2014 *Code_Saturne* User Meeting

EDF – R&D
Chatou, France

02 April 2014

Development and use of *Code_Saturne* at Renuda

Contact

For further information please contact:

Brian ANGEL
Director
RENUDA France

brian.angel@renuda.com

T: +33 4 27 49 26 38

Nicolas TONELLO
Director
RENUDA UK

nicolas.tonello@renuda.com

T: +44 20 33 71 17 09

www.renuda.com

Contents

1. Introduction
2. Software Development
3. Verification and Validation
4. Applications
5. Summary and Perspectives

1. Introduction

Introduction

- *Code_Saturne* and its ecosystem of tools/complementary software are used extensively by Renuda

- The CFD solver is part of an open source calculation chain
  - SALOME for CAD, volume meshing and results analysis
  - Syrthes for conjugate heat transfer

- Activities
  - Code development
  - Code verification and validation
  - Industrial projects
  - Internal Renuda projects

- This presentation presents brief examples of this work

2. Software Development

Code Development

- **Code developed from user subroutines** for more high-level functionalities. Customisation purposes

- For example
  - I/O: initialisation, outputs
  - Properties calculation
    - e.g. Multiphase or combustion

- **Code developments by direct alteration of the source** for more permanent changes and when required by the functionalities themselves

- For example
  - Modification of the pressure calculation
  - Modification of the Lagrangian model

Development Context and Procedures

- Implemented within the general code, *to add additional functionality rather than creating a special version*

- Code obtained from the online repository

- Creation of optimised and debug ports
  - Compatible with free debuggers such as dbx
  - ‘make’ procedures are clear and efficient

- Test case creation and verification within the OSS chain: SALOME and ParaView

- All the tools are there to carry out professional development
  - If you know F90 and C..

Level Set Implementation

- Design and optimise systems to harness wave and tidal energy, such as hydro-turbines
- Work carried out with The University of Edinburgh as a partner of the Energy Technology Institute (ETI) – PerAWaT Project

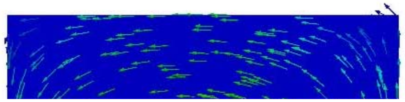
Level Set Implementation

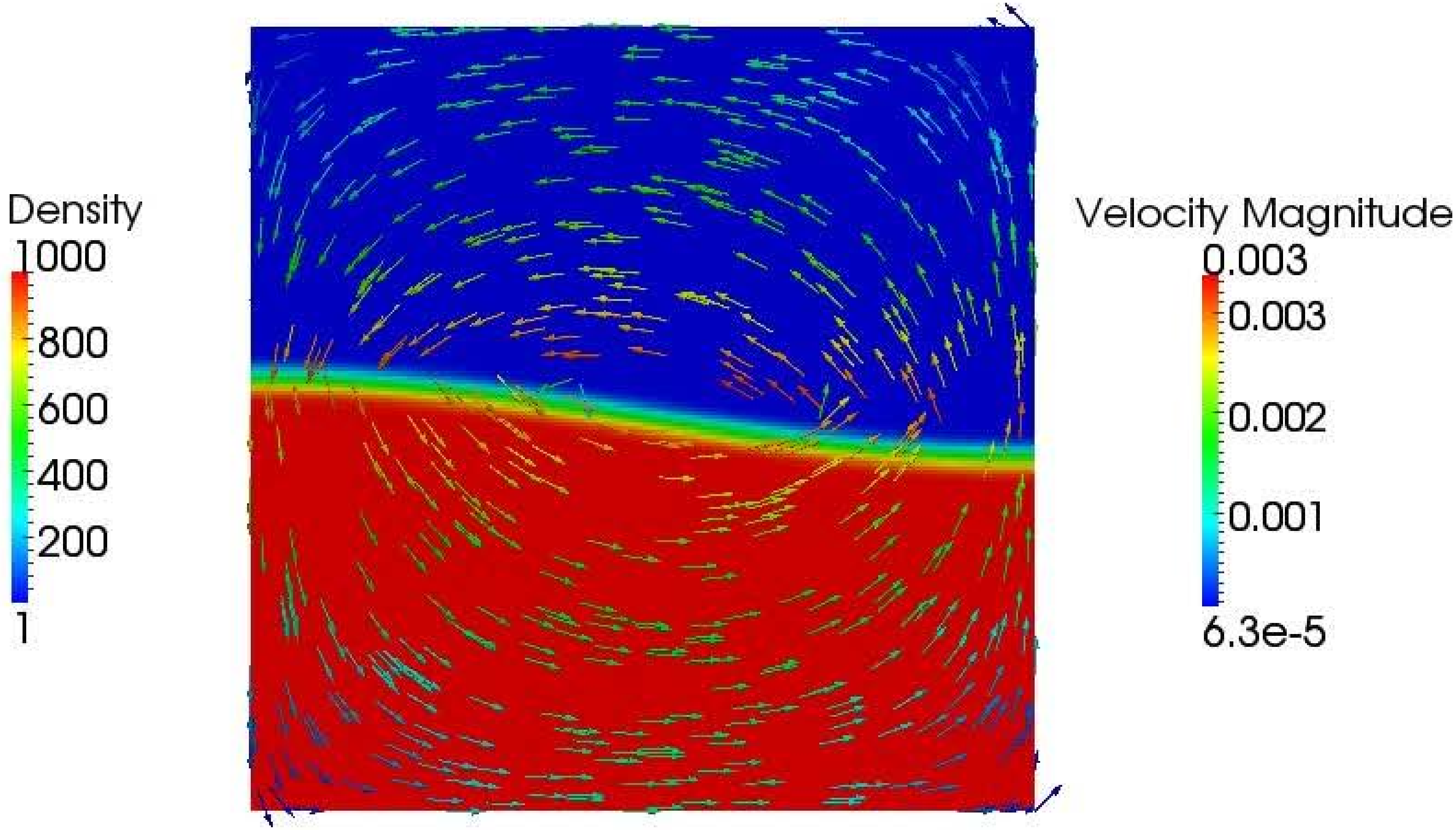
- Single fluid model
    - Free surface is captured by a scalar, the distance function
    - Fluid properties are computed based on the function’s value

