## TIME TABLE

| TIME | Monday | Tuesday | Wednesday | Thursday | Friday |
|---|---|---|---|---|---|
| | September 6 | September 7 | September 8 | September 9 | September 10 |
| 9.00 - 9.45 | Registration | Quarteroni | Sherwin | Farhat | Iaccarino |
| 9.45 - 10.30 | Wall | Quarteroni | Sherwin | Farhat | Iaccarino |
| 11.00 - 11.45 | Quarteroni | Sherwin | Iaccarino | Sherwin | Wall |
| 11.45 - 12.30 | Quarteroni | Sherwin | Iaccarino | Sherwin | Wall |
| 14.30 - 15.15 | Wall | Bottasso | Farhat | Wall | |
| 15.15 - 16.00 | Wall | Bottasso | Farhat | Wall | |
| 16.30 - 17.15 | Quarteroni | Farhat | Bottasso | Bottasso | |
| 17.15 - 18.00 | Quarteroni | Farhat | Bottasso | Iaccarino | |

## ADMISSION AND ACCOMMODATION

Applicants must apply at least one month before the beginning of the course. Application forms should be sent on-line through our web site: http://www.cism.it or by post.

A message of confirmation will be sent to accepted participants. If you need assistance for registration please contact our secretariat.

The 700,00 Euro registration fee includes a complimentary bag, four fixed menu buffet lunches (Friday not included), hot beverages, on-line/downloadable lecture notes and wi-fi internet access.

A limited number of participants from universitites and research centres who are not supported by their own institutions can be offered board and/or lodging in a reasonably priced hotel. Requests should be sent to CISM Secretariat by **July 6, 2010** 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.

The Deutscher Akademischer Austausch Dienst (DAAD) and the Deutsche Forschungsgemeinschaft (DFG) offer support to German students. Please contact:

DAAD, Kennedyallee 50, 53175 Bonn
tel. +49 (228) 882-0
e-mail: postmaster@daad.de
web site: http://www.daad.de/de/kontakt.html

DFG, Kennedyallee 40, 53175 Bonn
tel. +49 (228) 885 2655
e-mail: ing4@dfg.de
web site: http://www.dfg.de

Information about travel and accommodation is available on our web site, or can be mailed upon request.

Please note that the centre will be closed for summer vacation the first three weeks in August.

For further information please contact:

CISM
Palazzo del Torso - Piazza Garibaldi 18
33100 Udine (Italy)
tel. +39 0432 248511 (6 lines)
fax +39 0432 248550
e-mail: cism@cism.it

ACADEMIC YEAR 2010
The Zienkiewicz Session
Centre International des Sciences Mécaniques
International Centre for Mechanical Sciences

# COMPUTATIONAL FLUID-STRUCTURE INTERACTION

Advanced School
coordinated by

**Wolfgang A. Wall**
Technische Universität München
Germany

Udine, ***September 6 - 10,*** 2010

# COMPUTATIONAL FLUID-STRUCTURE INTERACTION

Fluid-structure interaction problems, as well as many other multi-field problems, have received much attention in recent years and their importance is still continuously growing. The main reason for this is that they are of great relevance in all fields of engineering (aerospace, bio, civil, mechanical, etc.) as well as in the applied sciences. Hence, the development and application of respective modeling and simulation approaches have gained great attention over the past decades. While modeling and simulation of most relevant problems were far out of reach still a couple of years ago, this possibility is now available or only a short distance away– thanks to advances in computational power, computational modeling approaches and methods.

In recent years research in the area of computational fluid-structure interaction has seen great progress. But most of the individual topical areas are still seeing heavy research activities. Besides more theoretical aspects and the beginning of an in-depth mathematical analysis some current endeavours in this field are: the advancement from special purpose or special problem to quite general approaches; the desire to capture very general and complex systems; and the exigent need of robust high quality approaches for complex cases, i.e. approaches that have the potential to turn over from being a challenging and fascinating research topic to a real development tool with real predictive capabilities.

