

## TIME TABLE

TIME	Monday May 25	Tuesday May 26	Wednesday May 27	Thursday May 28	Friday May 29
9.00 - 9.45	Registration	Stone	Stone	Shelley	Crowdy
9.45 - 10.30	Stone	Stone	Stone	Shelley	Crowdy
11.00 - 11.45	Stone	Audoly	Audoly	Lindner	Lindner
11.45 - 12.30	Audoly	Audoly	Audoly	Lindner	Lindner
14.00 - 14.45	Audoly	Shelley	Crowdy	Crowdy	
14.45 - 15.30	Shelley	Shelley	Crowdy	Crowdy	
16.00 - 16.45	Breuer	Breuer	Lindner	Breuer	
16.45 - 17.30	Breuer	Breuer	Lindner	Breuer	

## 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 **March 25, 2015** 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  
 Palazzo del Torso  
 Piazza Garibaldi 18  
 33100 Udine (Italy)  
 tel. +39 0432 248511 (6 lines)  
 fax +39 0432 248550  
 e-mail: [cism@cism.it](mailto:cism@cism.it)

ACADEMIC YEAR 2015  
The Nieuwstadt Session

Centre International des Sciences Mécaniques  
International Centre for Mechanical Sciences



# INTERACTION OF MICROSCOPIC STRUCTURES AND ORGANISMS WITH FLUID FLOWS

COST Training Summer School  
coordinated by

**Olivia du Roure**  
PMMH, ESPCI, Paris  
France

**Michael Shelley**  
New York University  
NY, USA



**Udine May 25 - 29 2015**

# INTERACTION OF MICROSCOPIC STRUCTURES AND ORGANISMS WITH FLUID FLOWS

The interaction of fluids and structures is an area of tremendous activity, most notably for low Reynolds number flows which are described by the Stokes equations. This regime, where the suspended structures are microscopic, is especially important to chemical engineering, materials science, soft-condensed matter physics, and biophysics. This course will focus on the interactions of fluids with microscopic objects, such as deformable particles, swimming microorganisms and “active” particles, and the collective behavior of these systems.

Students will first be given a thorough foundation in the physics and mathematical description of the Stokesian flow regime as well as relevant matter on material elasticity. On the theoretical side it will include mathematical

aspects such as singularity, boundary integral, and approximate treatments of the Stokes equations, as well as Faxen relations and treatment of many-body interactions. The classical elastica will be described with emphasis on “extreme mechanics” of buckling and opening. On the experimental side, material will include basic methods and modern microfluidic techniques for fabrication.

Students will then learn many different aspects of the dynamics of flexible structures suspended in viscous flows. The viscous forces acting upon flexible objects can deform them, say through continuous bending or an abrupt buckling, and these deformations in turn modify the flow, leading to a highly non-linear coupling. This arises in modeling the flagellae or cilia involved in micro-organismal

locomotion and mucal transport, in determining the shape of biofilm streamers, and in new methods of structure self-assembly. Micro-organisms locomote in a variety of ways, singly and collectively, and in many kinds of environments. This example of fluid-structure interaction is a central example of “active matter”. Lectures will cover both theoretical and experimental aspects, discussing classical results as well as modern advances in understanding collective hydrodynamics, and the effects of confinement and complex media on motility.

This course will give the possibility to the students to learn the state of the art of this still developing area. We have designed a program for the courses in which both experimental and theoretical aspects will be treated and that

will provide students with a strong background on the fundamentals of the field as well as recent developments on open questions. The course is addressed to doctoral students and postdoctoral researchers in hydrodynamics, mechanics, materials science, applied physics and applied mathematics, academic and industrial researchers and practicing engineers.

## PRELIMINARY SUGGESTED READINGS

Audoly B and Pomeau Y. *Elasticity and Geometry* (2010). From hair curls to the non-linear response of shells. Ed. Oxford Press University.

Crowdy D.G., Lee S., Samson O., Lauga E. and Hosoi A.E., (2011) A two-dimensional model of low-Reynolds number swimming beneath a free surface. *J. Fluid. Mech.*, 681, 24-47.