- Implementation is a combination of
    - Changes to the core subroutines to handle the time-varying density and scalar advection
        - Modification of the pressure solution equation
    - User coding for initialisation, code settings, and properties update

- Renuda also added surface tension
    - The CSF model has been implemented

Level Set Validation





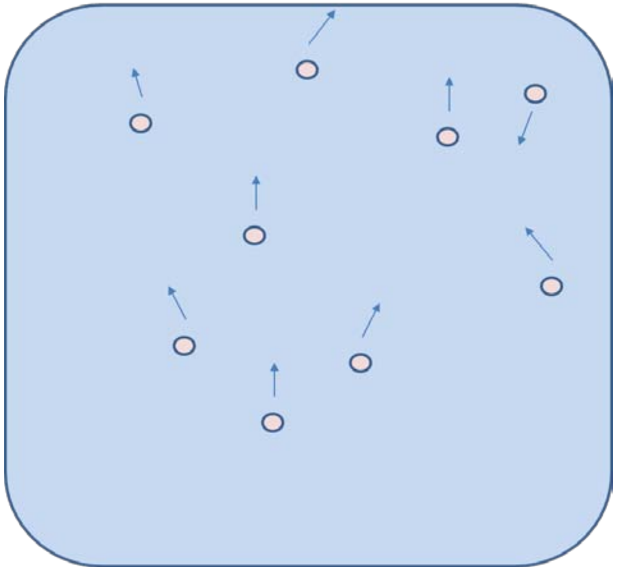
Level Set Implementation

- **Conclusions**
  - The Level Set version makes it possible to handle free surface flows with the very large density ratios required for marine applications and above (> 1000)
  - Good quantitative validation have been obtained for theoretical cases
  - The Level Set functionality benefits directly from the already available framework, such as parallel capabilities
  - The code was also tested with viscous and turbulent flows

- **Perspectives**
  - Further developments to bring in redistancing or similar. Hybrid methods? The framework could also be adapted to VOF
  - Boundary conditions

