Salome_CFD: a Complete Fluid Dynamics Toolchain for Complex Industrial Applications

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1. Introduction: CFD simulations required in NPP

2. Salome_CFD platform multiphysics

3. An industrial example

4. Conclusion and discussion
EDF’s R&D Strategic Priorities

**CONSOLIDATE AND DEVELOP COMPETITIVE AND ZERO-CARBON PRODUCTION MIXES**
- Consolidate the nuclear assets of the Group and build its future
- Control and anticipate environmental impacts
- Contribute to the success of renewable energy projects and prepare tomorrow’s technologies
- Ensure a flexible articulation in the nuclear and renewable mix

**DEVELOP AND TEST NEW ENERGY SERVICES FOR CLIENTS**
- Develop new offers for our customers
- Promote new uses of electricity
- Develop offers for cities and territories
- Develop energy efficiency services

**PAVE THE WAY FOR ELECTRIC SYSTEMS OF THE FUTURE**
- Optimize the life of network infrastructure to contribute to the success of smart meter projects
- Contribute to the success of smart meters project
- Develop advanced management tools for electrical systems to integrate intermittent energy
- Develop local energy solutions and integrate into the overall system
Three scales of modelling

**System scale**
- 0D modelling
- global mass/momentum/energy balances
- correlations
- the boilers, the vessel, ...

**Component scale**
- 1D, 2D, (3D) modelling
- mass / momentum / energy balances of mixture of fluid and solid
- correlations and porous approach for the core or the boilers

**local CFD scale**
- 3D local modelling
- explicit representation of solids
- local mass/momentum/energy balances of the fluid
Computational Fluid Dynamics in Nuclear Power Plants

Some applications for safety or design

- Boron dilution scenarii
- Fuel pool issue
- H₂ risk in reactor building
- Heat sink
- Atmospheric modelling
- Condenser
- Heat sink
- Cooling tower
- Pressurised thermal shock

Intro CFD Ex. Conclusion
Salome_CFD in short
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Advanced scripting capabilities
Salome_CFD in short

Single-phase solver *Code_Saturne*
Multi-phase solver *NEPTUNE_CFD*
Salome_CFD in short

Distant-visualisation / co-visualisation / live-visualisation for Big Data
Live demonstration during the poster session
Salome_CFD in short

UQ studies
Design
Live demonstration during the poster session
Development of **Code_Saturne** at EDF

Multiphysics modules merged into **Code_Saturne** framework

- **Arbitrary Lagrangian Eulerian (ALE)**
- **Electric Arcs**
- **Atmospheric flows**
- **Fire modelling**
- **Combustion (fuel, coal, gas)**
- **Groundwater flows**
- **Lagrangian particle tracking**
- **Thermohydraulics for Nuclear applications**
- **Turbomachinery**
In-house CFD code: Code_Saturne

development under Software Quality Assurance

open-source:
www.code-saturne.org

- Transparency
- Co-development
- (Academic) partnerships
- on Linux (workstations to clusters), Mac, Windows

Software Quality Assurance

- 2 years of dev. between production versions
- Under version control
- Nightly partial validation
- 21 verification testcases (986 runs)
- 59 validation testcases (570 runs)
Multiphase CFD solver developed in the NEPTUNE project (EDF, Framatome, CEA, IRSN): NEPTUNE_CFD

- $n$-fields Eulerian formalism
- Models for: free-surface flows, dispersed bubble-flows (adiabatic or not), particle/gas
- Share HPC capabilities with Code_Saturne

Main nuclear applications

- Departure from Nuclear Boiling (DNB)
- Two-phase Pressurized Thermal Shock (PTS)
- $H_2$-risk with spray
- Spent-fuel pool in case of accident
- In-vessel corium retention

Verification & Validation process: around 70 cases
(from elementary cases to integral cases)
Thermal diffusion in solids and radiative transfer solver: SYRTHES

Thermal load of 1000 bolts in 900 PWR internals
1h30 on 2048 BG cores

Solid coupled to fluid (Code_Saturne)
- **Observed fact : control rod vibration with large displacements**
  - No coupling for the moment
  - Two-way coupling is probably mandatory
Objectives

- To better understand hydraulics in entire Control Rod Guide Assembly (CRGA)
- To identify sources of control rod vibration
- To model and calculate hydraulic loading on rods from CFD simulations
- To calculate rod vibrations from mechanical calculations

HPC calculation: fine periodic LES calculations on one plate with prescribed massflow
  - To be used in validation of hydraulics and loading
  - To provide more directly useable data for mechanics

Periodicity
Numerical set-up

- Wall-resolved LES on one plate
- \( \text{Re} = 10,000 \) (output velocity 0.2 m/s)
- 1.1 billion cells
  (450x28 cores on EOLE for about 2 months)
- Mesh extruded from 2 meshes
  with the extrusion option available in Code_Saturne
  (3 minutes on 50 to 300 cores)
- 1 billion time-steps, of which 400,000 time-steps are provided for mechanical calculations
- 500 Gb of ASCII data
- Remark:
  only 11 million cells for a wall-modeled LES mesh at \( \text{Re}=30,000 \)
Grand challenge on EOLE EDF cluster: 450 nodes

Billion cell LES to get pressure load on rods
Results: first lessons on hydraulic forces

- Mean forces
  - The force tackling towards the inside is mainly located upstream the plate
  - If we consider the very fine LES calculation (on the basis of force similarity) as reference calculation, the coarse LES calculation seems to predict mean forces fairly well (which would permit validation of coarse LES calculation)
Results: first lessons on hydraulic forces

- Fluctuating pressure forces
  - The fluctuating pressure force is also more important upstream of the plate than downstream
Results: first lessons on hydraulic forces

- Fluctuating pressure force according to rod location
  - Rods E and F can be distinguished from others by an higher level of fluctuations
  - This coherent with on-site observations where the highest level of wear is observed for rods E and F

![Graph showing hydraulic forces](image.png)
Conclusion messages

Come to our user meeting (5&6/04)! Use it! Ask what you want!

WebSite

Forum

BugTracker