EUROMECH Colloquium 591

" Three-dimensional instability mechanisms in transitional and turbulent flows"
18 – 20 September 2017, Bari, Italy

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It is still considered a remarkable fact that three-dimensional coherent motion develops in fluid flows at Reynolds numbers much smaller than the critical value for the rise of two-dimensional instabilities. This behaviour is recovered in simple parallel flows, such as pipes, boundary layers and channels, which are prone to subcritical transition, as well as in wall-bounded or open flows around solid objects of complex geometry, such as the flow over a roughness element or a wall cavity. It also occurs in fully turbulent flows, in which three-dimensional coherent structures such as streaks and hairpin vortices are repeatedly observed.

For the case of parallel flows, the presence of three-dimensional coherent structures and the consequent transition to turbulence has been interpreted recently on the basis of a simplified self-sustained cycle relying on simple modal and non-modal energy growth mechanisms, coupled through non-linearity. This self-sustained cycle has proved to be able to explain recurrent exact coherent structures of different types (equilibria, periodic orbit, and chaotic motions) which appear to form the backbone of transition. However, it is still unclear if and how this simplified theory can be extended to the case of fully turbulent flows, where coherent structures develop on top of random, chaotic fluctuations at different (outer and inner) scales, or even to the case of more complex flows in which the laminar solution is far from being parallel, such as three-dimensional flows around solid objects.
In these cases, three-dimensional modal or non-modal instability might develop and interact with each other, potentially sharing some features with the self-sustained coherent structures found for the simpler parallel flows.

The purpose of EUROMECH Colloquium 591 has been to bring together researchers studying the rise and development of instability mechanisms leading to three-dimensional flow structures in different shear flows, with the aim of trying to find some common features between the structures triggering or sustaining turbulence in such different cases. Deep knowledge of exact coherent structures in parallel flows, as well as the recent possibility of performing instability analysis on complex three-dimensional or fully turbulent flows, now make it possible to achieve such an ambitious goal.

These topics were discussed in depth during the 3-day long Colloquium 591, which brought together about 57 participants, 54 of them presenting their recent works in 20-minute talks. Three key-note lectures were given by:

- Denis Sipp, France;
- Dwight Barkley, UK;
- Matthew Juniper, UK.

During the conference, the discussions were grouped in different themes, listed and explained as follows.

- **Mean Flow and Resolvent**

In recent years, the question of performing stability analyses in turbulent flows linearizing the Navier-Stokes operator around the mean flow has become an important issue. Many presentations addressed this point by showing the latest developments in this topic and more particularly the use of the resolvent to evaluate the optimal response of a turbulent flow. This theme has shown considerable potential, especially for applications around the dynamics of jet flows and their control.

- **Subcritical Transition & Transitional and Turbulent Flows**

One of the objectives of Colloquium 591 was to bring together the "turbulence/sub-critical transition" community with the "linear instability" community. Many works have been presented on the computation of exact coherent solutions (ECS) of Navier-Stokes equations and the different connections between them, in particular concerning turbulent spot dynamics or the development of turbulent stripes in shear flows such as Couette, channel or Couette-Poiseuille flows. The first results have been shown on the role of optimal trajectories, in the sense of the energy of the system, in the dynamics around the ECS.

- **Modal and non-Modal Instabilities**

The set of presentations in the "modal and non-modal instability" sessions have shown that the related numerical methods are now sufficiently mature to be applied to highly three-dimensional flow configurations.

- **Wake Instabilities**

This session demonstrated the possible evolution of instability computation methods, especially around periodic solutions. The methods presented in the previously discussed session can now allow the computation of secondary instabilities, especially around forced or pulsed flows for complex geometries, which is the new point of current developments.

- **Rotating and Centrifugal Instabilities**

This session was a special application of the more general "Modal and non-Modal Instabilities" sessions. It mainly focused on the analysis of Goertler's instabilities for curvilinear geometries and more particularly their non-linear evolution until transition to turbulence.

- **Control and Reduced Models**

This last session showed a possible extension of stability and transition analyses to turbulence. In particular, the important transfer of knowledge and methods on modal decomposition, developed for several years to study instabilities, towards the construction of a reduced order model for flow control was demonstrated. A very impressive and promising example was shown by T. Colonius' team at Caltech on jet flows where DMD, POD and resolvent methods are used to develop efficient models for turbulent jet control.

The success of Colloquium 591 encourages us to continue with the aim of bringing together the "instability’’, “subcritical transition” and “turbulence" research communities. It would be interesting to repeat this conference in two or three years to evaluate the scientific evolution of these communities, and their upcoming interactions. We thank EUROMECH for making this meeting possible, and for all the financial and organizational support. More specifically, we thank Dr Sara Guttilla for her efficiency and availability.