

TIME TABLE

TIME	Monday June 27	Tuesday June 28	Wednesday June 29	Thursday June 30	Friday July 1
9.00 - 9.45	Registration	Wall	Poster	Wall	Farhat
9.45 - 10.30	Wall / Farhat	Wall	Ohayon	Wall	Farhat
11.00 - 11.45	Farhat	Ohayon	Badia	Gerbeau	Wall
11.45 - 12.30	Farhat	Ohayon	Badia	Gerbeau	Wall
14.00 - 14.45	Gerbeau	Poster	Farhat	Badia	
14.45 - 15.30	Gerbeau	Poster	Farhat	Badia	
16.00 - 16.45	Badia	Poster	Gerbeau	Ohayon	
16.45 - 17.30	Badia	Poster	Gerbeau	Ohayon	

ADMISSION AND ACCOMMODATION

The registration fee is of 575,00 Euro + VAT taxes*, where applicable (bank charges are not included).

The registration fee includes a complimentary bag, four fixed menu buffet lunches (Friday subject to numbers), 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 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.

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

If cancellation occurs less than two weeks prior to the start of the course, a Euro 50,00 handling fee will be charged. Incorrect payments are subject to Euro 50,00 handling fee.

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

Requests should be sent to CISM Secretariat by **April 27, 2016** 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 our web site, or can be mailed upon request.

* Italian VAT is 22%.

For further information please contact:

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



COMPUTATIONAL FLUID- STRUCTURE INTERACTION

CISM-ECCOMAS International Summer School
coordinated by

Charbel Farhat
Stanford University
CA, USA

Wolfgang A. Wall
Technical University of Munich
Germany



Udine June 27 - July 1 2016

COMPUTATIONAL FLUID-STRUCTURE INTERACTION

Fluid-Structure Interaction (FSI) problems, as well as many other coupled multi-field problems, have received much attention in recent years and continue to attract more interest. The main reason is that they are of great relevance to many fields of engineering (civil, mechanical, aerospace, bio, etc.) and applied sciences. Similarly, the development and application of corresponding numerical simulation methodologies have received wide attention over the past decades. Thanks to many advances in computational sciences and computing hardware, the numerical modeling and solution of a difficult subset of such problems that was thought to be unfeasible even five years ago, is either feasible today or will become feasible within the nearby future. In recent years, research in computational FSI has witnessed great progress. However, the field remains an active topic of research with many remaining

open problems. Current foci center on the better understanding of various numerical approaches via more rigorous analysis, the generalization of special-purpose solution schemes to comprehensive methodologies, and the maturing of computational technologies that have demonstrated great potential a decade ago to transcend them into numerical assets for the solution of grand challenge FSI problems. Nevertheless, the bar for entering this exciting research field is considerably high. It requires mastering a fair amount of computational fluids or fluid dynamics, linear and/or nonlinear computational solid and/or structural dynamics, time-integration, linear algebra, and parallel computing, among other topics. Textbooks in this general area are either specialized, or tend to cater to specific solution approaches rather than fundamental issues. This latter gap

is what this CISM course modestly attempts to address. To this effect, the course brings together experts in the area of computational FSI who will cover complementary aspects of this topic from different perspectives. On the disciplinary side, incompressible and compressible flow regimes and linear and nonlinear structural behaviors will be covered. On the interaction side, all three classes of FSI problems will be discussed: (1) those where the interaction is of short duration and the fluid subsystem is characterized by limited displacements, as in shock and impact problems; (2) those problems where the fluid subsystem is also characterized by limited displacements but the interaction is of longer duration, as in elastoacoustic problems; and (3) those problems where the fluid and structural subsystems have large relative motions and the interaction process is dominated by the flow, as in aeroelasticity problems. The

formulations of these problems in the Arbitrary Lagrangian Eulerian (ALE) and purely Eulerian settings will be discussed and contrasted. Various associated semi-discretization and discretization schemes will be covered, and their strengths and weaknesses will be explained. These will include ALE and embedded boundary methods for CFD in the first case, and monolithic and partitioned solution procedures in the second case. To address the issue of CPU intensive parametric problems, the course will also include a few lectures on model order reduction in the context of FSI problems.

Participants will be given the opportunity to present a poster covering their interest and contribution to this field. This will enable fostering a collegial discussion and provide the lecturers with an opportunity to tailor their material to address specific applications and concerns.