One problem for people trying to do high level research in this area is the multitude of topics one has to be familiar with – from computational fluid dynamics to computational solid dynamics, from efficient solver of large scale systems to coupling schemes, etc. And for real progress and high quality research or applications it is important to have the essentials in all these fields and their respective interplay available. On the other hand there are neither good text books, nor good courses – at university level or outside – available. This is exactly the huge gap that this CISM course tries to fill.

The aim of the course is to bring together world leading experts in the area of computational fluid-structure interaction and beyond (more general multi-field and multi-material problems). The course tries to not only look at the problem from one specific point of view but from very different perspectives. These different perspectives refer to both the methods used and to the types of fields covered as well as to the types of applications. As for the fields: it will cover all different types of fluid fields – from compressible to incompressible, etc. – and also different structural fields – large deformations, thin-walled, rigid bodies, nonlinear materials, bio solids, etc. As for the methods: the course will cover very different discretization schemes – from finite elements to finite volumes to spectral/hp methods and multibody dynamics. It will also cover the different ways one can formulate such a problem, i.e. different moving grid and fixed grid / immersed boundary approaches. The most important coupled solution strategies and their range of applicability (w.r.t. fields and methods) will also be dealt with in detail: from partitioned to monolithic, from staggered to semi-implicit to strong coupling schemes. As for applications: the course will cover some of the most important application areas, from aero-(thermo-)elasticity (fixed wing and rotary wing) to aerospace, from bio-engineering to yacht engineering, from automotive engineering to wind energy, etc.

The course is addressing a rather wide audience: from doctoral students to more senior researchers (from all different engineering disciplines as well as the applied sciences); in addition it will also be interesting for people from industry including commercial software companies.

## PRELIMINARY SUGGESTED READINGS


CFD-Based Nonlinear Computational Aeroelasticity, C. Farhat, Encyclopedia of Computational Mechanics, E. Stein, R. De Borst and T. Hughes (eds.), John Wiley & Sons, Vol. 3, 2004.

Cardiovascular Mathematics – Modeling and simulation of the circulatory system, Series: MS&A , Vol. 1 Formaggia, Luca; Quarteroni, Alfio; Veneziani, Alessandro (Eds.) Springer, 2009.

Spectral/hp element methods for computational fluid dynamics, Karniadakis, G.E. Sherwin,S.J , Oxford University Press, 2005.

A comparison of fictitious domain methods appropriate for spectral/hp element discretisations, Vos, P.E.J., van Loon, R, Sherwin, S.J , Computational Methods in Applied Mechanical Engineering, Vol: 197, Pages: 2275-2289, 2008.

Immersed Boundary Methods, R. Mittal and G. Iaccarino, Annual Review of Fluid Mechanics, Vol. 37, pp. 239-261, 2005.

DNS of buoyancy-dominated turbulent flows on a bluff body using the immersed boundary method, S. Kang, G. Iaccarino, and F. Ham, Journal of Computational Physics, Vol. 228, pp. 3189-3208, 2009.

Flexible Multibody Dynamics: A Finite Element Approach, A. Cardona, M. Geradin, John Wiley & Sons Inc, 2001.

Advances in Computational Fluid-Thin-Walled-Structure Interaction – Formulations and Solvers, W.A. Wall, U. Küttler, A. Gerstenberger, M. Gee and Ch. Förster, Series: CISM, New Trends in Thin Structures, P.M. Pimenta, P. Wriggers (eds.), Springer 2009.


## INVITED LECTURERS

**Carlo Bottasso** - Politecnico di Milano, Italy
*5 lectures on:* Non-linear flexible multibody dynamics for aero-servo-elastic applications. Geometrically exact formulations in multibody dynamics. Time integration of high index DAEs. Practical applications in rotorcraft aero-servo-elasticity and flight mechanics. Practical applications in wind power engineering.