Duprat C and Stone HA (2014) Low Reynolds Number Flows. to appear in *Fluid-structure interactions at low Reynolds numbers*, eds. C. Duprat and H. A. Stone.

Hinch, E.J. (1988) Hydrodynamics at low Reynolds number: a brief and elementary introduction in *Disorder and Mixing* ed. Guyon, E., Nadal J-P. & Pomeau, Y. (Kluwer) N.A.T.O. A.S.I. E, 152, 43-55.

Lauga, E., & Powers, T. R. (2009). The hydrodynamics of swimming microorganisms. *Reports on Progress in Physics*, 72(9), 096601. doi:10.1088/0034-4885/72/9/096601

Lindner, A. and Shelley, M. (2014) Elastic fibers in flows. to appear in *Fluid-structure interactions at low Reynolds numbers*, eds. C. Duprat and H. A. Stone.

Powers, T. R. (2010). Dynamics of filaments and membranes in a viscous fluid. *Reviews of Modern Physics*, 82(2), 1607–1631. doi:10.1103/RevModPhys.82.1607

Saintillan, D. and Shelley, M. (2013) Active Suspensions and Their Nonlinear Models. *Comptes Rendus Physique* 14, 497-517.

## INVITED LECTURERS

**Basile Audoly** - Université Pierre et Marie Curie and CNRS, Paris, France  
*6 lectures on: [Elasticity and Geometry](#)*. Introduction to the Elastica; justification by dimensional reduction; linear models: bars and beam. Stability and bifurcations: buckling analysis, snap-through, flutter. Discrete methods for simulating the dynamics of nonlinear rods: discrete elastic rods, discrete viscous threads.

**Kenneth Breuer** - Brown University, Providence, RI, USA  
*6 lectures on: [Swimming at small Reynolds number](#)*. Introduction to swimming at low Reynolds number; Bacterial flagellar motility: Running, Tumbling, Reverses and Flicks - modes of swimming with helical flagella; The mechanics of flagellar bundling and hydrodynamic synchronization of flagella and cilia; Taylor swimmers and travelling-wave swimming; Swimming in Newtonian and non-Newtonian fluids.

**Darren Crowdy** - Imperial College, London, UK  
*6 lectures on: [MOFs, microfluidics and micro-organisms: a crash course in complex variable techniques for Stokes flow modelling](#)*. 2D Stokes flows; Goursat representations in terms of analytic functions; Fundamental singularities; conformal mapping; free boundary problems; Mixed boundary value problems; transform techniques; numerical methods; Applications of all the above to modelling microstructured optical fibres, Superhydrophobic surfaces, and low-Reynolds-number swimmers/particles.

**Anke Lindner** - ESPCI, Paris, France  
*6 lectures on: [Flow of complex suspensions](#)*. Introduction to complex fluids; Principles of rheology and recent developments in microfluidic rheometry; Effective properties of complex suspensions (anisotropic, deformable and active particles); Link to individual and collective particle dynamics (deformation, orientation, structural arrangement....).

**Michael Shelley** - New York University, NY, USA  
*5 lectures on: [Elastic fibers in viscous flows](#)*. Slender-body theory, local and nonlocal, for elasticae in fluids; Buckling, bending, rheology, and transport; Fibers made active – the dynamics of swimming rod suspensions; Numerical methods; Modeling microtubule/motor-protein assemblies; Suspensions of elastic fibers, biological applications.

**Howard Stone** - Princeton University, NJ, USA  
*6 lectures on: [Low Reynolds number hydrodynamics](#)*. Equations of motion; reciprocal theorem; Applications and integral equation representations; Motion of spheres and ellipsoids; Lubrication theory and thin film flows.

## 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.

**INTERACTION OF MICROSCOPIC STRUCTURES  
AND ORGANISMS WITH FLUID FLOWS**

**Udine, May 25 - 29, 2015**

**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](http://www.cism.it).

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

Date \_\_\_\_\_ Signature \_\_\_\_\_