European Mechanics Society

Colloquium Final Report

N. 631 – Control of skin friction and convective heat transfer in wall-bounded flows

Dates and location: **18/03/2024 - 20/03/2024, Madrid, Spain**

Chairperson **Stefano Discetti**

Co-Chairperson **Marios Kotsonis, Andrea Ianro, Woutijn Baars**

Conference fees

- Early-bird registration - STUDENT **220.0 €**
- Early-bird registration **270.0 €**
- Regular registration - STUDENT **270.0 €**
- Regular registration **320.0 €**
- Keynote registration **0.0 €**

What other funding was obtained? **This event is supported by the the ERC Starting Grants NEXTFLOW (#949085) and GloWing (#803082), and Proof of Concept Grant DeLaH (#101138326), funded from the European Research Council under the European Union's Horizon 2020 Research and innovation programme.**

What were the participants offered? **The registration fees included:**

- A bag containing a notebook, pen, printed program, folder, and a map of Madrid
- 2 coffee breaks and one lunch per day (a total of 6 coffee breaks and 3 lunches)
- 1 informal welcome social event
- 1 social dinner
- A hands-on course on infrared thermography for convective heat transfer measurements for selected participants, and transfer via bus to the course location.

Number of members of Euromech (reduced registration fee) **12**

Number of non-members of Euromech (full registration fee) **29**

Applicants (members)

- Lionel Agostini
- Shervin Bagheri
- Jeffrey Crouch
- Oscar Flores

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- Max Knoop
- Marios Kotsonis
- Alessandro Scala
- Alberto Vela Martín

Applicants (non members)

- Enrico Amico
- Marina Barahona
- Gabriele Bellani
- Daniel Burnett
- Gioacchino Cafiero
- Rodrigo Castellanos
- Julien Cerutti
- Yifu Chen
- Antonio Cuéllar Martín
- Giulio Dacome
- Stefano Discetti
- Artur Dróżdż
- Peng-Yu Duan
- Abdelrahman Elshaer
- Isabella Fumarola
- Bharathram Ganapathisubramani
- Lou Guerin
- Lorenzo Lazzarini
- Qihong Lorena Li Hu
- Pablo López Gavilán
- Babak Mohammadikalakoo
- Hajime Nakamura
- Osman Giray Oguzman
- Isaac Robledo
- Lucas Schneeberger
- onofrio semeraro
- Jacopo Serpieri
- YANIS ZATOUT
- Zisong Zhou

Scientific Report

Active control of wall-bounded flows is an everlasting and evergrowing topic of research in the fluid dynamics community. Skin friction drag reduction and convective heat transfer control are of paramount importance in an overwhelming number of applications, involving transportation means, renewable energy exploitation, industrial processes, turbomachinery for power generation and propulsion, etc.

Fast-paced advancement of experimental hardware and computational power have fostered, on the one hand, the establishment of efficient techniques for sensing and actuation, and on the other hand, the development of techniques to efficiently distill the information available from sensors and select the most effective control strategy.

A grand challenge in spectrally-rich wall-bounded flows is the identification of effective open- and closed-loop control laws for both transitional and turbulent

flows. Opposition control has been standing for long as a very efficient, rugged, and simple strategy for this purpose. Recent advances in data-driven techniques and machine-learning methods are paving the way toward more refined solutions, with higher potential for transition delay, skin friction drag reduction, and convective heat transfer control.

The challenge of controlling wall-bounded flows has triggered interesting developments over the years in open-loop, with remarkable histories of success (see e.g. transition delay). Closed-loop control, on the other hand, promises a higher potential for transition control, turbulent skin friction reduction, and heat transfer enhancement but requires proper state characterization to optimize the control action. Hardware and software advancements are leading to the first pieces of evidence of the possibility of achieving efficient closed-loop control in realistic applications, and at the same time pushing towards a better understanding of flow physics.

The EUROMECH Colloquium 631 aimed at discussing the state of the art of wall-bounded flow control, with an utter focus on active control of skin friction and convective heat transfer, addressing the main limitations, opportunities, and challenges ahead.