Particulate Collision Modelling

- Rust micro-particles in heat exchangers
- Work carried out with EDF R&D

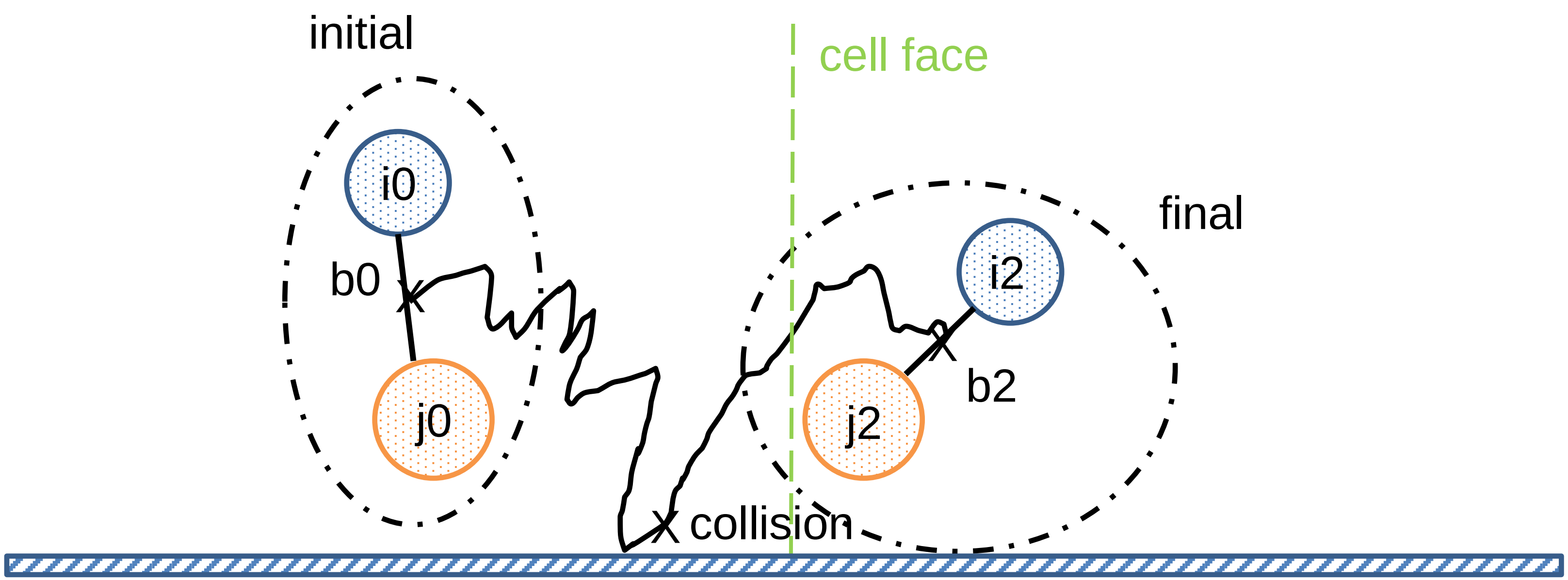


- Particles sizes of the order of microns
  - Deterministic approach is unrealistic
- *Stochastic models* based on the academic research of M. Mohaupt[1]
  - Diffusive regime, Brownian

[1] *M. Mohaupt, Modélisation et simulation de l'agglomération des colloïdes dans un écoulement turbulent, Thèse de doctorat, INPL, 31 octobre 2011*

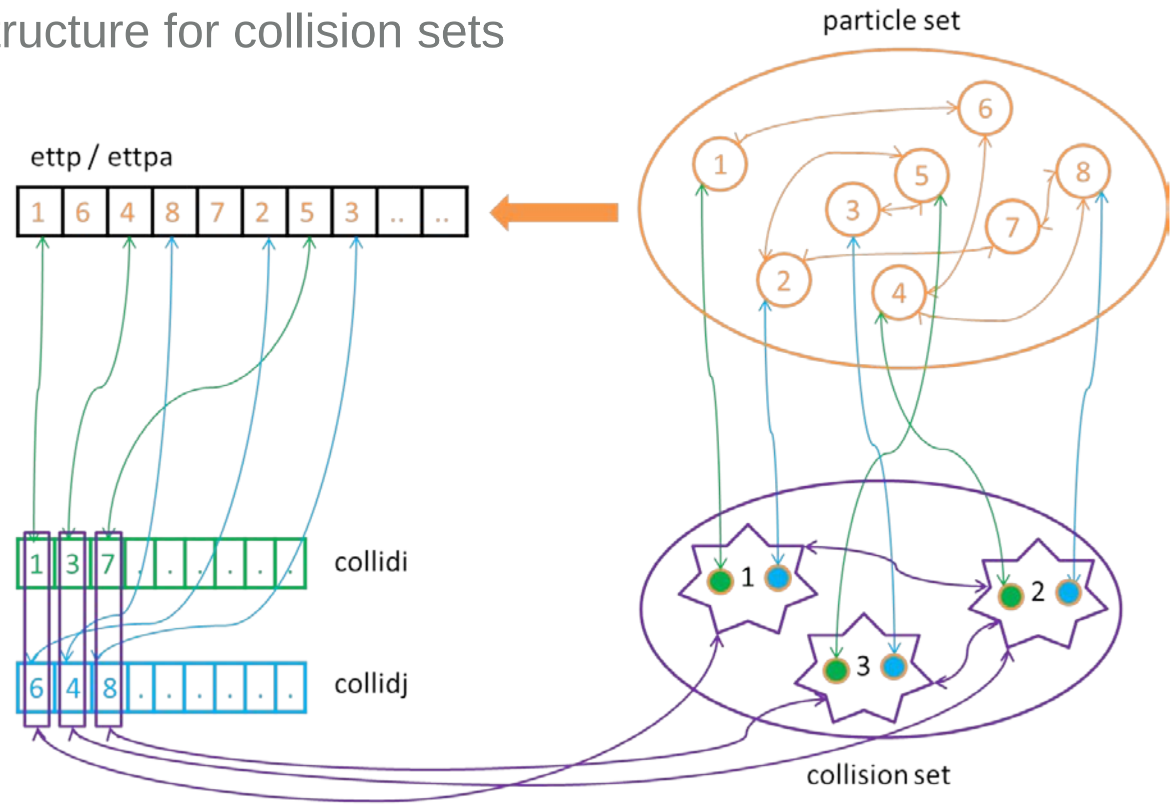
Particulate Collision Modelling

- Binary collisions
- A posteriori models, with a bias towards one particle



- Boundaries introduce significant complexities
- Dependency of particulates on one another

