Modélisation OD/1D
avec
COMSOL Multiphysics 3.4

17 avril 2008

LMCS 2008

Printemps de la Recherche

EDF – Chatou

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1. Introduction – E.D.P

$$e_a \frac{\partial^2 u}{\partial t^2} + d_a \frac{\partial u}{\partial t} + \nabla \cdot \Gamma = F$$

Heat Flux: $$\rho Cp \frac{\partial T}{\partial t} - \nabla \cdot \left(k \nabla T \right) = Q_{heat\ source}$$

Mass Convection-Diffusion: $$\frac{\partial c}{\partial t} - \nabla \cdot \left(D \nabla c \right) = R - \left(\mathbf{u} \cdot \nabla c \right)$$

DC Conductive: $$-\nabla \cdot \left(\sigma \nabla V \right) = 0$$

Electrostatics: $$-\nabla \cdot \left(\varepsilon_r \varepsilon_0 \nabla V \right) = 0$$

Modéliser presque tout!

$$e_a \frac{\partial^2 u}{\partial t^2} + d_a \frac{\partial u}{\partial t} + \nabla \cdot \Gamma = F$$

Structural Analysis:

$$\nabla \cdot [\boldsymbol{\sigma}] = \mathbf{F}$$

Acoustics:

$$\frac{1}{\rho c^2} \frac{\partial^2 p}{\partial t^2} + (0) + \nabla \cdot \left(\frac{-\nabla p}{\rho} \right) = Q_{Source}$$

Navier-Stokes:

$$\nabla \cdot (\rho \mathbf{u}) = 0$$

$$\rho \frac{d\mathbf{u}}{dt} + \nabla \cdot \left(p\mathbf{I} - \eta \left(\nabla \mathbf{u} + (\nabla \mathbf{u})^{\mathrm{T}} \right) \right) = \mathbf{F} - \rho \mathbf{u} \cdot \nabla \mathbf{u}$$

Gauss's Law:

$$\nabla \cdot \mathbf{D} = \rho$$

Faraday's Law :

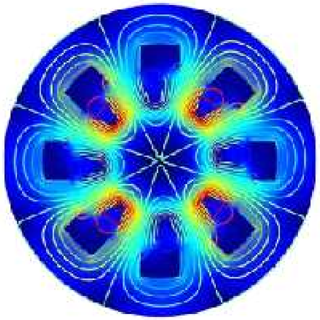
$$\frac{\partial \mathbf{B}}{\partial t} + \nabla \times \mathbf{E} = 0$$

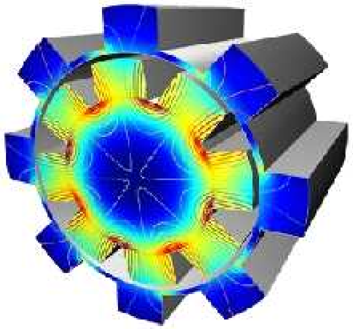
Générateur électrique

Dynamics of a Generator

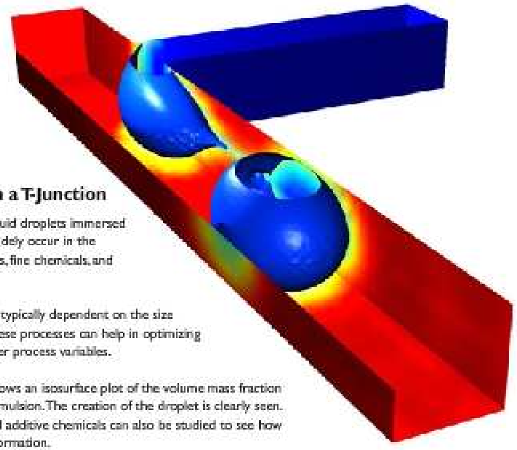
This example shows how the circular motion of a rotor with permanent magnets in a generator results in an induced EMF in the stator winding. The generated voltage is calculated as a function of time during the rotation.

The plot on the left shows the magnetic flux density along with a contour plot of the magnetic potential. Note the brighter regions, which indicate the position of the permanent magnets in the rotor. The figure on the right shows the geometry and a simulation of the generator in 3D.





Ecoulement diphasique



Droplet Breakup in a T-Junction

Emulsions consist of small liquid droplets immersed in an immiscible liquid and widely occur in the production of food, cosmetics, fine chemicals, and pharmaceutical products.

The quality of the product is typically dependent on the size of the droplets. Simulating these processes can help in optimizing these droplets as well as other process variables.

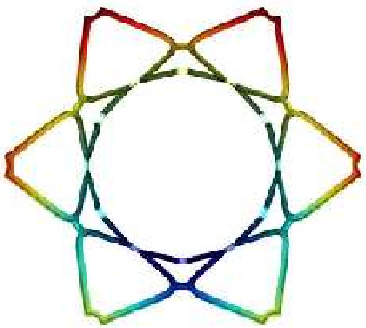
This model and animation shows an isosurface plot of the volume mass fraction of the immersed fluid in an emulsion. The creation of the droplet is clearly seen. Factors such as fluid flow and additive chemicals can also be studied to see how they affect droplet size and formation.

Ingénierie biomédicale

Plastic Deformation During the Expansion of a Stent

Percutaneous transluminal angioplasty with stenting is a widely used method for the treatment of atherosclerosis. During this procedure, a stent is deployed in to the blood vessel by means of a balloon. The expanded stent acts as a scaffold that keeps the blood vessel open.

This model studies the deformation of a stent subjected to a radial outward pressure using an elasto-plastic material model with linear hardening. The animation shows the total displacement and illustrates both the non-uniform expansion and foreshortening of the stent.

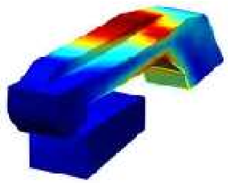


Contacteur test

Contact Analysis of a Snap Hook Fastener

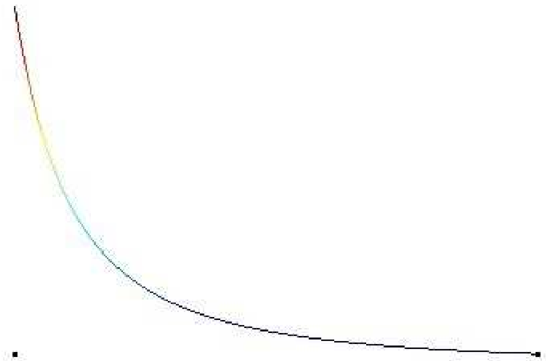
Fasteners like this are common in the automotive industry, for example in the control panel of a car. In this case it is important to know the force that must be applied in order to place the hook in the slot, as well as the force needed to remove it.

The animation shows the movement of the hook as it firstly snaps into its groove and then as it is detached. The color plot shows the von Mises stress.



Analyse financière:

Calcul de la valeur d'un indice européen avec l'équation de Black-Scholes



The famous Black-Scholes equation computes the cost u of a European stock option

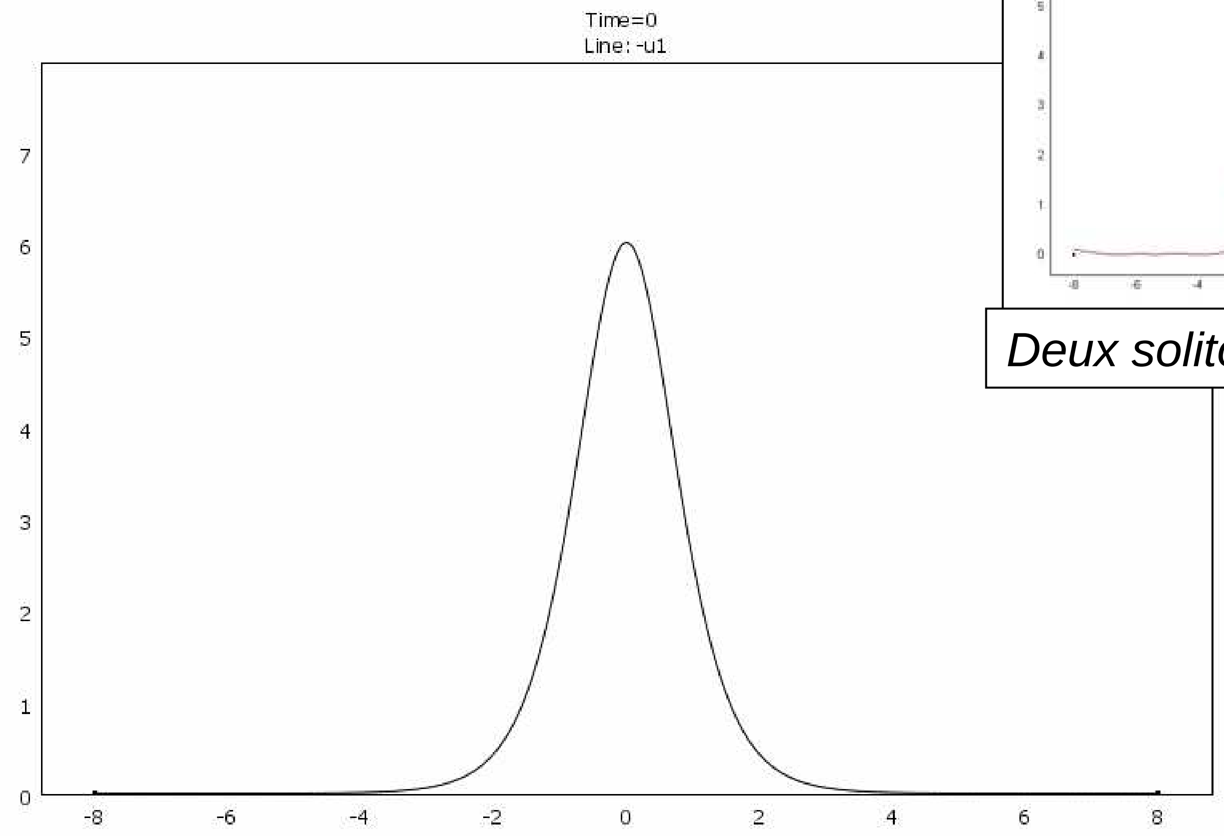
$$\frac{\partial u}{\partial t} + \frac{1}{2}\sigma^2 x^2 \frac{\partial^2 u}{\partial x^2} + r x \frac{\partial u}{\partial x} = r u$$

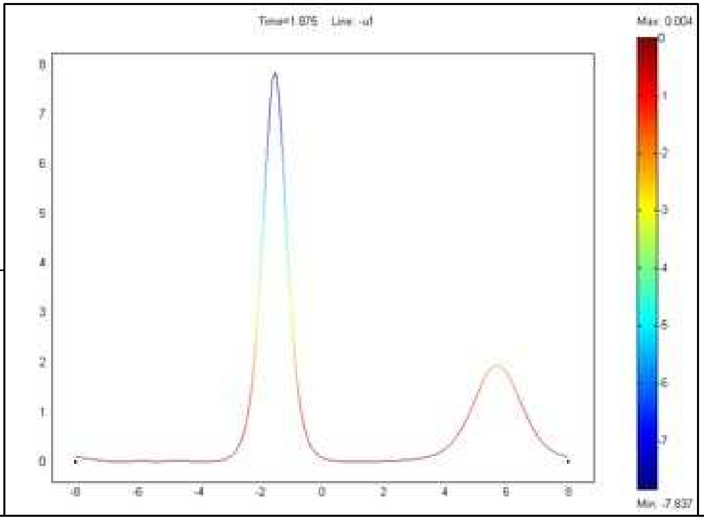
with the following parameters:

- x, the underlying asset price
- r, the continuous compounding rate of interest
- σ, the standard deviation of the asset's rate of return (also known as volatility)

Solitons : équation de Korteweg-De Vries

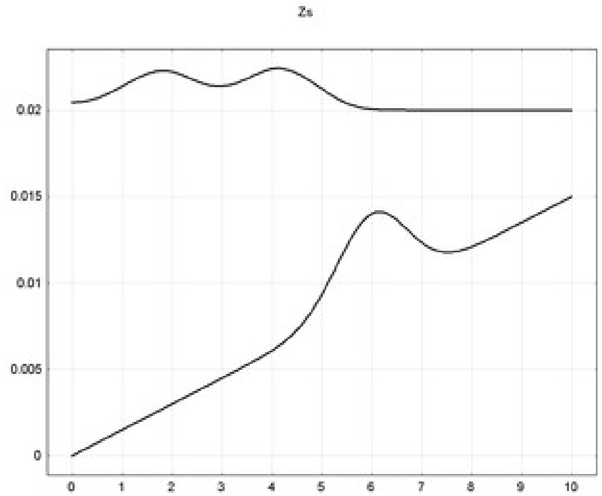
$$u_t + u_{xxx} = 6uu_x \qquad \text{in } \Omega = [-8, 8]$$
$$u(-8, t) = u(8, t), \qquad \text{periodic}$$





Deux solitons à l'instant t=1,875s

Vagues en eau peu profonde



Coupe de profil du fond et de la surface d'un lac.

- Equations de *Saint-Venant* :

$$\frac{\partial z}{\partial t} + \nabla \cdot (zv) = 0$$

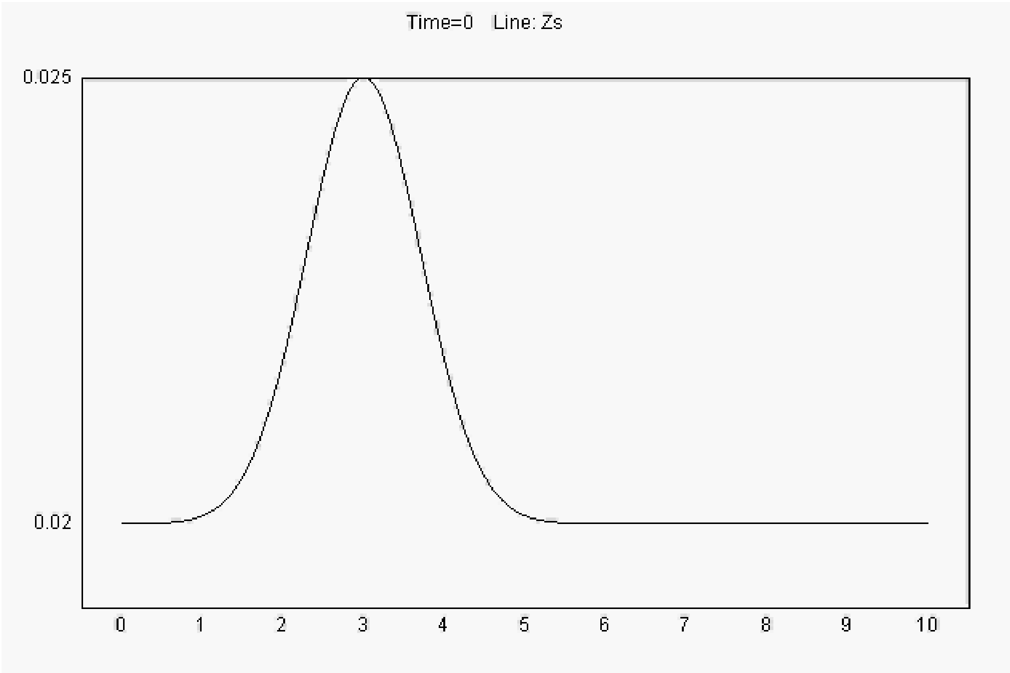
$$\frac{\partial (zv)}{\partial t} + \nabla \cdot (zv \cdot v) + gz\nabla z - \upsilon \Delta (zv) = 0$$

z = profondeur d'eau

v = vitesse verticale

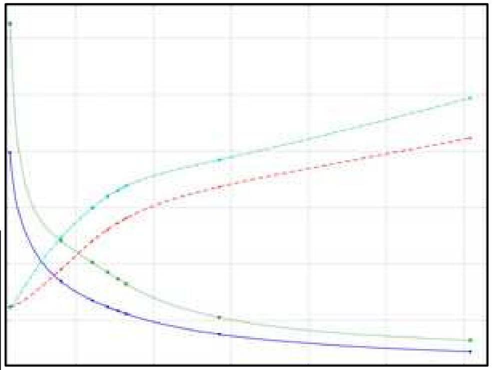
g = accélération de la pesanteur

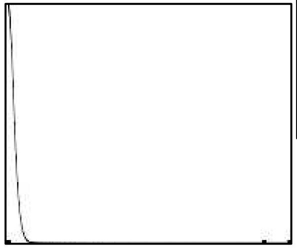
ν = viscosité cinématique



Equation de Boltzmann

Résolution de l'équation de Boltzmann à deux termes: propriétés de transport (haut) et fonction de distribution de l'énergie (milieu) des électrons dans un plasma d'oxygène (bas).





