2014 Code_Saturne User Meeting

EDF – R&D
Chatou, France

02 April 2014
Development and use of *Code_Saturne* at Renuda
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1. 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
  o SALOME for CAD, volume meshing and results analysis
  o Syrthes for conjugate heat transfer

• Activities
  o Code development
  o Code verification and validation
  o Industrial projects
  o Internal Renuda projects

• This presentation presents brief examples of this work
2. Software 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..
• 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
  o Free surface is captured by a scalar, the distance function
  o Fluid properties are computed based on the function’s value

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

  o Renuda also added surface tension
    o The CSF model has been implemented
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
• 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
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

**k-ε model**

**Time Average LES**

**Instantaneous LES**

**Horizontal measuring line at x=3.6D**

**Vertical measuring line at x=1.6D**
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 assess
  - 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
Tet
Accidents in Reactor Buildings

- PANDA test case results

Tetrahedral Mesh

Block Hex Mesh

$\begin{align*}
&\text{t} = 0s \quad \text{t} = 50s \quad \text{t} = 150s \quad \text{t} = 300s \quad \text{t} = 1000s \quad \text{t} = 4000s \\
&\text{FLUID SOLUTIONS} \quad \text{WWW.RENUDA.COM} \\
\end{align*}$
Accidents in Reactor Buildings

• Simulation of hydrogen dispersion
  o Automatic meshing strategies - snappyHexMesh
Accidents in Reactor Buildings

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

• Perspectives
  o Study mesh sensitivity on more complex configurations such as reactor buildings
  o 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
  o 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
  o *Code_Saturne* offers a strong development platform within the required, complete ecosystem
  o 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
  o Significant cost reductions
  o Undertake more complex simulations

• The SALOME – \textit{Code\textsubscript{Saturne}} – Syrthes open source calculation chain can be considered to be a viable alternative to commercial codes for certain applications

• Improvements desired
  o CAD, Volume meshing
  o \textit{Code\textsubscript{Saturne}}
    o Additional capabilities
    o Documentation
  o Post processing