- Data structure for collision sets



Particulate Collision Modelling

- **Conclusions**
  - The two stochastic models were implemented
  - The new collision structures should provide a flexible data structures for collision modelling with these or other models
  - Likewise for the subset structures
  - Interaction between the F90 and C code can be a source of complexity

- **Perspectives**
  - Further runs
    - Validation
    - Derive macro-models – collision kernels
  - Parallelisation
  - Generalise the use of the subset data structures to the general Lagrangian algorithm

3. Verification and Validation

Verification and Validation

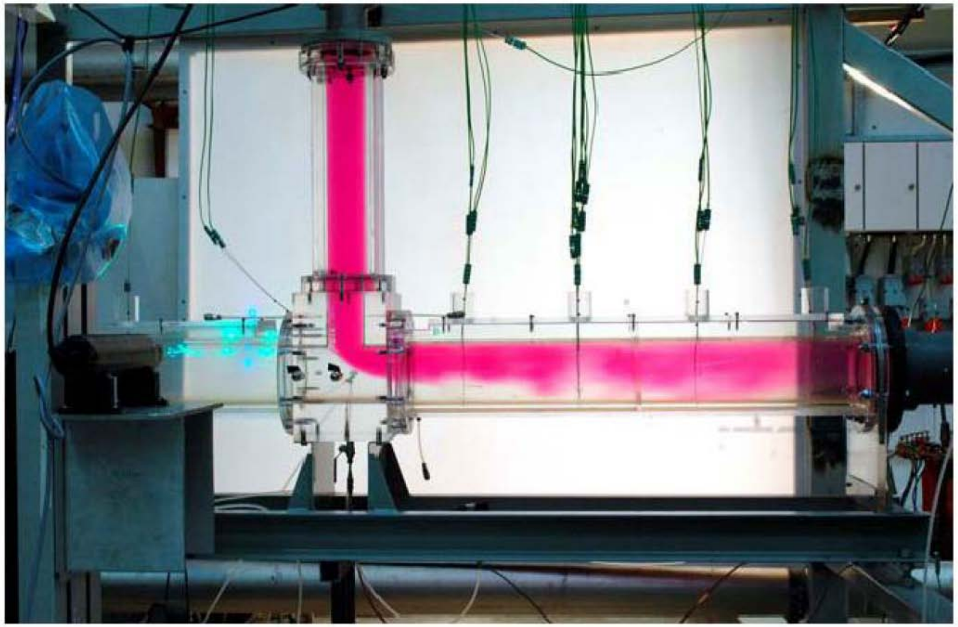
- *Code_Saturne* has been tested using a variety of validation and verification test cases

- Validation
  - Turbulent flat plate flows and impinging jet flows
  - Buoyancy driven flows
  - Mixed hot and cold water pipe flow
  - Buoyancy driven flows (comparison with DNS)
  - Flow in a reactor core mock-up