**Charbel Farhat** - Stanford University, Palo Alto, CA, USA
*6 lectures on:* Arbitrary Lagrangian Eulerian framework: discrete geometric conservation laws and relationship to nonlinear stability, algorithms for computing flow-induced loads on non-matching grids. Embedded Eulerian framework: discretization of transmission conditions. Staggered solution schemes: stability and accuracy analysis. Aerospace and automotive applications.

**Gianluca Iaccarino** - Stanford University, Palo Alto, CA, USA
*6 lectures on:* Formulation of the immersed boundary (IB) method for fluid flow problems. Direct forcing and reconstruction approaches: accuracy and robustness. Modeling of turbulence on IB surfaces: direct numerical simulations and Reynolds averaged closures. Treatment of conjugate solid/fluid heat transfer: conservative treatment and common interface tessellation. Validation studies: unsteady flow around a cooled cylinder. Applications to electric motors and turbine blade cooling systems

**Alfio Quarteroni** - Politecnico di Milano, Italy
*6 lectures on:* Variational formulation of coupled fluid-structure problems. Equivalent formulation by Steklov-Poincaré interface operators. Fixed-point, semi-implicit and fully implicit algorithms. Splitting algorithms issuing from inexact algebraic factorizations. Application to blood flow modeling in large arterial vessels and to sail-wind interaction in yacht engineering.

**Spencer Sherwin** - Imperial College, London, UK
*5 lectures on:* Implementation of spectral/hp element method for incompressible fluid dynamics highlighting how to balance the use of classical h-type with p-type discretisations when considering a practical implementation similar to the Nektar++ initiative (www.nektar.info). Application of these techniques in bluff body and biomedical fluid structure interaction problems and discussion of issues related to high order fictitious domain techniques.

**Wolfgang A. Wall** -Technische Universität München, Germany
*7 lectures on:* Introduction and overview on fluid-structure-interaction. Fixed-grid approaches for FSI: overview, 3d XFEM based approach, embedding interface conditions. Fluid-Structure-Contact-Interaction. Strong coupling schemes: taxonomy, truly monolithic algebraic multigrid FSI approach. Application areas will include biomechanics, biophysics, material processing and more classical engineering disciplines.

## LECTURES

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

# COMPUTATIONAL FLUID-STRUCTURE INTERACTION

**Udine, September 6 - 10, 2010**
**Application Form**
(Please print or type)

Surname _____

Name _____

Affiliation _____

Address_____

_____

E-mail _____

Phone_____Fax_____

**Method of payment upon receipt of confirmation (Please check the box)**

*The fee of Euro 700,00 includes IVA/VAT tax and excludes bank charges.*

❑ *I shall send a check of Euro* _____

❑ *Payment will be made to CISM - Bank Account N° 094570210900, VENETO BANCA - Udine (CAB 12300 - ABI 05418 - SWIFT AMBPIT2M - IBAN CODE IT83Z 05418 12300 09457 0210900). Copy of the receipt should be sent to the secretariat.*

❑ *I shall pay at the registration counter with check, cash or VISA Credit Card (Mastercard/Eurocard, Visa, CartaSi).*

**IMPORTANT: CISM is obliged to present an invoice for the above sum. Please indicate to whom the invoice should be addressed.**

Name _____

Address _____

_____

_____

C.F.* _____

VAT/IVA* No_____

(*) Only for EU residents or foreigners with a permanent business activity in Italy.

**Only for Italian Public Companies**

❑ *I ask for IVA exemption (ex law n. 537/1993 - art. 14 comma 10).*

**Privacy policy:** I understand that data received via this form will be used only to provide information about CISM and its activities, within the limits set by the Italian legislative decree no. 196/2003 and subsequent amendments.
Complete information on CISM's privacy policy is available at www.cism.it.

I have read the "Admission and Accommodation" terms and conditions and agree.

Date _____ Signature _____