$$f(\mathbf{v}) = f_0(v) + f_1(v)\cos\theta + \ldots, \quad \cos\theta \equiv \mathbf{v}\cdot\mathbf{E}/(vE)$$

$$\frac{\partial}{\partial\varepsilon}\left(\frac{\varepsilon}{3\sigma_m}\frac{\partial f_0}{\partial\varepsilon}\left(\frac{E}{N}\right)^2 + \sigma_\varepsilon\varepsilon^2\left(f_0 + \frac{k_B T}{e}\frac{\partial f_0}{\partial\varepsilon}\right)\right) = S, \qquad f_1 = \frac{E}{N}\frac{1}{\sigma_m}\frac{\partial f_0}{\partial\varepsilon}$$

$$\sigma_\varepsilon = \sum_{k\in\{\text{elastic}\}} 2\frac{m_e}{M}\sigma_k \qquad S = \sum_{k\notin\{\text{elastic}\}} C_k$$

$$C_{k\in\{\text{attachment}\}} = -\varepsilon\sigma_k(\varepsilon)f_0(\varepsilon)$$

$$C_{k\in\{\text{exc., dissoc.}\}} = -[\varepsilon\sigma_k(\varepsilon)f_0(\varepsilon) - (\varepsilon+\Delta\varepsilon_k)\sigma_k(\varepsilon+\Delta\varepsilon_k)f_0(\varepsilon+\Delta\varepsilon_k)]$$

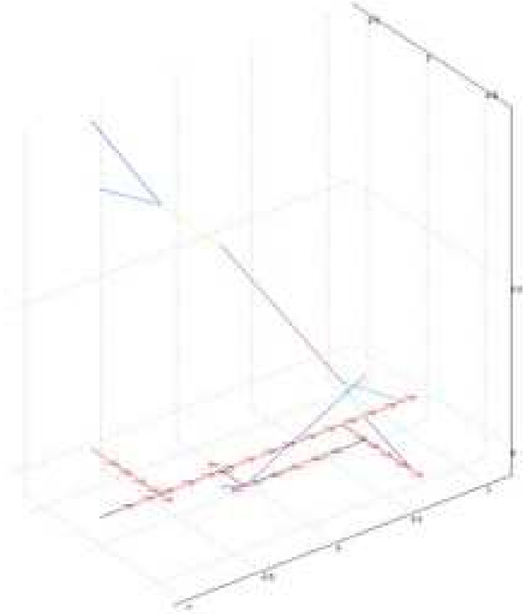
$$C_{k\in\{\text{ionization}\}} = -[\varepsilon\sigma_k(\varepsilon)f_0(\varepsilon) - 2(2\varepsilon+\Delta\varepsilon_k)\sigma_k(2\varepsilon+\Delta\varepsilon_k)f_0(2\varepsilon+\Delta\varepsilon_k)]$$

Perte de charge dans un réseau hydraulique

Forme faible:

$$\int_{\Omega} \hat{q}\frac{dp}{dl} = -\int_{\Omega} \hat{q}F(q)$$

$$\int_{\Omega} \hat{p}\frac{dq}{dl} = 0$$



Calcul de débit dans un réseau de tuyaux.

Réduction de modèles complexes

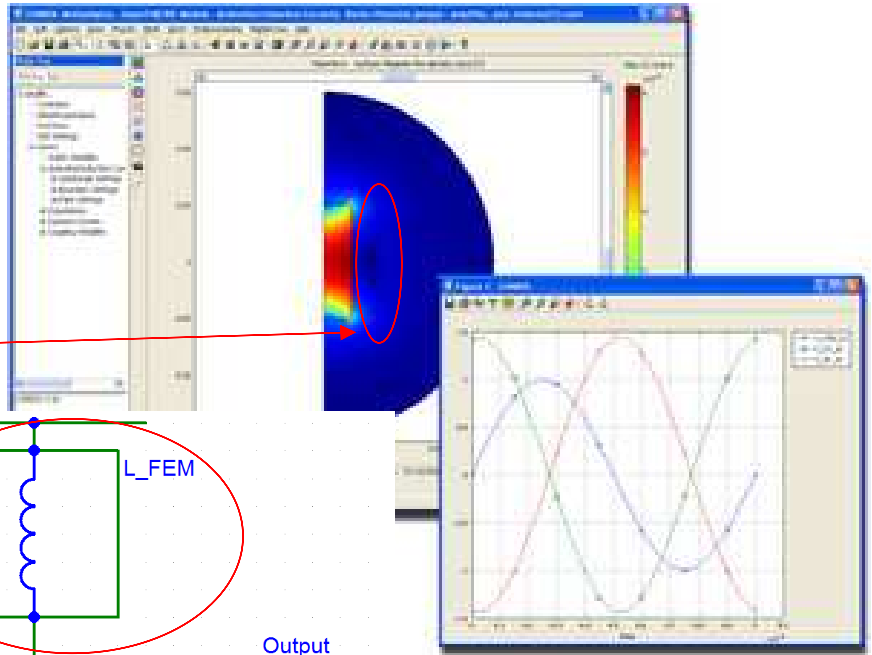
Inducteur dans un Circuit Amplificateur

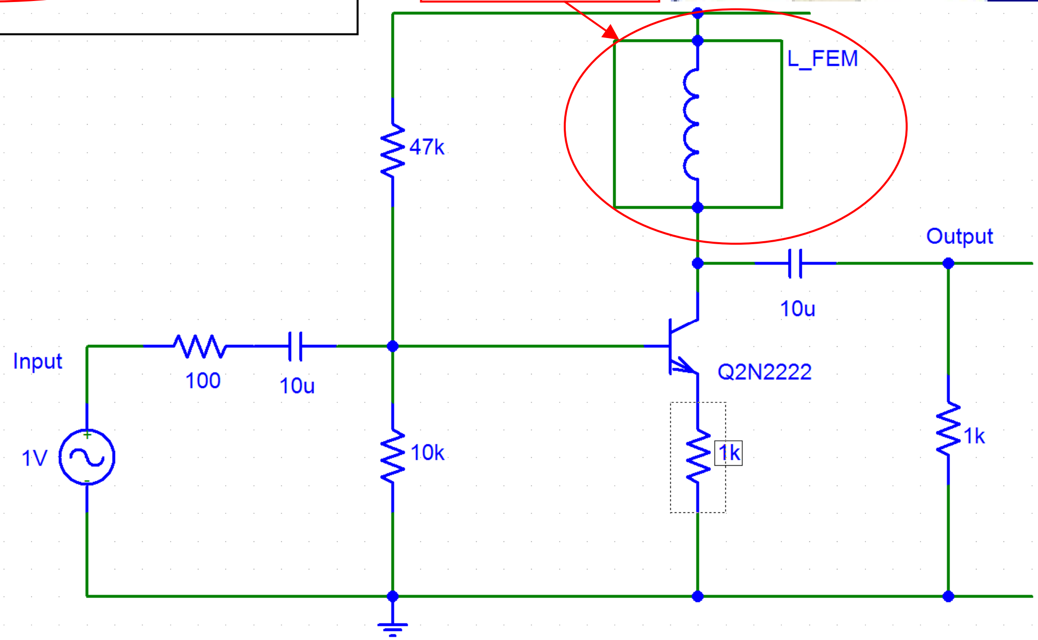
- Densité de flux magnétique

```
Vin     1     0     1
Vcc     4     0     15
Rg      1     2     100
Cin     2     3     10u
R1      4     3     47k
R2      3     0     10k
RE      7     0     1k
Cout    5     6     10u
Rl      6     0     1k
Q1      5     3     7     Q2N2222
.LIB "femlab.lib"
.END
```

