Development of an AMR code for the advanced simulation of incompressible turbulent flows with complex geometries

Context

The objective of this project is the realization of advanced simulations of incompressible turbulent flows with the consideration of complex geometries in a immersed boundary code. Mesh refinement techniques and intensive computing environment will be considered. This project is part of the LRC COSiMS between the CEA and the Institute of Mechanics and Engineering of Bordeaux (I2M). I2M develops the Notus massively parallel computational code (https://notus-cfd.org) for the study of incompressible single or multiphase flows, on Cartesian meshes with complex geometries taken into account by Immersed Boundary Methods (IBM) [1-5]. It was recently used in the context of a national GENCI HPC challenge on the Irene-rome supercomputer of GENCI/TGCC (up to 131,072 processors) [6].

The CEA is a major player in the field of supercomputing and is preparing the next exaflop-scale supercomputers, which are interested in the simulation of incompressible turbulent flows in complex geometries. These flows require the consideration of a large variety of spatio-temporal scales (boundary layer meshing in high dimensional geometries for flows with Reynolds number higher than 100 000). This project aims to overcome scientific and technological barriers by proposing a tool based on adaptive mesh refinement (AMR) techniques taking advantage of the computing power of the latest generation of supercomputers.

Objectives

The physical modeling will be based on the resolution of the incompressible Navier-Stokes equations. Turbulence will be modeled by LES and RANS (k-ω SST) approaches. A hybrid DES approach may be considered. The need to solve the finest near-wall scales around $y^+=1$ requires adaptive meshes coupled with immersed boundary methods and CAD of the studied geometry. It should be noted that the proposed IBM/AMR coupled approach avoids the costly step of creating an unstructured mesh. The AMReX library [7] developed at LBNL, NREL and ANL offers a complete environment oriented towards exascale computing and hybrid architectures (CPU/GPU). It can be coupled with the Notus code whose schemes will be adapted to the new data and mesh structure. The code will be ported to the CEA machines.

Bibliography

[1] J. Picot, S. Glockner, Discretization stencil reduction of direct forcing immersed boundary methods on rectangular cells: the Ghost Node Shifting Method, Journal of Computational Physics, 364, pp18-48, 2018

[2] A. M. D. Jost and S. Glockner, Direct forcing immersed boundary methods: Improvements to the Ghost Node Method, Journal of Computational Physics, volume 438, 110371, 2021

[3] A. Lemoine, S. Glockner, J. Breil, Moment-of-Fluid Analytic Reconstruction on 2D Cartesian Grids, Journal of Computational Physics, 328, 131-139, 2017

[4] A. Lemoine. Analytic Gradient for the Moment-of-Fluid Method in Axisymmetric and on General Polyhedrons in Any Dimension. Journal of Computational Physics, Volume 422, 109741, 2020

[5] T. Milcent, A. Lemoine, Moment-of-Fluid Analytic Reconstruction on 3D Rectangular Hexahedrons, Journal of Computational Physics, Volume 409, 109346, 2020

[6] S. Glockner, A.M.D. Jost, A. Erriguible, Advanced petascale simulations of the scaling up of mixing limited flow processes for materials synthesis, Chemical Engineering Journal, volume 431, Part 1, 1 March 2022, 133647.

[7] AMReX, A software framework for massively parallel, block-structured adaptive mesh refinement (AMR) applications, https://amrex-codes.github.io/amrex/

Desired profile

The candidate should have a strong background in numerical methods and associated development on parallel architectures. The candidate will also have to show organizational skills, take initiatives, and have a strong taste for code development and simulation of turbulent flows. Mastering of different languages is required, such as FORTRAN (2003), MPI, OpenMP, OpenACC, etc.

Application

Please send to the contacts below a CV, a letter of motivation detailing the candidate's interest in the subject, the thesis reports (of the manuscript and the defense), and the contact information of referees.

Contacts

Dr. Stéphane Glockner - I2M glockner@bordeaux-inp.fr
Dr. Jérôme Breil - CEA jerome.breil@cea.fr
Dr. Antoine Lemoine antoine.lemoine@bordeaux-inp.fr