- Verification
  - Poiseuille and Couette type flows

Verification and Validation

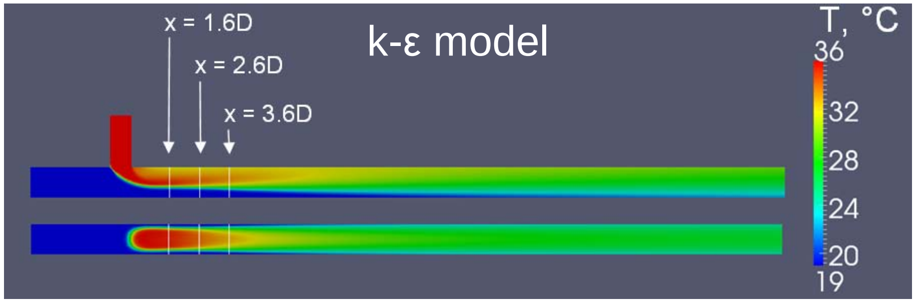
- Mixing of hot and cold water streams

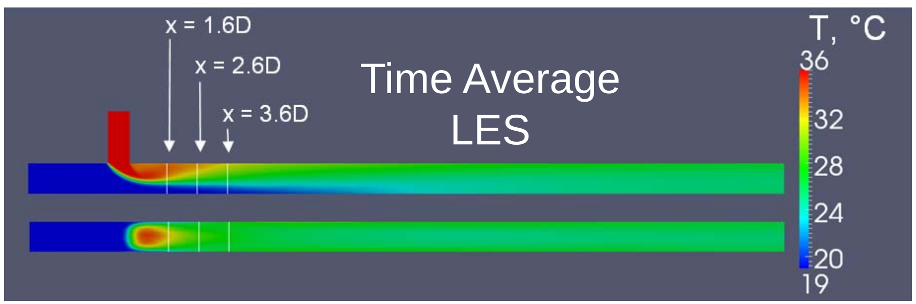


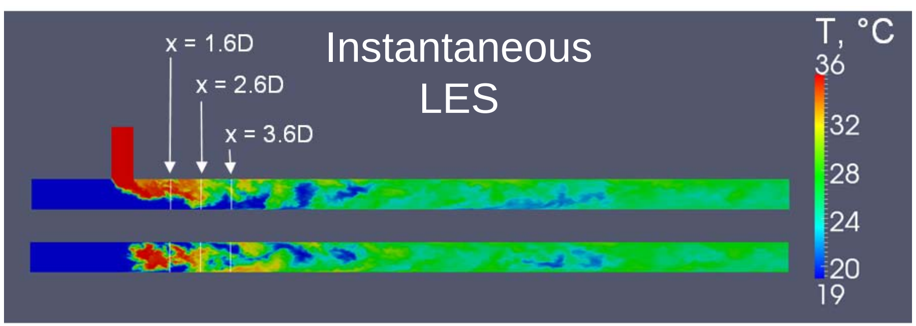
- SALOME for volume meshing – block structured hex mesh
- Unsteady flow calculation
- Both k-ε and LES turbulence modelling
- ρ, μ, C_p and k = f(T)
    - User routines for physical properties and post processing

