TIME TABLE

(Registration on Monday at 8.30)

TIME	Monday	Tuesday	Wednesday	Thursday	Friday
	July 18	**July 19**	**July 20**	**July 21**	**July 22**
9.00 - 9.45	Orlandi	Jimenez	Smits	Marusic	McKeon
9.45 - 10.30	Jimenez	Jimenez	Smits	Marusic	McKeon
11.00 - 11.45	Jimenez	Jimenez	Marusic	McKeon	Pirozzoli
11.45 - 12.30	Jimenez	Jimenez	Marusic	McKeon	Pirozzoli
14.00 - 14.45	Smits	Orlandi	Marusic	McKeon	
14.45 - 15.30	Smits	Orlandi	Marusic	Pirozzoli	
16.00 - 16.45	Smits	Orlandi	Orlandi	Pirozzoli	
16.45 - 17.30	Smits	Orlandi	Orlandi	Pirozzoli	

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 **May 18, 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:
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Piazza Garibaldi 18
33100 Udine (Italy)
tel. +39 0432 248511 (6 lines)
fax +39 0432 248550
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ACADEMIC YEAR 2016
The Leipholtz Session

Centre International des Sciences Mécaniques
International Centre for Mechanical Sciences

WALL-BOUNDED TURBULENCE

Advanced School
coordinated by

Sergio Pirozzoli
Sapienza Università di Roma
Italy

Udine *July 18 - 22* 2016

WALL-BOUNDED TURBULENCE

Despite significant progress achieved in recent years, fluid turbulence is still escaping our complete understanding, mainly because of its complex nonlinear behavior. Within the broad subject of turbulent flow, turbulence over solid walls is of special conceptual and practical importance, and its prediction is crucial for the accurate design of aircraft, turbo-machines and ships. Understanding the physics of wall turbulence may lead to effective techniques for the reduction of wall friction, with incurred benefits in terms of reduced power expenditure.
The present course is aimed at presenting the state-of-the-art of wall turbulence and highlighting avenues for future research.
The emphasis will be mainly on canonical flows over flat surfaces including boundary layers, pipes, and channels, in the case of both smooth and rough walls.
Wall-bounded turbulence has been tackled over the years along different fronts, which include theoretical analysis and experimental and numerical investigations. Regarding theory, it appears that the best established features of wall turbulence, including the presence of a logarithmic layer in the mean velocity profile and in the wall-parallel velocity variances can be explained within relatively well-established conceptual models. Important recent theoretical findings include the discovery that linear processes of transient growth may be responsible for the onset of self-sustained global modes in the wall layer.
Experimental techniques have also undergone major development in recent years, mainly with the introduction of high-resolution anemometry probes down to the nano-scale. This has allowed to shed light on such long-debated subjects as the presence of an outer peak in the streamwise velocity variance.
Computational experiments based on Direct Numerical Simulations (DNS) have lately become of widespread use to get insight into the physics of wall turbulence, because of the potential to access any flow property of interest. Also given the exponential growth of available computer power, DNS has reached Reynolds numbers comparable to those attained in experiments.
The course is manly addressed to doctoral students in mechanical and aerospace engineering and related subjects, but post-Doc fellows and young researchers are also warmly encouraged to attend. The course is intended to provide the audience with all fundamental notions about the structure of wall-bounded turbulent flows, but most classes will be devoted to advanced topics covering the freshest developments in the discipline, and to highlight paths for future investigation.
Theoretical, experimental, and numerical issues will be covered.
The course will be complemented by a short tutorial on DNS of turbulent flows. Attendants will be introduced to modern techniques of parallel computing, and will be made to exercise on sample channel and pipe codes to get familiar with important practical issues as mesh generation and data analysis.

PRELIMINARY SUGGESTED READING

Pope, S.B. “Turbulent flows”, Cambridge University Press, 2000.

Townsend, A.A., “ The structure of turbulent shear flow”, 2nd Edition, Cambridge University Press, 1976.

Orlandi, P., “Fluid flow phenomena: a numerical toolkit”, 2nd Edition, Springer, 2012.

Marusic, I., McKeon, B.J., Monkewitz, P.A., Nagib, H.M., Smits, A.J. and Sreenivasan, K.R. “Wall-bounded turbulent flows at high Reynolds numbers: Recent advances and key issues.” Physics of Fluids., 22, 065103 (2010).

Smits, A.J., McKeon, B.J. and Marusic, I. “High Reynolds number wall turbulence,” Annu. Rev. Fluid Mech. 43, pp. 353-375 (2011).

Klewicki, J.C. “Reynolds number dependence, scaling, and dynamics of turbulent boundary layers”, J. Fluids Eng., 132, 094001 (2010).

McKeon, B.J., Sharma, A.S. & Jacobi, I., “Experimental manipulation of wall turbulence: a systems approach”, Phys. Fluids 25, 031301 (2013).

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.

INVITED LECTURERS

Javier Jimenez - Universidad Politecnica de Madrid, Spain
7 lectures on: Fundamental physics of wall turbulence. Basic statistical concepts of equilibrium and non-equilibrium wall turbulence will be discussed and interpreted in the light of the turbulence cascade paradigm and of recent conceptual models based on modal instability and transient growth. The role of coherent structures will be highlighted.

Alexander J. Smits - Princeton University, NJ, USA
6 lectures on: Evidence from experimental data: the Princeton superpipe experience. Fundamental aspects of Reynolds-number scaling for wall-bounded flows will be discussed, based on data from high Reynolds number facilities and measurements. Mean flow and turbulent statistical behavior from experiments will be presented, and insights from spectral behavior and POD analysis will be discussed.

Ivan Marusic - Melbourne School of Engineering, VIC, Australia
6 lectures on: Structural models of wall turbulence. The formulation of the attached-eddy model of wall turbulence will be discussed, including details on Biot-Savart integration for vortex-based models. Model predictions will be compared with experimental data, including structure functions and high-order statistics. The interactions between the inner and the outer part of the wall layer (imprinting and modulation) will also be scrutinized.

Beverley McKeon - California Institute of Technology, Pasadena, CA, USA
5 lectures on: Dynamical systems approach to wall turbulence. The lectures will introduce to non-normal mechanisms for amplification, transient growth and systems approaches to wall turbulence, including resolvent analysis, with implications for Reynolds number scaling and (active and passive) flow control. Self-sustaining and exact solutions in turbulent wall-bounded flows will be also presented.

Paolo Orlandi - Sapienza Università di Roma, Italy
1 lecture on: Historical background of wall turbulence.
5 lectures on: Turbulence over rough walls. Numerical methods and basic physics of flows over rough walls will be presented, with emphasis on the importance of the wall-normal stresses, and on verifying the validity of Townsend's similarity hypothesis. Issues related to conjugate heat transfer over rough walls will also be discussed, and hints for RANS and LES closures provided.

Sergio Pirozzoli - Sapienza Università di Roma, Italy
5 lectures on: Evidence from DNS data. Essential information on DNS of wall-bounded turbulence will be presented, including current numerical methods, resolution requirements, and statistical convergence issues. Two hours will be devoted to computer exercises with sample codes. The structure of wall layers resulting from recent large-scale DNS will be discussed.

WALL-BOUNDED TURBULENCE

Udine, July 18 - 22, 2016
Application Form
(Please print or type)

Surname ____

Name ____

Affiliation____

Address____

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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 ____

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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 ___________________