inducteur

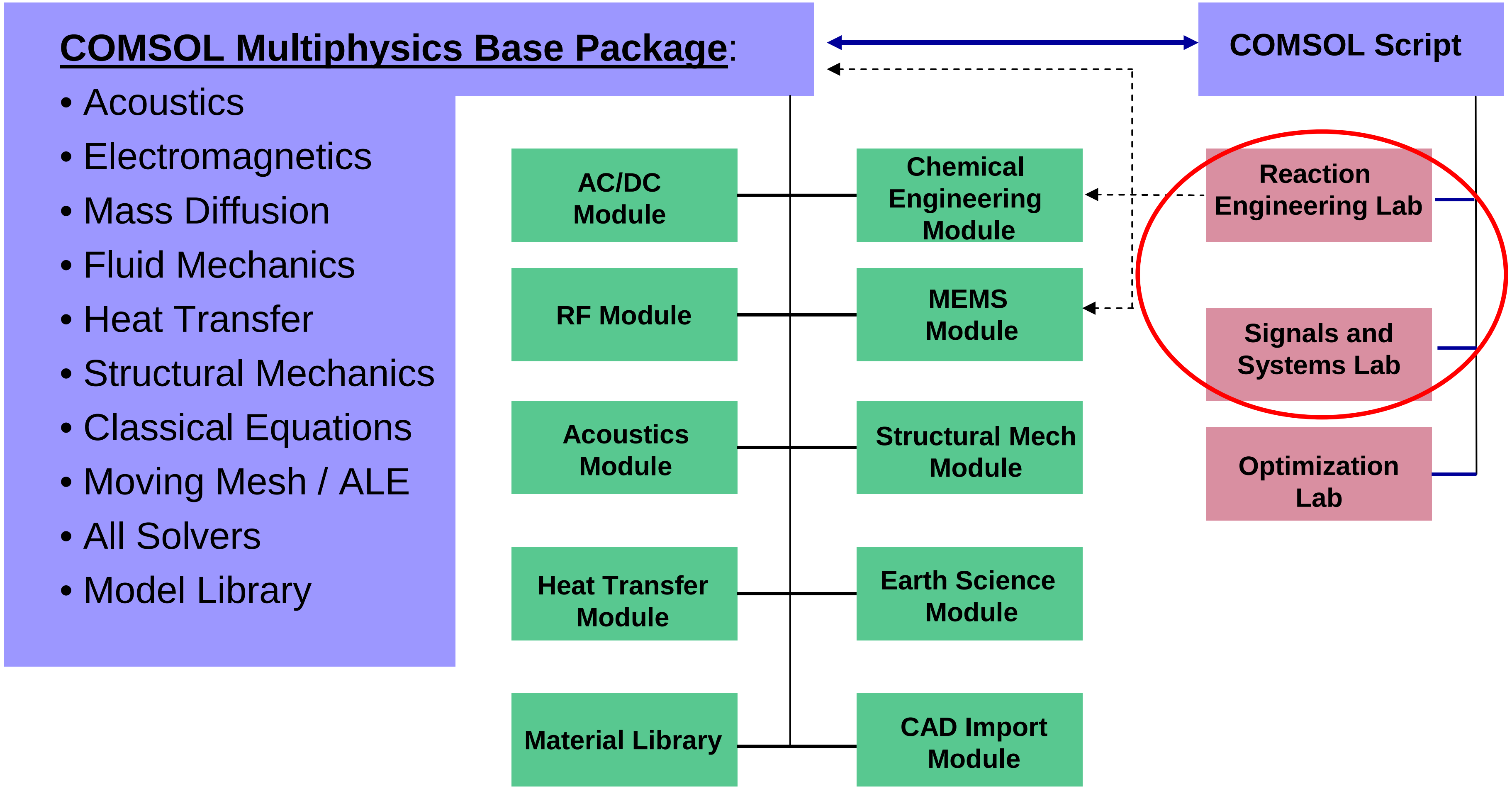
Densité de flux magnétique



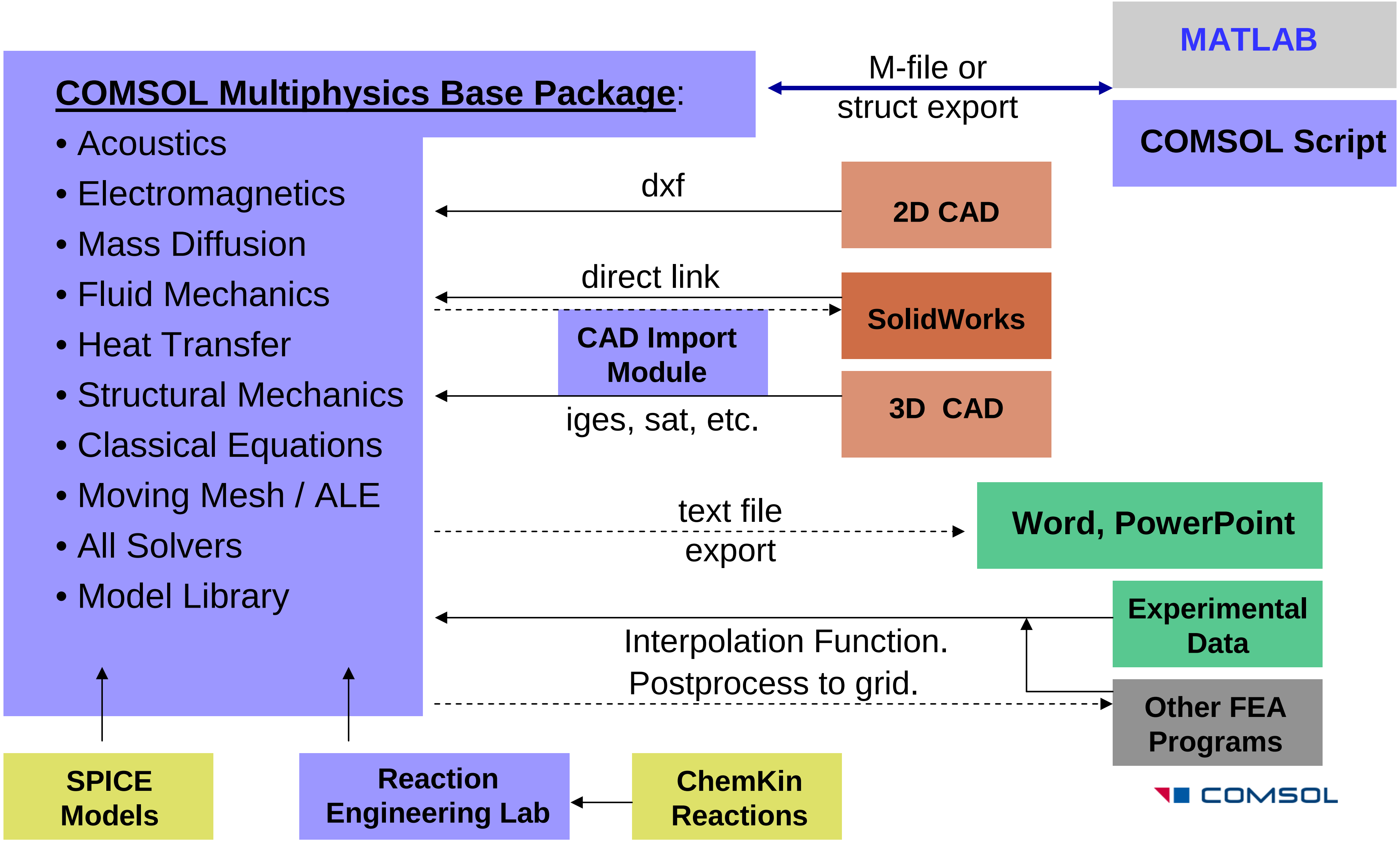


Tension des signaux d'entrée, de sortie et de l'inducteur

2. La Famille COMSOL au complet !

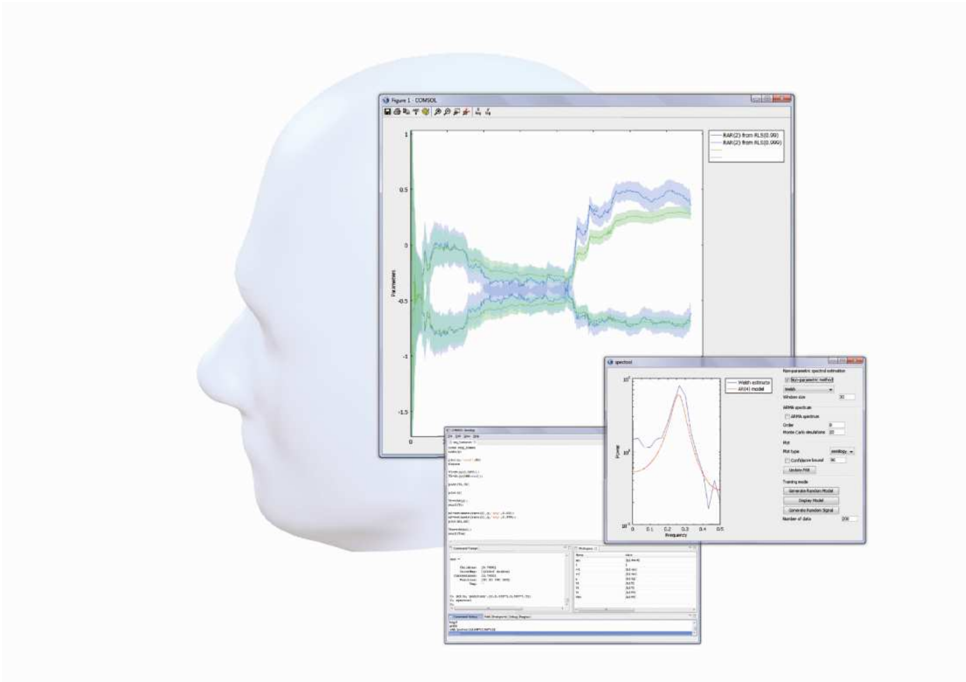


COMSOL & Autres Programmes



Signals & Systems Lab

- New functionality for model calibration and parameter estimation using nonlinear least-squares methods
  - Implemented for multiple sets of data
- New examples



Signals and Systems Lab

- Contains over 100 functions to support :
  - signal processing,
  - system simulation,
  - system identification,
  - design and analysis of control systems,
  - adaptive filtering,
  - non-stationary signal and statistics.

