## TIME TABLE

Registration on Monday at 8.30

| TIME | Monday | Tuesday | Wednesday | Thursday | Friday |
|---|---|---|---|---|---|
| | May 21 | May 22 | May 23 | May 24 | May 25 |
| 9.00 - 9.45 | Sengupta | Sengupta | Iaccarino | Poinsot | Iacarino |
| 9.45 - 10.30 | Sengupta | Sengupta | Iaccarino | Poinsot | Iaccarino |
| 11.00 - 11.45 | Poinsot | Pirozzoli | Poinsot | Tucker | Tucker |
| 11.45 - 12.30 | Poinsot | Pirozzoli | Poinsot | Tucker | Valedictory Function |
| 14.00 - 14.45 | Pirozzoli | Azaïez | Azaïez | Pirozzoli | |
| 14.45 - 15.30 | Pirozzoli | Azaïez | Azaïez | Pirozzoli | |
| 16.00 - 16.45 | Azaïez | Iaccarino | Poster Session | Sengupta | |
| 16.45 - 17.30 | Azaïez | Iaccarino | Poster Session | Sengupta | |
| 18.00 | Welcome Aperitif | | | | |

## ADMISSION AND ACCOMMODATION

The registration fee is 600.00 Euro + VAT*, where applicable (bank charges are not included). The registration fee includes a complimentary bag, four fixed menu buffet lunches (on Friday upon request), hot beverages, downloadable lecture notes and wi-fi internet access.

Applicants must apply at least one month before the beginning of the course. Application forms should be sent on-line through the following web site: http://www.cism.it. A message of confirmation will be sent to accepted participants. Applicants requiring assistance with the registration should contact the secretariat at the following email address cism@cism.it.

Applicants may cancel their course registration and receive a full refund by notifying CISM Secretariat in writing (by email to cism@cism.it) no later than two weeks prior to the start of the course.

Cancellation requests received during the two weeks prior to the start of the course will be charged a 50.00 Euro handling fee. Incorrect payments are also subject to a 50.00 Euro handling fee.

A limited number of participants from universities and research centres who are not supported by their own institutions can be offered lodging and/or board, if available, in a reasonably priced hotel or student guest house.

Requests should be sent to CISM Secretariat by **March 21, 2018** along with the applicant's curriculum and a letter of recommendation by the head of the department or a supervisor confirming that the institute cannot provide funding. Preference will be given to applicants from countries that sponsor CISM.

Information about travel and accommodation is available on the web site www.cism.it, or can be mailed upon request.

* Italian VAT is 22%.

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ACADEMIC YEAR 2018
The Cowin Session
Centre International des Sciences Mécaniques
International Centre for Mechanical Sciences

# HIGH-PERFORMANCE COMPUTING OF BIG DATA FOR TURBULENCE AND COMBUSTION

Advanced School
coordinated by

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Indian Institute of Technology Kanpur
India

**Udine *May 21 - 25* 2018**

# HIGH-PERFORMANCE COMPUTING OF BIG DATA FOR TURBULENCE AND COMBUSTION

The main aim of this course is to acquaint the participants with present state of art of high accuracy scientific computing and its future prospects, as applicable to the broad areas of fluid mechanics and thermal analysis, across all speed regimes. Beginning with the concepts of space-time discretization and dispersion relation in numerical computing, the foundation will be laid for the solution of Navier-Stokes equation and its solution strategies for RANS (Reynolds-averaged Navier-Stokes), LES, DES (detached eddy simulation) and DNS using classical discretization techniques. Also, newer, approaches to cope with geometrical complexity like immersed boundary methods will be used not only for high accuracy computing, emplyoing high performance computing, but also for futuristic exascale computing.

Basics of high accuracy computing is rooted to the concept of stability, dispersion and phase errors, which require global spectral analysis (GSA) of discrete computing by rigorously following error dynamics. In this context we present high-order methods from finite difference, finite volume and finite element (including spectral element). We will specifically discuss compact schemes, which promise very high accuracy computing for DNS/LES of incompressible and compressible flows. Naturally, discussion would involve high performance computing (HPC) with various concepts of parallel computing. With the added help of multi-dimensional filtering, results have been produced for turbulence starting from receptivity stage without any modeling from first principle. This will be one case that will be discussed for simulating transitional and turbulent flows.

Another interesting case is the simulation of wall bounded turbulence for both incompressible and compressible flows, which will be described in all essential details. With growth of available computer power, DNS has recently got to the stage of simulating high Reynolds number flows, where comparison with experiments is a distinct possibility. It is now even conceivable to solve for even higher values of Reynolds number. We plan to discuss about complex fluid-structure interaction problems involving moving bodies and heat transfer.