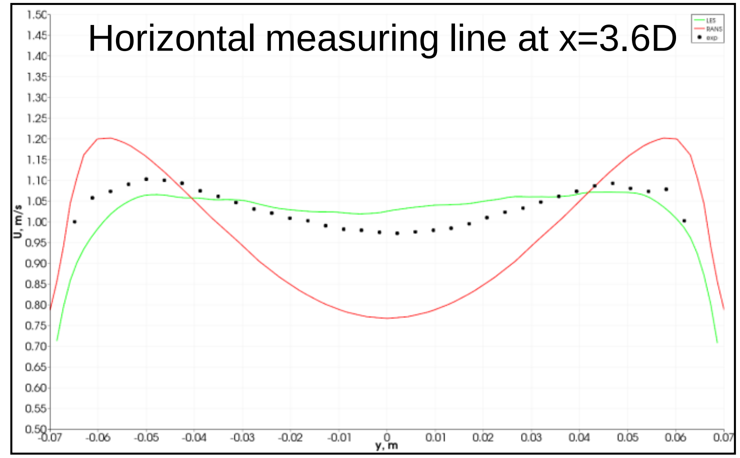
Verification and Validation

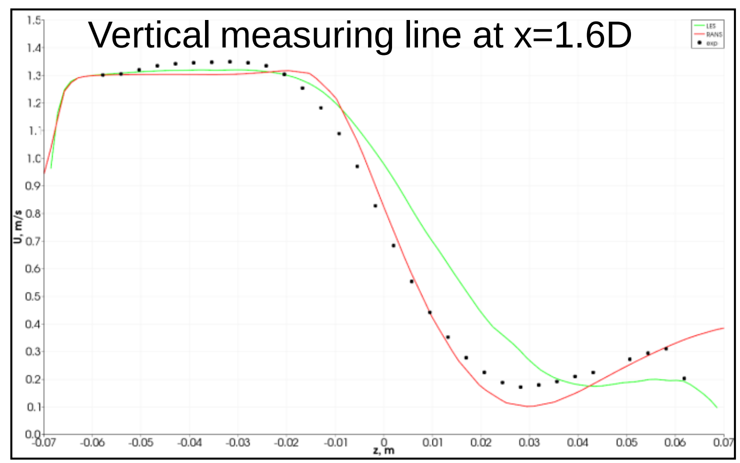
- Mixing of hot and cold water streams











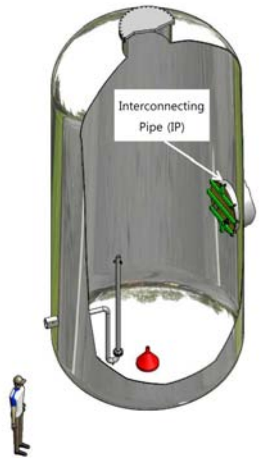
4. Applications

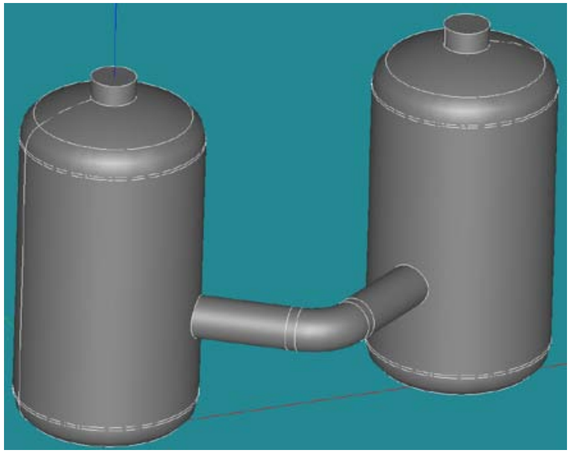
Applications

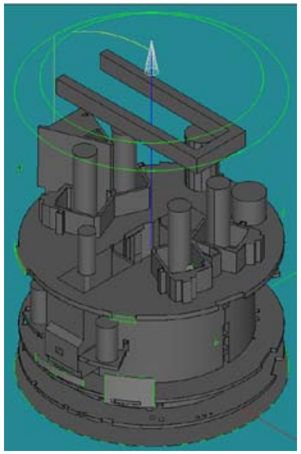
- *Code_Saturne* has been used for modelling several industrial applications
  - Accidents in reactor buildings
    - Hydrogen dispersion
  - Combustion of heavy fuel oil
  - Heat recovery system

Accidents in Reactor Buildings

- EDF is looking to put in place a methodology for simulating nuclear accidents in reactor buildings
  - SALOME and *Code_Saturne*
- Initial project to asses
  - SALOME meshing capability
  - *Code_Saturne* for running calculations on a variety of mesh / cell types
  - Experimental tests and actual reactor buildings
    - PANDA, PANDA ST1_7 and the P’4 reactor building