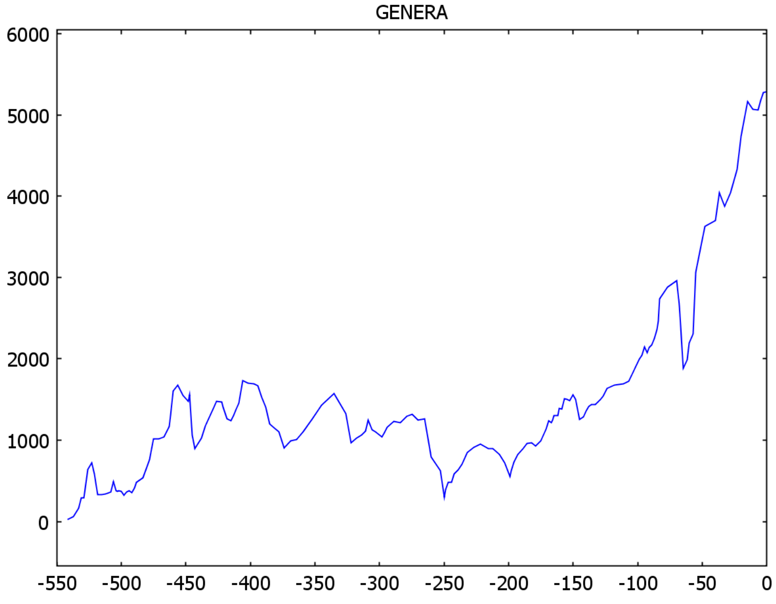
- Spectral tool GUI

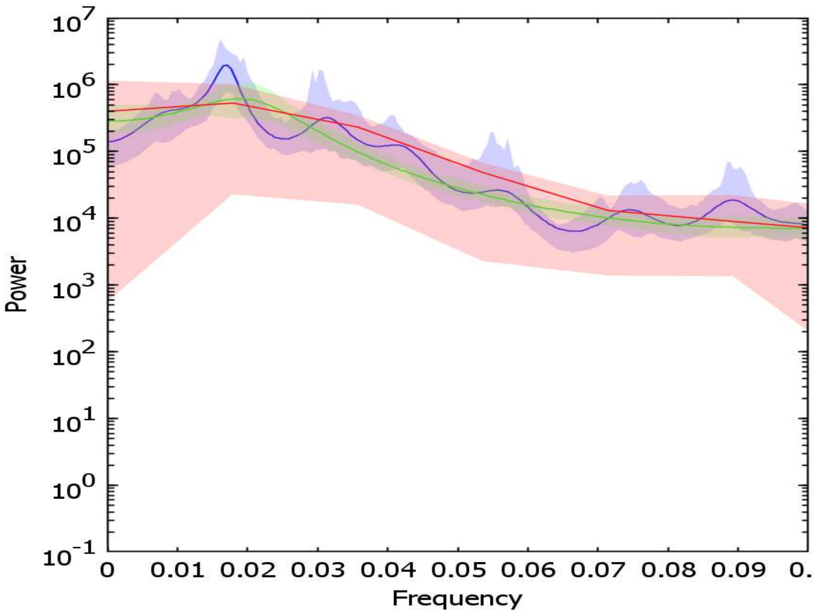
- Transfer Function tool GUI

- Probability Density Function tool GUI

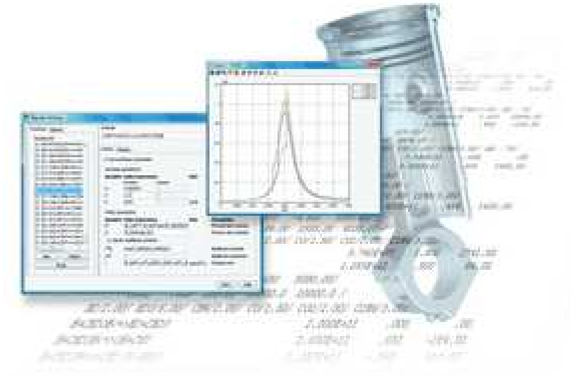
FFT analysis of Genera Evolution

- Perform a frequency analysis of genera evolution





Reaction Engineering Lab



- Modèles de systèmes de réactifs à partir de formules de réactions chimiques.
- Equations de bilan de matière et d'énergie pour les réacteurs idéaux.
- Calibrer et valider des modèles par comparaison avec les résultats expérimentaux : estimation de paramètres
- Modèles dépendants de l'espace dans Comsol Multiphysics.

The Reaction Engineering Lab

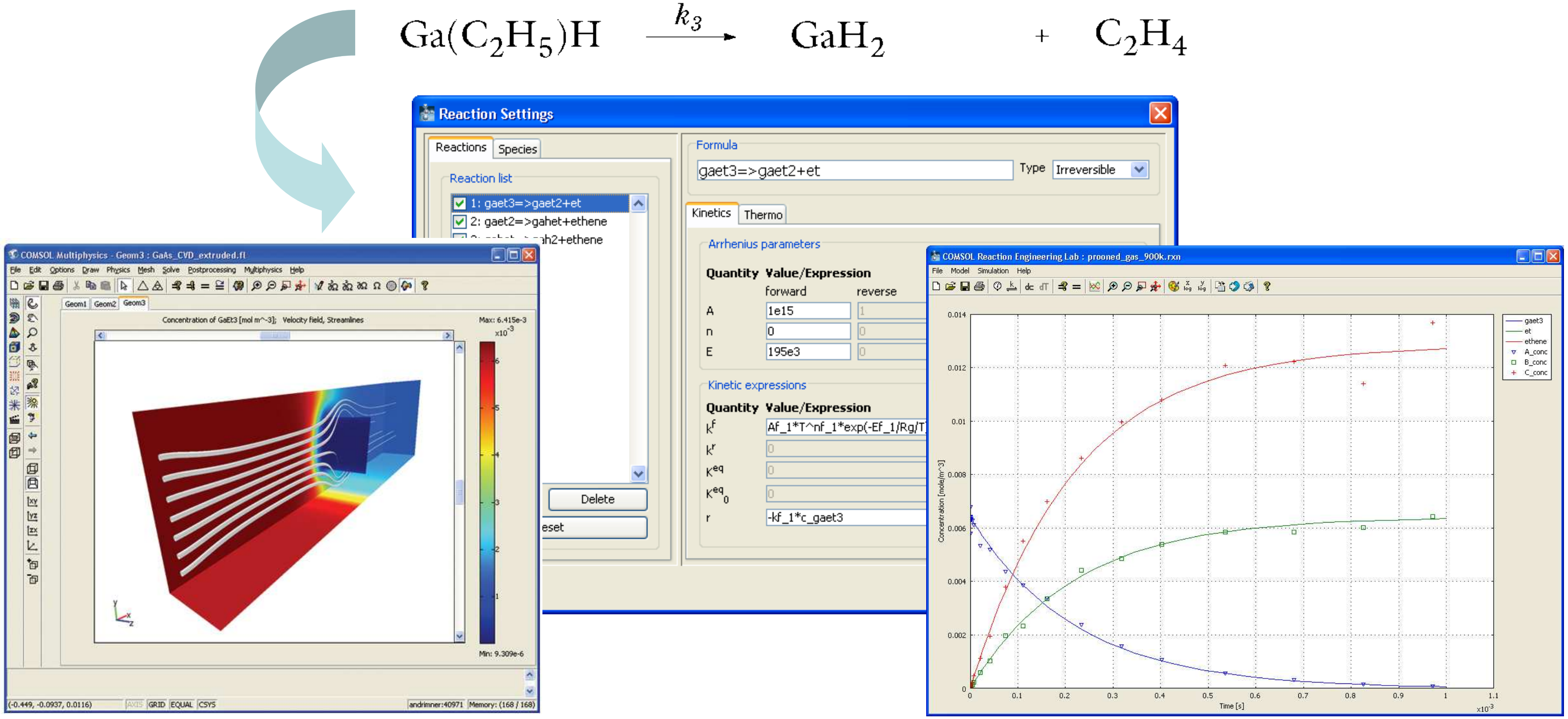
- Reaction Engineering Lab sets up models of reacting systems from chemical reaction formulas
- It solves material and energy balances for ideal reactors
- Parameter estimation allows for calibration and validation of models to experimental data
- It sets up space dependent models in COMSOL Multiphysics

