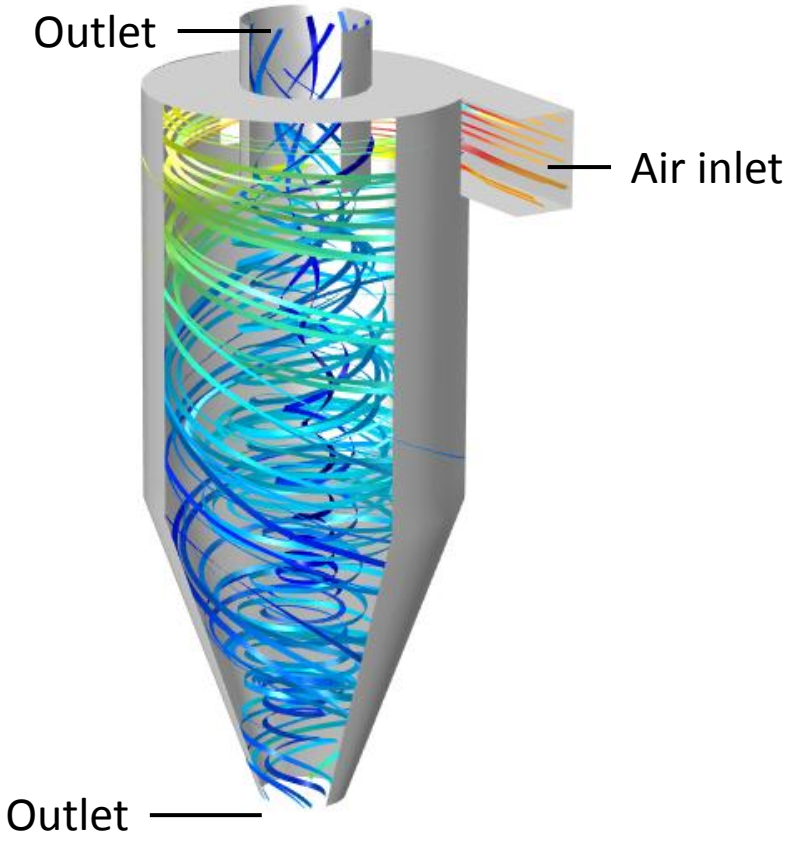
$$Gr = \frac{g\alpha\Delta T \cdot L^3}{\nu^2}$$