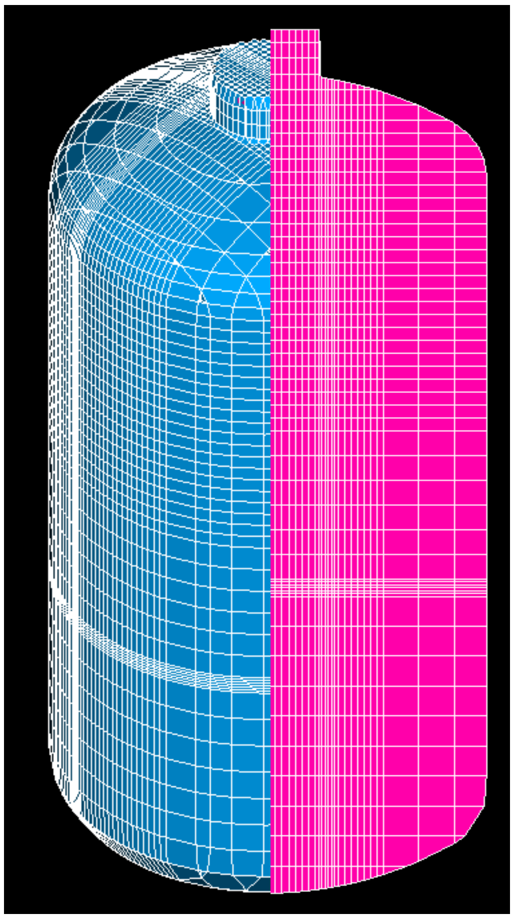




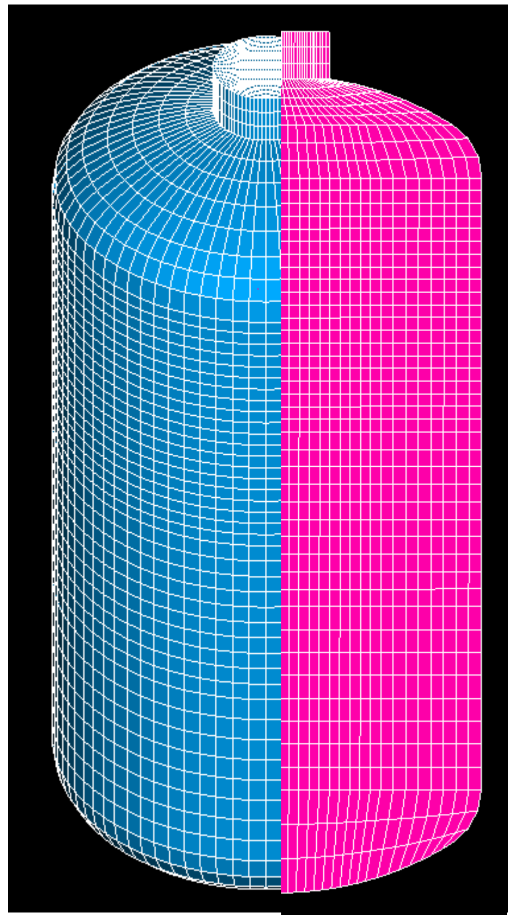
Accidents in Reactor Buildings

- Three types of volume mesh

Cubic



Block structured



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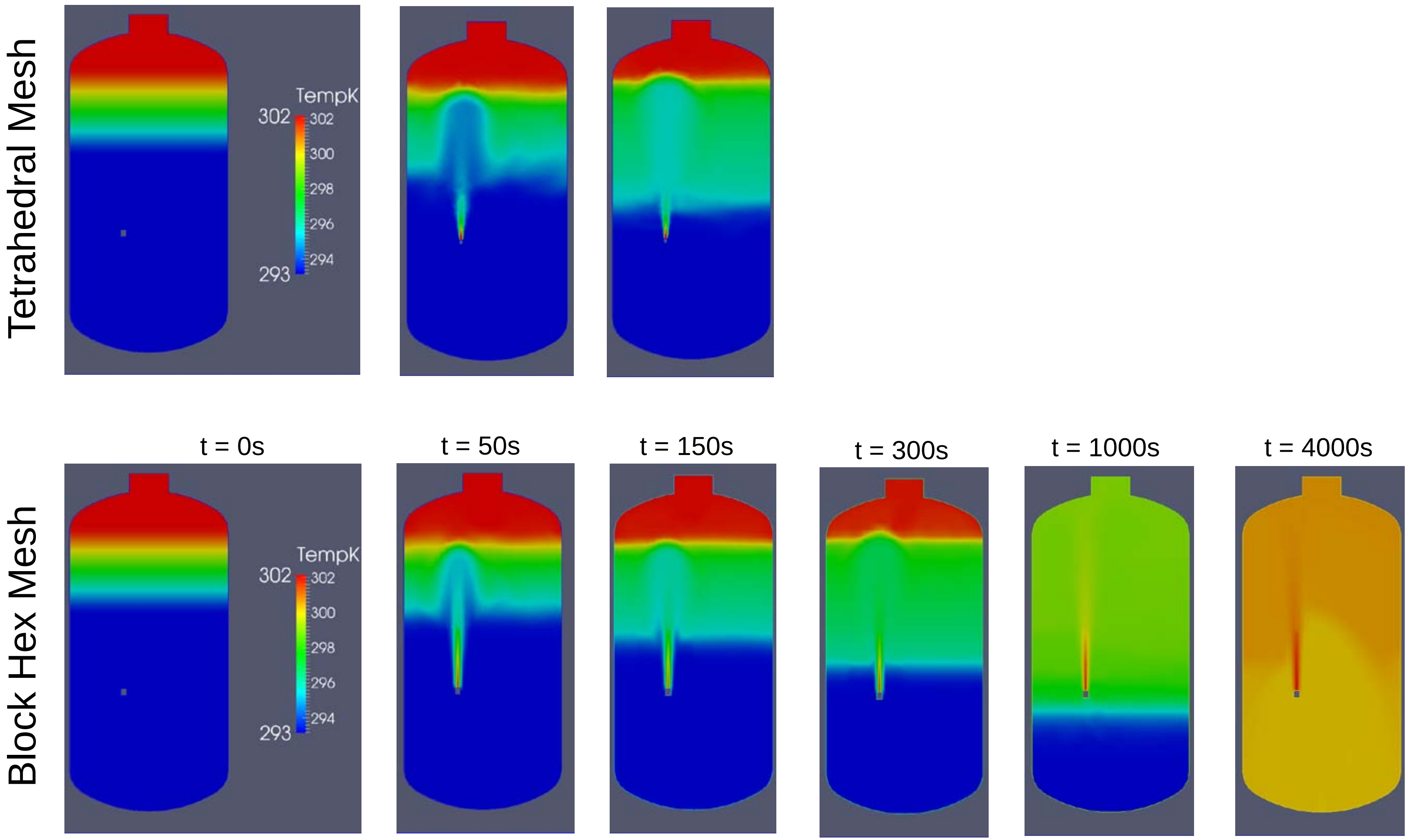
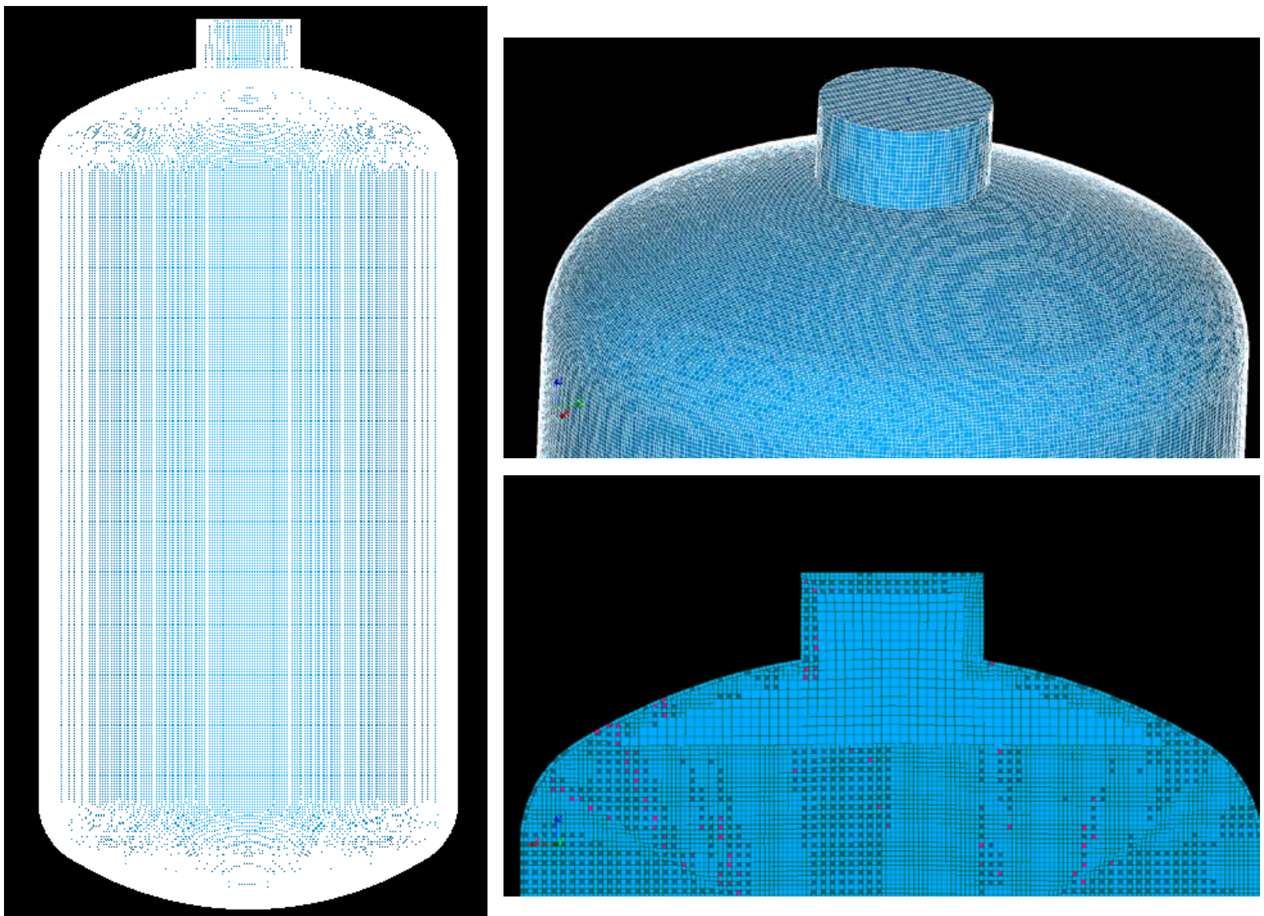
Accidents in Reactor Buildings