INVITED LECTURERS

Santiago Badia - UPC and CIMNE, Barcelona, Spain
6 Lectures on: Coupled Solvers for FSI. Specific topics: Segregated algorithms; Introduction to iterative Krylov methods and preconditioning strategies; Block-Jacobi and block-Gauss-Seidel solvers; Block-preconditioning techniques and Schur complement approximations; Physics-based domain decomposition preconditioning; Parallel solvers for linear systems of equations, scalability and the importance of effective preconditioning; Scalable domain decomposition methods for FSI; Balancing domain decomposition and FETI-type preconditioning strategies.
Website: <http://badia.rme.upc.edu/>

Charbel Farhat - Stanford University, CA, USA
6 lectures on: FSI in the compressible flow regime & Model reduction for FSI. Specific topics: Introduction and formulation of compressible fluid-structure interaction problems; Eulerian and Arbitrary Lagrangian Eulerian computational frameworks; The FIVER method for highly nonlinear multiphase fluid-structure interaction problems; Linearized model order reduction: theory, stability, and accuracy; Real-time fluid-structure computations: interpolation on matrix manifolds.
Website: <https://web.stanford.edu/group/frg/>

Jean-Frédéric Gerbeau - INRIA and Sorbonne Universités UPMC-Paris 6, France
6 Lectures on: FSI in hemodynamics & coupling algorithms. Specific topics: Incompressible fluid-structure interaction algorithms: implicit, semi-implicit, and explicit schemes. The role of the added-mass effect in the design of the algorithms. Data assimilation in fluid-structure interaction: variational and sequential approaches; state and parameter estimation with Luenberger observers and nonlinear filtering. Applications in hemodynamics.
Website: <http://www-rocq.inria.fr/who/Jean-Frederic.Gerbeau>

Roger Ohayon - Laboratoire de Mécanique des Structures et des Systèmes Couplés, CNAM, Paris, France
5 Lectures on: Modeling and discretization of linear FSI in the frequency domain. Specific topics: Computational aspects of linear vibrations of incompressible liquids contained in elastic tanks with free surface effects (hydroelasticity, sloshing); Compressibility effects in liquids and gas for vibroacoustic noise and vibration problems; Specific aspects will be on mechanical modeling, choice of the unknowns fields of the boundary value problem, appropriate variational formulations and symmetry considerations, finite element methods and reduced order models through appropriate dynamic substructuring concepts.
Website: <http://www.lmssc.cnam.fr/fr/equipe/roger-ohayon>

Wolfgang A. Wall - Technical University of Munich, Germany
6 Lectures on: FSI in the incompressible flow regime & Immersed methods. Specific topics: Introduction and formulation of fluid-structure interaction with incompressible flows; Monolithic multilevel approach for FSI; Framework for monolithic solution approaches for general n-field coupled problems; Overview on fixed-grid algorithms; Cut-Element based approach for FSI; Extension towards fluid-structure-contact interaction and fluid-structure-fracture interaction.
Website: <http://www.lnm.mw.tum.de>

PRELIMINARY SUGGESTED READING

Added-mass effect in the design of partitioned algorithms for fluid-structure problems. P Causin, JF Gerbeau, F Nobile. *Computer methods in applied mechanics and engineering* 194 (42), 4506-4527, 2005.

Algorithms for fluid-structure interaction problems. MA Fernández, JF Gerbeau - p. 307-346 *Cardiovascular mathematics*, 2009 Springer.

H. Morand and R. Ohayon, *Fluid Structure Interaction*, Wiley, 1995.

R. Ohayon and C. Soize, *Advanced Computational Vibroacoustics*, Cambridge University Press, 2014.

H.C. Elman, D.J. Silvester and A.J. Wathen, *Finite elements and fast iterative solvers: with applications in incompressible fluid dynamics*, Oxford University Press, 2005.

Gerstenberger A., Wall W.A.: An extended finite element method /lagrange multiplier based approach for fluid-structure interaction. *Computer Methods in Applied Mechanics and*

Engineering 197 (2008) 1699-1714.

Gee M., Küttler U., Wall W.A.: Truly monolithic algebraic multigrid for fluid-structure interaction. *International Journal for Numerical Methods in Engineering* 85 (8) (2011) 987-1016.

C. Farhat, P. Geuzaine and C. Grandmont, "The Discrete Geometric Conservation Law and the Nonlinear Stability of ALE Schemes for the Solution of Flow Problems on Moving Grids," *Journal of Computational Physics*, Vol. 174, pp. 669-694 (2001).

C. Farhat, J.-F. Gerbeau and A. Raldu, "FIVER: A Finite Volume Method Based on Exact Two-Phase Riemann Problems and Sparse Grids for Multi-Material Flows with Large Density Jumps," *Journal of Computational Physics*, Vol. 231, pp. 6360-6379 (2012).

D. Amsallem and C. Farhat, "An Interpolation Method for Adapting Reduced-Order Models and Application to Aeroelasticity," *AIAA Journal*, Vol. 46, pp. 1803-1813 (2008).

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.

**COMPUTATIONAL FLUID-STRUCTURE
INTERACTION**

Udine, June 27 - July 1, 2016

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 is 575,00 Euro + 22% Italian VAT taxes, where applicable (bank charges are not included).

I shall send a check of Euro _____

Payment will be made to CISM - Bank Account No. 094570210900,
VENETO BANCA - Udine (CAB 12300 - ABI 05035 - SWIFT/BIC
VEBHIT2M - IBAN CODE IT46 N 05035 12300 09457 0210900).
Copy of the receipt should be sent to the secretariat

I shall pay at the registration counter with check 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 _____