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

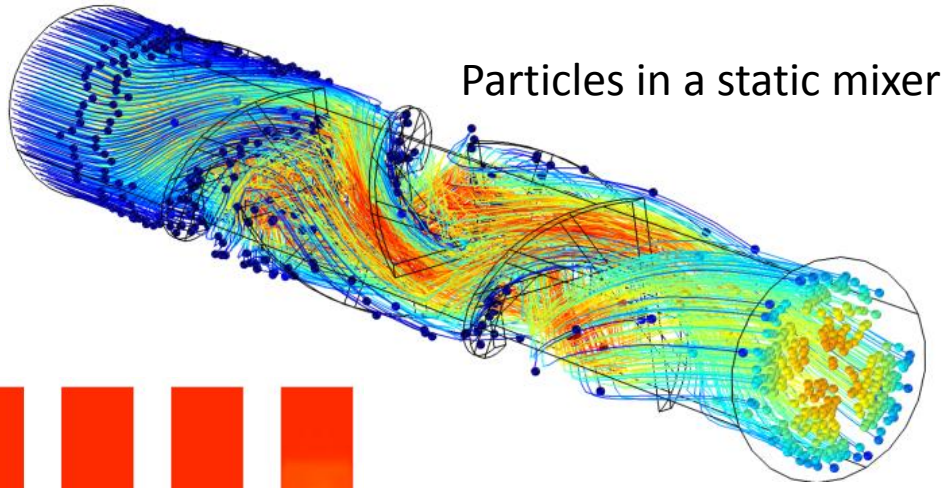


# Which Turbulent Model

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

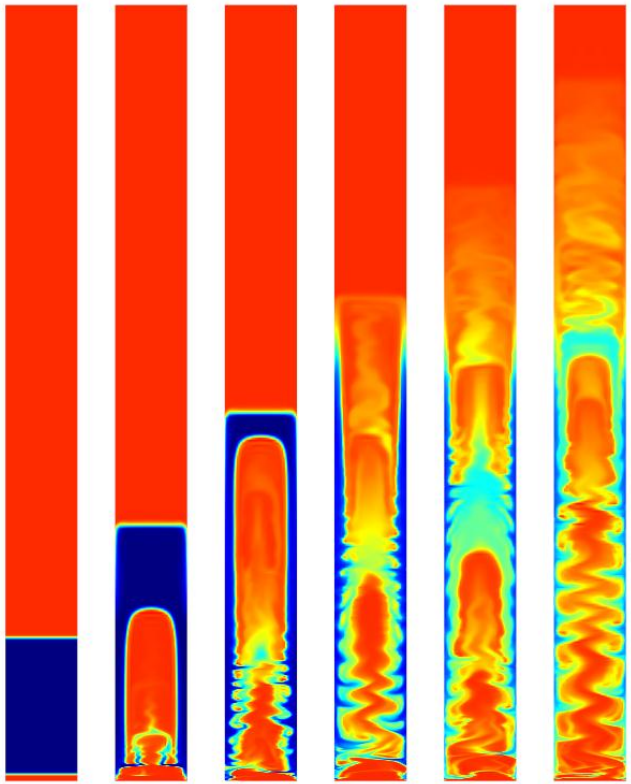


# Multiple Phases

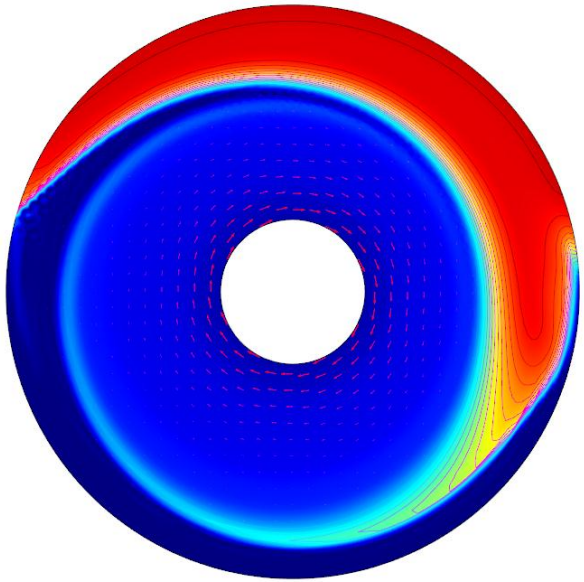


Particles in a static mixer

- Mixture
- Euler-Euler
- Particles



Solid Spherical Particles Fluidized by Air



Spinning Suspension

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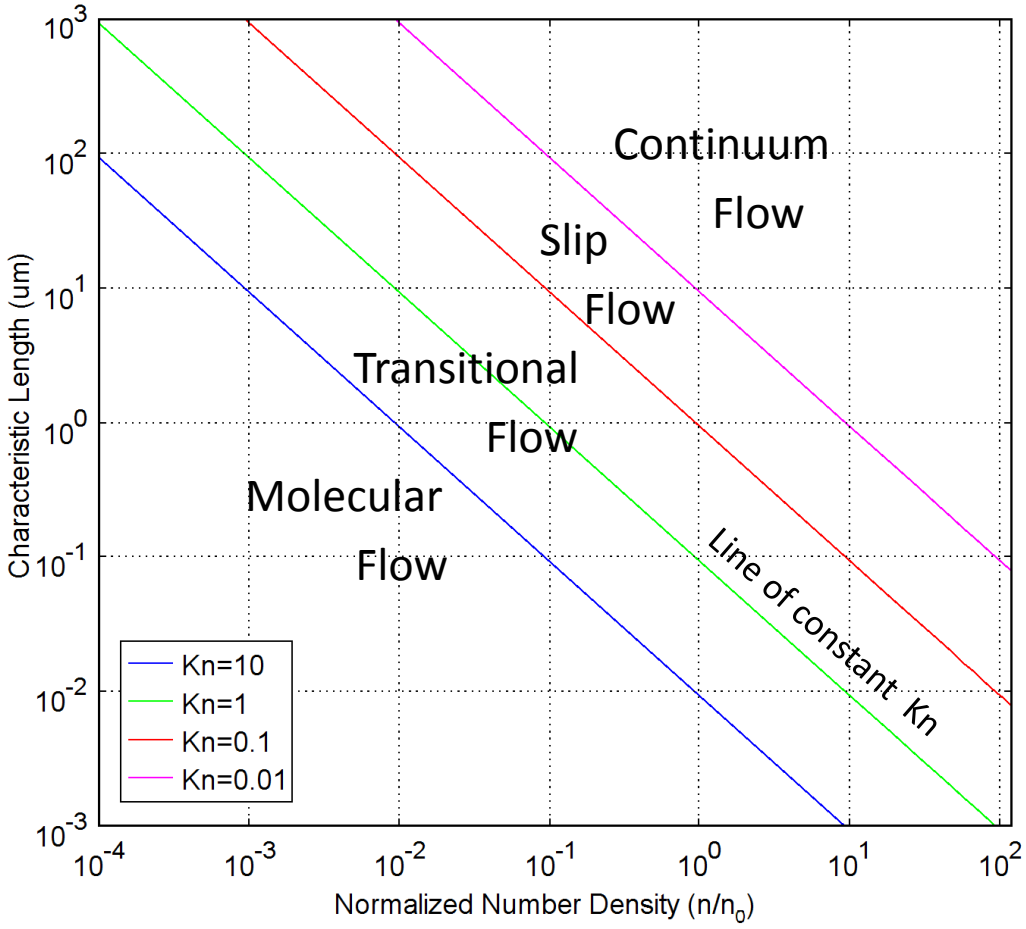
# Rarefied Flows




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

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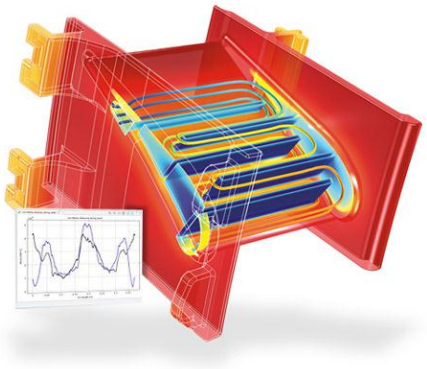
# COMSOL Multiphysics

- **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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