- PANDA test case results



Accidents in Reactor Buildings

- Simulation of hydrogen dispersion
  - Automatic meshing strategies - snappyHexMesh



Accidents in Reactor Buildings

- **Conclusions**
  - First computations with different mesh types has given encouraging results that are comparable with cubic mesh results
  - The analysis needs to be completed using a stratified multi-species flow at t = 0s
  - Enhancements to the SALOME cubic meshing method have been proposed

- **Perspectives**
  - Study mesh sensitivity on more complex configurations such as reactor buildings
  - Generate all meshes using SALOME meshing technology and propose enhancements appropriate for modelling accidents in reactor buildings

5. Summary and Perspectives

Summary

- Renuda has developed, validated and used *Code_Saturne* over the last 12 months for a variety of applications
  - Used in conjunction with SALOME and Syrthes

- Software developments have been carried out within user-subroutine and at kernel level to add modelling capabilities whilst keeping a general CFD solver
  - *Code_Saturne* offers a strong development platform within the required, complete ecosystem
  - Further steps would involve modifying the GUI as well

- Validation and verification programme has shown that *Code_Saturne* can be used to simulate a variety of flows with confidence

- Industrial applications have shown that *Code_Saturne* can be used to model complex flows

Perspectives

- Open source CFD is becoming more accepted in industry as more companies are prepared to exploit this option
  - Significant cost reductions
  - Undertake more complex simulations

- The SALOME – *Code_Saturne* – Syrthes open source calculation chain can be considered to be a viable alternative to commercial codes for certain applications

- Improvements desired
  - CAD, Volume meshing
  - *Code_Saturne*
    - Additional capabilities
    - Documentation
  - Post processing