The Reaction Engineering Lab

$$\mathrm{Ga(C_2H_5)_3} \xrightarrow{k_1} \mathrm{Ga(C_2H_5)_2} + \mathrm{C_2H_5^{\bullet}}$$

$$\mathrm{Ga(C_2H_5)_2} \xrightarrow{k_2} \mathrm{Ga(C_2H_5)H} + \mathrm{C_2H_4}$$

$$\mathrm{Ga(C_2H_5)H} \xrightarrow{k_3} \mathrm{GaH_2} + \mathrm{C_2H_4}$$

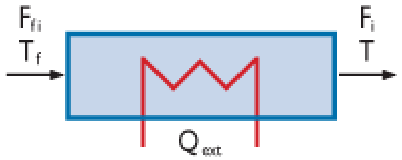


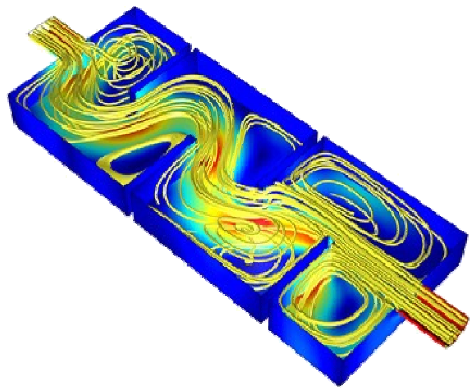
Reaction Engineering Lab exports to COMSOL Multiphysics

- Transfer the kinetic model and physical properties of the reacting mixture from ideal reactors to space-dependent systems
- Move into detailed reactor analysis and design

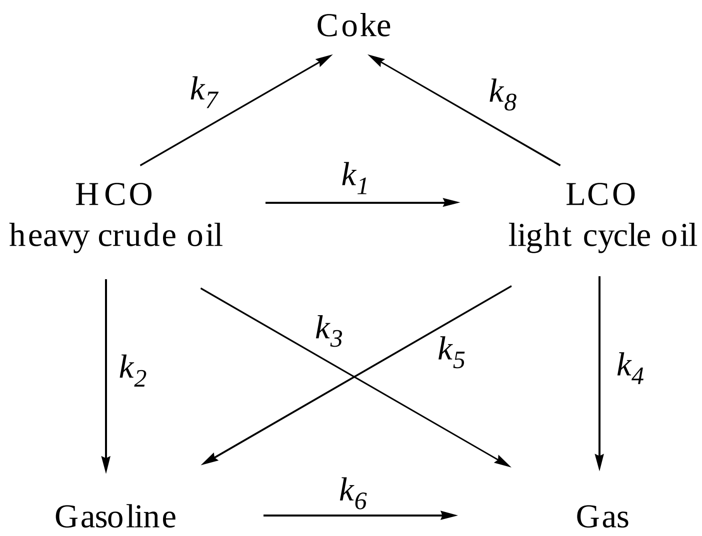
$$\frac{d(u_x c_i)}{dx} = R_i$$

$$\frac{\partial c_i}{\partial t} + \nabla \cdot (-D\nabla c_i + \mathbf{u} c_i) = R_i$$



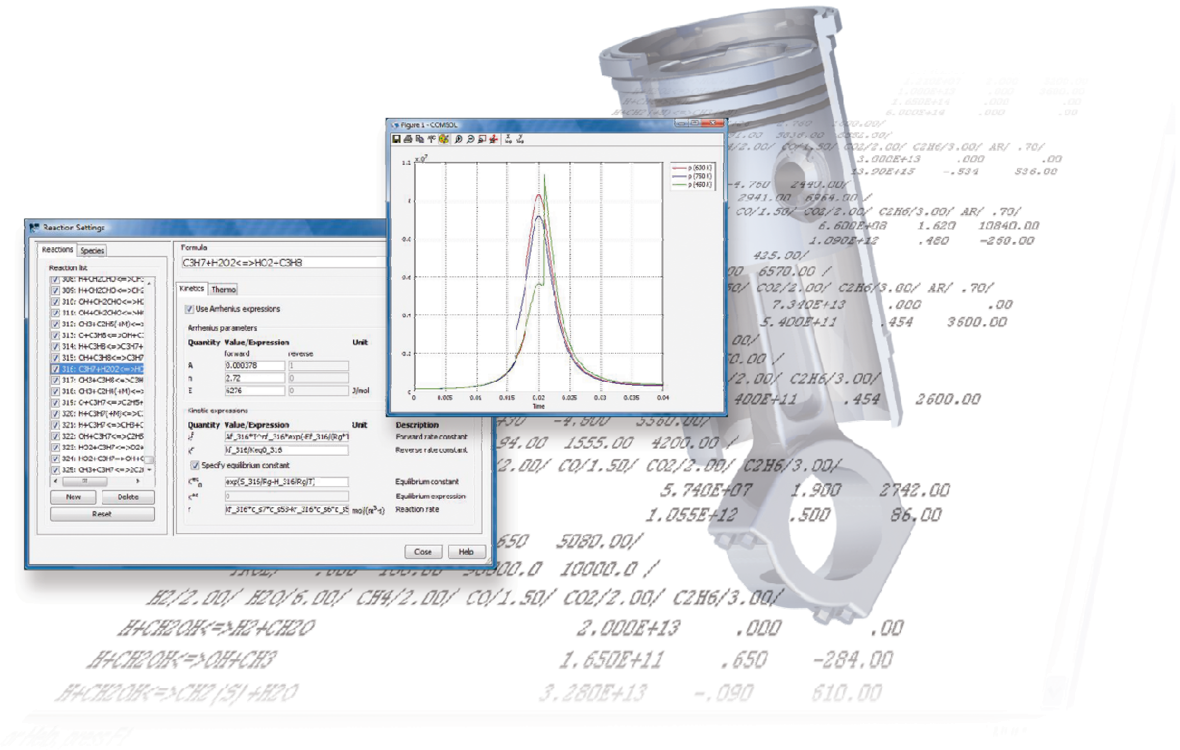


Fluid Catalytic Cracking



- Reaction Engineering Lab
  - Automatic generation of complex kinetics
  - Ideal reactor modeling

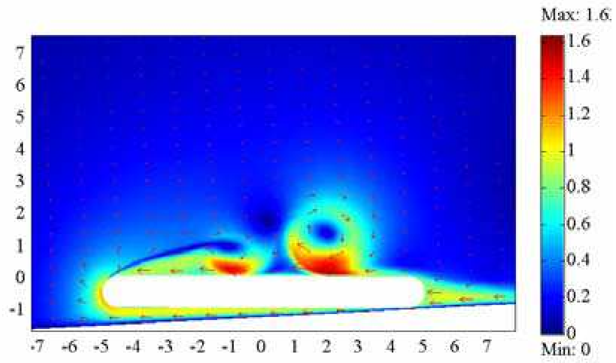
Compression Ignition of Methane



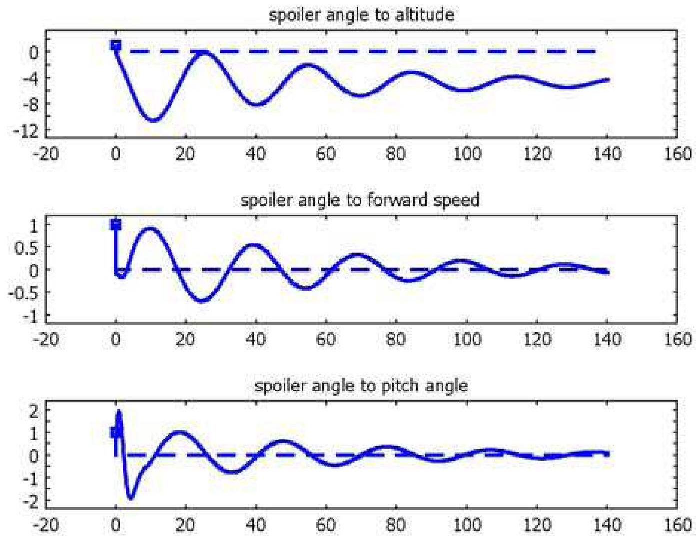
- Reaction Engineering Lab
  - Import and solve combustion kinetics