This course aims to raise the bar above the pedagogical usage of high- accuracy computing in addressing more complex physical scenarios, like discussing turbulent combustion. This will span from modeling level to investigation of complex combustion instabilities in gas turbines, which may also incorporate acoustically coupled causes. The participants would also gain insights into the industry practices in the areas of turbomachines via the usage of hybrid-RANS, LES modeling. Such advanced industrial simulations using LES also require innovative hybrid turbulence models. The pre- and post-processing of LES data is another challenge that is faced in present day industrial practices.

Obtained results of Navier-Stokes equation in time-accurate manner constitute huge data bases, whose analysis poses significant challenges already to researchers. In the near future one would aim at peta and exascale computing.

To visualize and analyze such big data arising from models in industrial scale simulations, LES and DNS of canonical problems one needs to familiarize oneself with various pre- and post-processing tools. We specifically present tools like proper orthogonal decomposition (POD), proper generalized decomposition (PGD), singular value decomposition (SVD), recursive POD, high order SVD in multi-parameter spaces. Special attention would be paid to bivariate and multivariate data sets in the course, with respect to various canonical flow and heat transfer cases.

The course is manly addressed to doctoral students in mechanical, aerospace engineering and all applied disciplines including applied mathematics. We believe that the covered materials would also significantly benefit post-doctoral fellows and young professional working in related fields. The course will be offered with enough scope of interaction between the lecturers and the participants. As we expect that some of the participants would be already involved in similar activities, an afternoon would be set aside for participants to discuss their specific problems orally via informal and/ or poster presentations.

## PRELIMINARY SUGGESTED READINGS


M. Azaïez, M. Deville, E. H. Mund, Éléments finis pour les fluides incompressibles, PPUR Presses polytechniques (2011).

R. Mittal,G. Iaccarino, Immersed boundary method, Ann. Rev. Fluid Mech., 37, 239-261 (2005).

S. Pirozzoli, Numerical methods for high speed flows, Annual Rev. of Fluid Mechanics, 43, 163-194 (2011).

T. Poinsot, D. Veynante, Theoretical and Numerical Combustion, Third Edition, http://elearning.cerfacs.fr/ (2012).

T. K. Sengupta, High Accuracy Computing Methods: Fluid Flows and Wave Phenomena, Cambridge Univ. Press, USA (2013).

Tapan K. Sengupta, Instabilities of Flows and Transition to Turbulence, CRC Press, USA (2012).

P. G. Tucker, Advanced computational fluid and Aerodynamics, Cambridge Univ. Press, UK (2016).


## INVITED LECTURERS

**Mejdi Azaïez** - University of Bordeaux, France
*6 lectures on:* Proper Orthogonal Decomposition; Proper Generalized Decomposition and Singular Values Decomposition; Recursive Proper Orthogonal Decomposition; High Order Singular Values Decomposition; Example; High Reynolds number flow dynamics inside a singular lid driven cavity.

**Gianluca Iaccarino** - Stanford University, USA
*6 lectures on:* Immersed Boundary Method; Governing equations; Discrete IB schemes; Geometry and Grid Generation; Fluid Flow Simulations; High Performance Computing; Domain decomposition approaches; MPI-based tools.

**Sergio Pirozzoli** - "La Sapienza" University of Rome, Italy
*6 lectures on:* Energy-preserving discretizations: FD methods for DNS of incompressible and compressible flows; Numerical issues in DNS and LES; Parallelization issues; Examples of DNS of wall-bounded flows.

**Thierry Poinsot** - CERFACS, Toulouse, France
*6 lectures on:* Introduction to combustion, Flame regimes; Turbulent flames; Detonations; Instabilities: Turbulent combustion models for arbitrary regimes; Which codes for combustion; RANS, DNS, LES; The impact of HPC on combustion codes: Modeling and simulations of combustion instabilities in gas turbines; Bifurcations in swirling flows.

**Tapan K. Sengupta** - IIT Kanpur, India
*6 lectures on:* High Accuracy Computing; Spatial and temporal discretizations; Error dynamics and Dispersion relation preservation (DRP) Schemes; Global spectral analysis (GSA); Time Integration for DNS/ LES; Computing transitional and turbulent flows; Nonlinear receptivity and enstrophy transport equation for POD and ROM.

**Paul G. Tucker** - University of Cambridge, UK
*3 lectures on:* Industrial hybrid-RANS LES modeling; Pre and post processing of LES; Advanced industrial simulation and LES.

## LECTURES

All lectures will be given in English. Lecture notes can be downloaded from the CISM web site. Instructions will be sent to accepted participants.