EUROMECH Colloquium 586

"Turbulent superstructures in closed and open flows"
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The classical picture of turbulence which has prevailed since the pioneering works by Kolmogorov, Prandtl and others from the first half of the last century is that turbulent fluid motion is characterized by a cascade of vortices and swirls of different sizes that give rise to a featureless and stochastic fluid motion. Our daily experience shows, however, that open and closed turbulent flows in nature and technology are often organized in prominent large-scale and long-living structures, which are called turbulent superstructures. These large-scale structures dominate the global transport of mass, heat and momentum; they act as barriers to transport and they increase the variability and fluctuations in the flow.

The analysis of turbulent superstructures is now possible due to significant advances in measurement techniques, numerical simulation, and mathematical characterization. Tomographic laser-based measurement techniques can track the dynamics of turbulent structures with unprecedented resolution in space and time. Direct numerical simulations on massively parallel supercomputers have advanced to a level where turbulent flows in extended domains can be simulated at sufficiently high Reynolds numbers and in parameter ranges where superstructures emerge. Efficient Eulerian and Lagrangian methods to characterize dominant vortices and flow structures, as well as determining the transport across their boundaries, have been developed in applied mathematics. Computer science provides efficient algorithms for the visualization of structures in very large data sets.

The goal of EUROMECH Colloquium 586 was to exchange new results on the structure and physics of turbulent superstructures and to discuss future directions in this field of turbulence research among scientists from applied mathematics, physics, engineering and computer science. The colloquium programme thus included recent experimental and numerical results on the processes that generate and sustain turbulent superstructures, on their dynamics, the transport across their (relatively sharp) interface and their impact on turbulent flow properties in simple open (e.g. boundary layers) and closed flows (e.g. pipe flows, Taylor-Couette flows or Rayleigh-Bénard convection). The focus of the presentations was on simple flow geometries.

For each of these specific topics, a keynote presentation was scheduled (45 minutes presentation time plus 15 minutes discussion time). The five invited keynote speakers are well-known experts in their research fields and beyond:

- Kathrin Padberg-Gehle, Lüneburg reported on the Lagragian analysis of transport by coherent sets and/or turbulent superstructures;
- Ivan Marusic, Melbourne and Javier Jimenez, Madrid on new statistical detection methods of turbulent superstructures and the connection of superstructures to smaller vortices and packages of vortices near the walls;
- Themistoklis Sapsis, Cambridge, USA discussed the role of large-scale extreme events for the global statistics in turbulent flows and presented new strategies to predict their appearance, which are based on the solution of an optimization problem.
- Jerry Westerweel, Delft gave a keynote presentation on the dynamics in the vicinity of turbulent/non-turbulent interfaces. Recent experiments and simulations determined the so-called viscous small-scale nibbling as the main mechanism of transport across sharp interfaces. These interfaces are considered as transport barriers that surround turbulent superstructures.

In addition to the 5 keynote talks, 13 contributed talks lasting 30 minutes and 11 short talks lasting 20 minutes were scheduled. There were also 10 poster presentations in a session during the first evening of the meeting. The schedule of the colloquium was set up so that there wassufficient time for mutual and group discussions during the breaks between the sessions and over meals. The outcome of these discussions was summarized at the end of the meeting.

Specific open topics and resulting future tasks were identified during the course of the colloquium, which can be grouped and summarized as follows:

- **Detection of turbulent superstructures**

Which Eulerian and Lagrangian methods are suited best to detect turbulent superstructures and which new experimental and numerical techniques are necessary to monitor the structures in space and time? How important are spatial and statistical symmetries for the detection of superstructures? Are there new tools to compress the information of vector and tensor fields which are derived from the flow modeling effectively? The Related talks were by: Marusic, Melbourne; Encinar, Madrid; Weiss, Göttingen; Scheel, Los Angeles; Bross, München; Oberlack, Darmstadt; von Larcher, Berlin.

- **Origin and mechanics of turbulent superstructures**

What is the dynamical origin of turbulent superstructures? Can they be traced back to exact coherent states and/or primary flow instabilities? How sensitively do turbulent superstructures depend on specific boundary conditions in the flow system? Are superstructures composed of a whole hierarchy of smaller-scale structures? How are superstructures connected to extreme events? Related talks: Jimenez, Madrid; Hwang, London; Wesfreid, Paris; Blass, Twente, Sapsis, Cambridge, USA; Pausch Marburg.

- **Transport by turbulent superstructures**

How much do turbulent super-structures contribute to the global turbulent transport? How important is the superstructure interface as a transport barrier? How precisely can the interface of a turbulent superstructure be resolved by Lagrangian methods? Related talks: Padberg-Gehle, Lüneburg; Karrasch, München; Öttinger, Zürich; Westerweel, Delft.

- **Reduced modelling and control**

What are efficient ways to reduce the number of degrees of freedom to describe superstructures? Which strategies can be applied to control turbulent superstructures, i.e. to stabilize such structures in a turbulent shear flow? Related talks: Schlatter, Stockholm; Feldmann, Bremen; Gerlach, Paderborn.

From this list of open points, it becomes clear that many questions which are related to turbulent superstructures are far from being completely answered. They will require further joint interdisciplinary efforts. There is now a priority programme on this subject, funded by the Deutsche Forschungsgemeinschaft.

Colloquium 586 was successful and fruitful. It provided a format which allowed us to summarize the current progress in the field and to generate new momentum and ideas for future research. The three organizers of the colloquium would therefore like to thank EUROMECH for making this colloquium possible.