5.2 Contrôle Actif avec COMSOL 3.4

- Contrôle d'écoulements
  - Conditions aux limites (variables de couplage)
  - Corps solides dans un domaine fluide (ALE, levelset, autres…)



- Analyse piézo-électrique en Acoustique, MEMS, …
- Interface d'import SPICE en électromagnétisme AC/DC
- Contrôle de systèmes: Signals & Systems Lab



Feedback and Control with COMSOL …

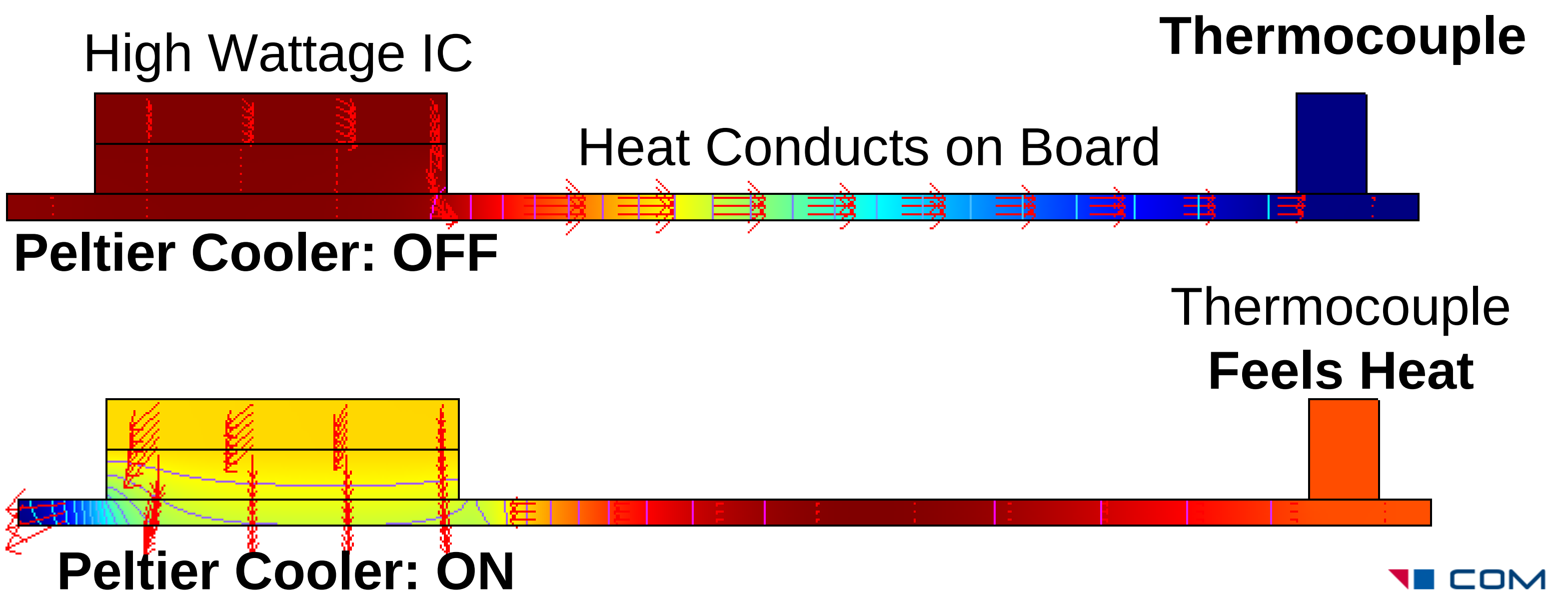
You can simulate your control loops in COMSOL

Full 2D or 3D detail rather than Lumped Mass Models …

- On / Off Control
- Proportional Control
- Full PID Control

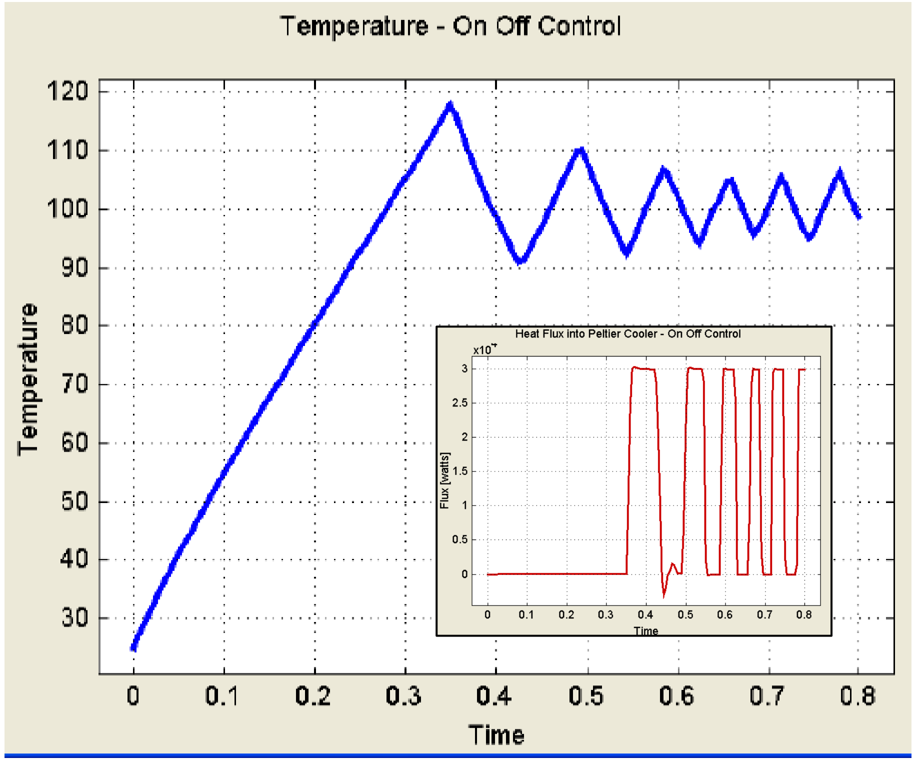
The Problem … Compare Thermal Control Performance: On/Off vs Proportional

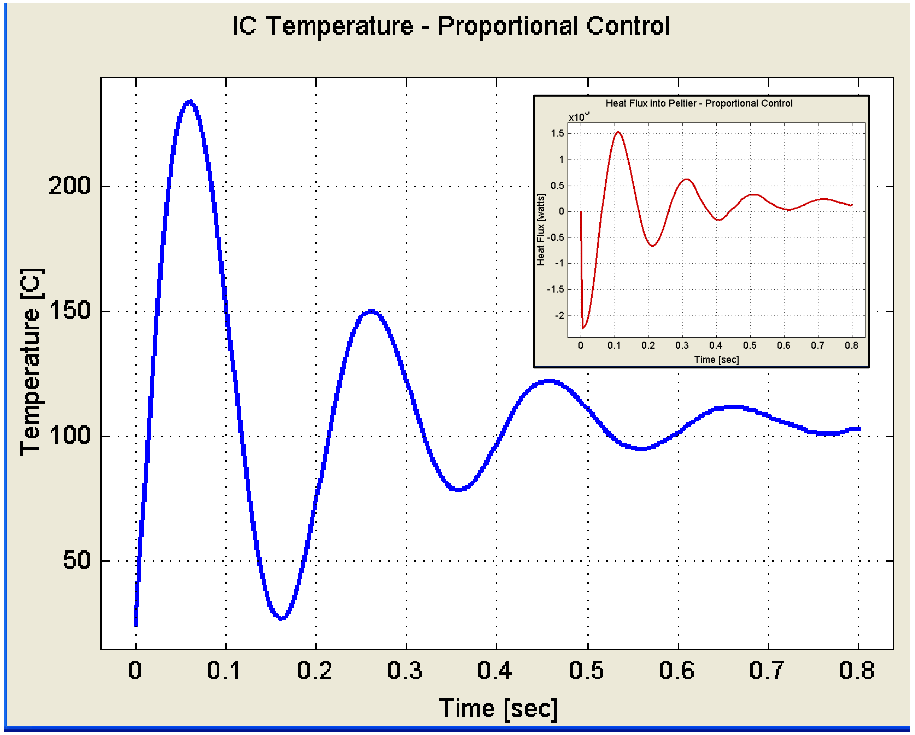
- Integration Coupling Variable – $T_{THERMOCOUPLE}$
- Feedback – Heatflux Boundary Cond - Peltier



