Example Simulations in OpenFOAM

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Objective

- Present an overview of most interesting simulations performed using OpenFOAM

Notes

- This is only a part of the OpenFOAM work!
- Chosen for (personal) interest and illustration of the range of capabilities
- Results from others (with my involvement)
Large Eddy Simulation

LES and Aeroacoustics

- 3-D and transient; sufficient mesh resolution
- Sub-grid scale model
- Special inlet and wall conditions
Aeroacoustics

Aeroacoustics Post-Processing

- Store time-pressure trace for selected boundaries
- Aero-acoustic post-processing on sources of noise for comparison with experimental data
Two-phase incompressible system

\[
\frac{\partial \gamma}{\partial t} + \nabla \cdot (u \gamma) = 0
\]
\[
\nabla \cdot u = 0
\]

\[
\frac{\partial \rho u}{\partial t} + \nabla \cdot (\rho uu) - \nabla \sigma = -\nabla p + \rho f + \sigma \kappa \nabla \gamma
\]

\[
u = \gamma u_1 + (1 - \gamma) u_2
\]

\[
\mu, \rho = \gamma \rho_1 + (1 - \gamma) \rho_2
\]
Droplet Splash

Droplet impact into a wall film, 1.3 million cells

Splash, $u = 50\text{m/s}$, $d = 0.3\text{mm}$
Droplet Splash

Droplet impact into a wall film, cutting plane

Splash, $u = 50\text{m/s}$, $d = 0.3\text{mm}$
Capillary Jet

Ink-jet printer nozzle, 20µm diameter

- Pulsating flow, $u_{mean} = 20\text{m/s}$
- Tuning frequency (50kHz) and amplitude (5%)
Free Surface LES

LES of a Diesel Injector

- \( d = 0.2\text{mm} \), high velocity and surface tension
- Mean injection velocity: \( 460\text{m/s} \)
- Diesel fuel injected into air, \( 5.2\text{MPa}, 900\text{K} \)
- Turbulent and subsonic flow, no cavitation
  - 1-equation LES model with no free surface correction
  - Fully developed pipe flow inlet
Free Surface LES

- Mesh size: 1.2 to 8 million CVs, aggressive local refinement, 50k time-steps
- $6\mu s$ initiation time, $20\mu s$ averaging time
Ice Modelling

- Ice represented as a 2-D continuum: \((h, A)\)
- Ice interaction model: Hibler 1979

\[
\sigma = 2\eta \dot{\varepsilon} + I (\zeta - \eta) \left[ tr(\dot{\varepsilon}) - \frac{P(h, A)}{2} \right]
\]

\[
\zeta = \frac{P(h, A)}{2\Delta}; \quad \eta = \frac{\zeta}{e^2}
\]

\[
\Delta = \sqrt{\left(1 - \frac{1}{e^2}\right) tr(\dot{\varepsilon})^2 + \frac{2}{e^2} \dot{\varepsilon} : \dot{\varepsilon}}
\]
Ice Modelling

- Wind + ocean current forcing
- Coriolis force, mean water surface gradient
- Simple melting and freezing model
Biscuit Baking Model

Physical Model of the Baking Process

- Complex heat and mass transfer model with stress analysis and large deformations
- Conservation of liquid water, vapour and air, simplified chemical reactions

Enthalpy distribution, t = 60, 600 and 1200 s
Diesel Combustion in Scania D-12 Engine

- 1/8 sector with 75 % load and n-heptane fuel
- RANS, $k-\varepsilon$ turbulence model, simplified 5-species chemistry and 1 reaction, Chalmers PaSR combustion model
- Temperature on the cutting plane
- Spray droplets coloured with temperature
Diesel Combustion

Diesel Combustion in Scania D-12 Engine
Lagrangian Particles

Hour-Glass: same tracking, different particles
Contact Stress

Contact Plasticity and Crack Propagation

- Plastic sample with initiated crack
- 3-body contact problem, including contact stresses: contact detection is available
- Slow impact corresponds to static test
- Crack propagates on the symmetry plane: implemented as a damage model
Contact Stress

Static Charpy Test, Plastic Sample, 1 m/s
Contact Stress

Dynamic Charpy Test, Plastic Sample, 10 m/s
**Fluid-Solid Coupling**

**Coupled Fluid Flow and Stress Analysis Simulations**

- **Loose coupling**: Fluid and solid solved in turn
- **Close coupling**: Solve solid and fluid together: same equation or matrix

![Wave propagation in a flexible tube](image)

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Fluid-Solid Coupling

Pipeline failure: crack propagation and leakage
Fluid-Solid Coupling

Enlarged deformation of the pipe
Surface Tracking

Free surface tracking
- 2 phases = 2 meshes
- Mesh adjusted for interface motion
- Surfactant transport

Air-water system
- 2-D: $r_b = 0.75 \text{ mm}$
- 3-D: $r_b = 1 \text{ mm}$
Surface Tracking

Clean surface

Pollution by surfactant chemicals
Surface Tracking

Complex coupling problem: FVM flow solver + FEM mesh motion + FAM surfactant transport
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