The full program and the book of abstracts of the event are available on the colloquium website. The program included 5 keynote talks and 28 contributed presentations, split into 5 thematic sessions. Each session was opened by a corresponding keynote talk and closed by a round table of discussion. This arrangement resulted in a lively environment, with vibrant discussion and a very fruitful exchange of ideas, which was highly appreciated by the participants.

The first thematic session was focused on active flow control. The session was opened by a keynote talk by Prof. Ganapathisubramani (University of Southampton, UK) on the interaction between synthetic jets and turbulent boundary layers. The session also included 6 contributions on experiments, simulations, and theoretical approaches for the active control of skin friction, transition, and turbulent statistics. The works covered a variety of actuation mechanisms based on spanwise forcing, plasma actuators for drag reduction, traveling surface waves, microbubble injection, and models for optimal laminar flow control. The session was closed by a discussion on the main challenges and opportunities in the field of actuation technology.

The second session targeted passive control, in particular as a benchmark for active control. The keynote talk by Dr. Crouch (Boeing, USA) on laminar flow control provided an overview of the perspective and industrial vision of flow control applications in aeronautics. The session comprised 5 talks, with contributions on riblets with different geometry, effects of surface texturing and wall corrugation, and on explainable artificial intelligence for the identification of coherent structures playing a leading role in the dynamics of turbulent boundary layers with and without passive control. The closing round table focused on the robustness of passive control and on the opportunities provided by active control to understand physics and allow us to learn and design new passive strategies.

The topic of the third session was heat transfer control. The session was opened by a keynote talk from Prof. Bagheri (KTH Royal Institute of Technology, Sweden) on biological surface lubrication to control both skin friction and heat transfer. The session included 6 talks, covering the effects on heat transfer of spanwise oscillations in breaking the Reynolds analogy, of effusion films, and of Large-Eddy Break-up devices. Furthermore, the effect of wall cooling on the stability of boundary layers on swept wings. Optimization of open-loop control logics with

genetic algorithms was also discussed. The final round table fostered discussion on the reward ahead by joining efforts from the communities working on skin friction and heat transfer.

The fourth session focused on sensing technology. Prof. Nakamura (National Defense Academy of Japan, Japan) opened the session with a keynote talk on spatially and temporally resolved heat transfer measurements in wall-bounded flows. Furthermore, 5 talks covered different aspects of sensing, including implementation in closed-loop control, strategies to leverage machine learning to obtain full-state estimations, and methods to determine average skin friction and time-resolved wall features. The final discussion was centered on how new avenues opened by technological advances will pave the way towards closed-loop control, considering sensing a fundamental part of the setup.

The final session of the colloquium targeted data-intensive strategies in wall-bounded flow control. The keynote lecture by Prof. Jiménez (Universidad Politécnica de Madrid, Spain) provided an overview of how large ensemble of data from simulations can be used to distill models for the flow dynamics. The session comprised 6 talks, covering machine-learning-based flow control (reinforcement learning, particle swarm optimization, genetic algorithms), and ensemble methods to predict the skin friction behavior and the dynamics of wall-bounded flows. The closing round table fuelled an insightful discussion on the perspectives opened by the recent advances of machine learning and on the opportunities provided by the progressively higher availability of large datasets from simulations and experiments.

The colloquium also featured a course on infrared thermography for convective heat transfer measurements. The course, given by Dr. Castellanos (INTA, Spain), covered aspects of sensor design, implementation, data processing, and an experimental demonstration.

One of the highlights of the colloquium was the copious time allocated for informal discussion among the participants, including coffee breaks, ample lunch breaks, 5 round tables for discussion moderated by the conference chairs, and a good offer of social activities for mingling. The organization and the stimulating atmosphere were highly appreciated by the participants.

Number of participants from each country

Country	Participants
Netherlands	7
Italy	6
Poland	1
United Kingdom	4
United States	1
Spain	12
Japan	1
France	4
Sweden	2
China	1
Germany	1
Belgium	1
Total	**41**

Please send this report in electronic form to the Secretary General of EUROMECH, within one month after your Colloquium.