On/Off vs. Proportional Control of Cooler

- Feedback through Flux Boundary Condition at Peltier
- $Q_{on\ off}$ = -q_peltier*(T_sense > T_threshold)
- $Q_{proportional}$ = -q_peltier*(T_sense - T_threshold) / 10

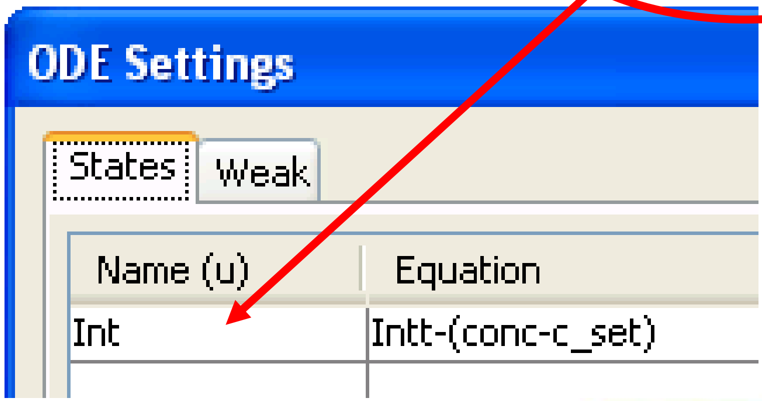


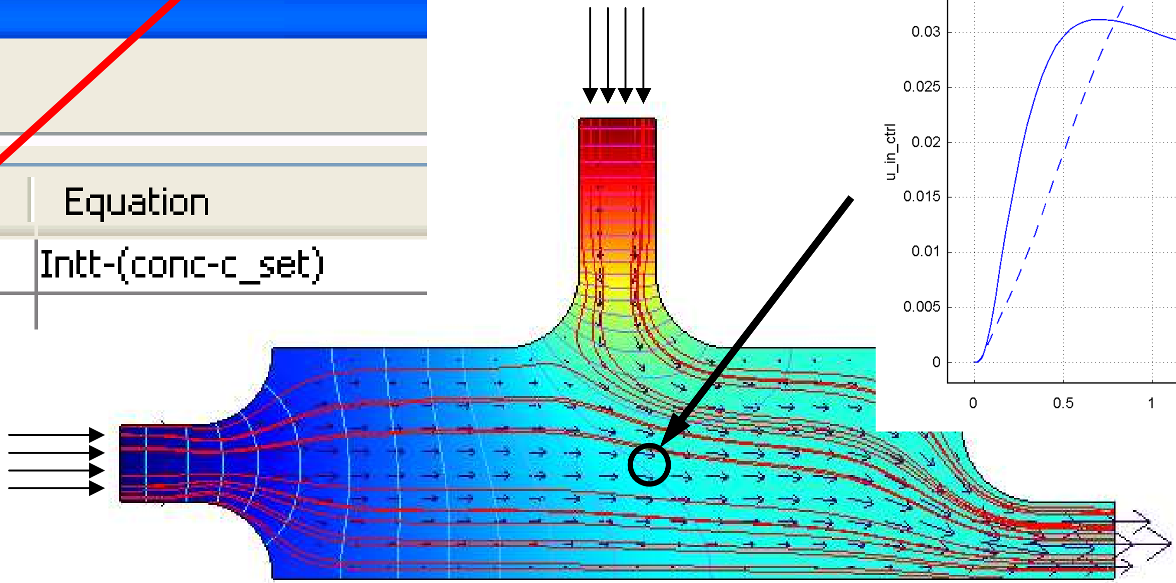


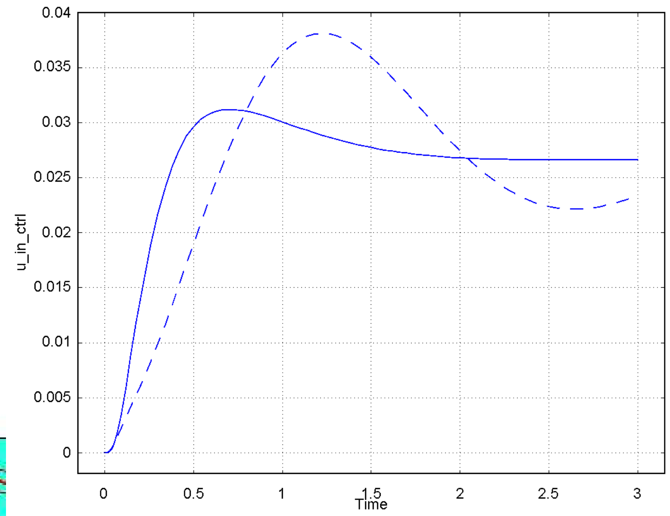
Related Problem … How about PID Control?

- Control top inlet gas flow rate by measuring concentration
- Use new ODE Solver to evaluate time integral part of control

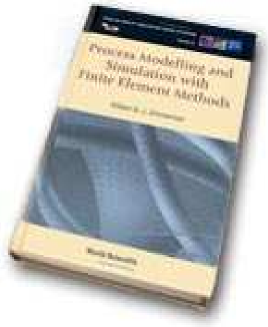
$$u_{in} = k_P(c - c_{set}) + k_I \int_0^t (c - c_{set})\,dt + k_D \frac{\partial}{\partial t}(c - c_{set})$$







Vous et COMSOL sur www.comsol.fr



- Version d'évaluation sur 2 semaines
  www.comsol.fr/contact/evaluation.php

- Documentation, formation, etc
  - Bibliothèques de modèles : www.comsol.fr/showroom/
  - Formations : www.comsol.fr/training/
  - Livres : www.comsol.fr/stories/books/
  - CD : www.comsol.fr/conference2007/cd/
  - Conférence COMSOL 2008

- Support avec support@comsol.com
  - Étude gratuite de faisabilité
  - Support technique

Conférence COMSOL 2008

4-6 novembre 2008 à Hanovre

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- 98 présentations orales

Conférences COMSOL 2007
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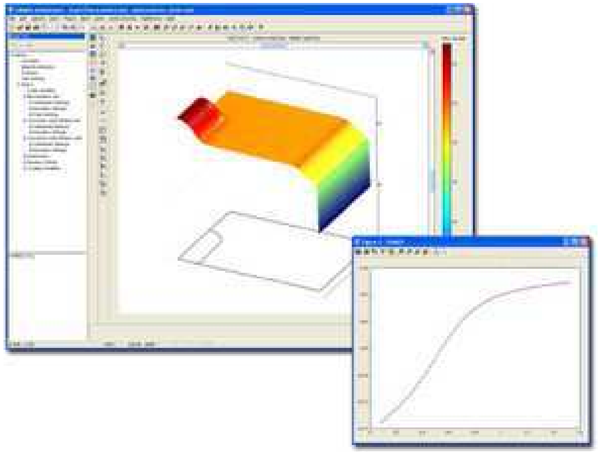
- 250 applications
- 190 présentations
- 40 modèles

\+ de 150 rdv de support   + de 540 places de minicours

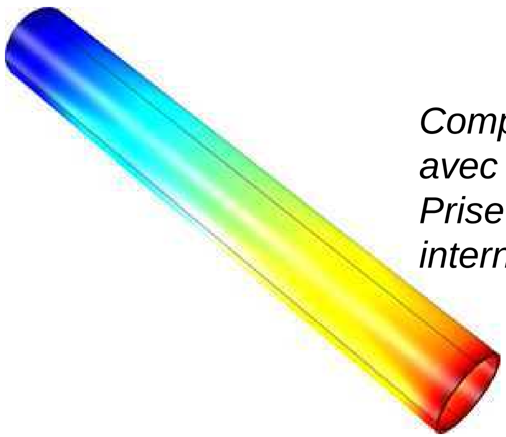
Optimisation des Paramètres SPICE décrivant une Diode Semi-conductrice



Graphique en relief de la concentration de trous (porteurs de charge positive, figure de gauche) et superposition des caractéristiques de fonctionnement de la diode et du circuit équivalent (droite).

Merci

de votre attention !



Comparaison d'un modèle de transfert thermique 3D avec un modèle réduit 1D.
Prise en compte du rayonnement entre les faces internes du tuyau par intégrales de convolution