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Preface

Unsteady separated flows and their control

This Special Issue represents papers selected by the Scientific Committee from amongst the oral presentations made at the IUTAM symposium on *Unsteady Separated Flows and their Control* held in Corfu, Greece, 18–22 June 2007, chaired by Marianna Braza and Kerry Hourigan. This was the second IUTAM symposium on this subject, following the symposium in Toulouse, in April 2002.

The symposium consisted of single plenary sessions with invited lectures, selected oral presentations, discussions on special topics and posters. The complete set of papers was provided to all participants at the meeting. A detailed list of all presentations is included in a latter section of this Issue. The topical sessions at the symposium had the following titles:

- Experimental techniques for the unsteady flow separation
- Theoretical aspects and analytical approaches of flow separation
- Instability and transition
- Compressibility effects related to unsteady separation
- Statistical and hybrid turbulence modelling for unsteady separated flows
- Direct and large-eddy simulation (LES) of unsteady separated flows
- Theoretical/industrial aspects of unsteady separated flow control.

The recent IUTAM symposium concerned an important domain of theoretical and applied mechanics nowadays. It focused on the problem of flow separation and of its control. It aimed at achieving a unified approach which regroups the knowledge coming from theoretical, experimental, numerical simulation and modelling aspects for unsteady separated flows with respect to incompressible and compressible regimes and to efficient control devices to achieve attenuation or suppression of separation. The subject areas covered important themes in the domain of fundamental research as well as in the domain of applications. These topics received a great deal of impetus from international research groups, including major research institutes and industrial companies especially in aeronautics in various countries and by leading government programs. This symposium brought together groups of researchers working on the problems related to the understanding of the prediction and control of unsteady, separated flows. The meeting addressed physical aspects of the dynamics of unsteady separation, as well as the state-of-the-art of methods for modelling this kind of flow at high Reynolds numbers. The physical understanding of the dynamics for the purpose of efficient turbulence modelling of unsteady separated flows is a serious problem in a number of engineering applications, including aeronautics, aeroelasticity, space and land vehicles. A round table discussion took place on Monday 18th June between the IUTAM symposium participants and those of the symposium "Hybrid RANS-LES methods", 17–18 June.

Scientists working in the experimental investigation of unsteady separated flows, and those working in the numerical simulation and turbulence modelling of these flows attended this symposium, stimulating discussion and advancing the knowledge of the related physical mechanisms. In this way, the symposium contributed to a better insight of this important category of flows from a fundamental and applied research point of view, by means of a synergy between the three main approaches: theoretical, experimental and prediction methods. The main objectives of this symposium, summarised below, were fulfilled. Among the invited *seventeen lectures*, two were devoted to provide the major outcomes from the European research programs in aeronautics, dealing with unsteady separated flows, the detached eddy simulation for industrial aerodynamics (DESIDER) and the unsteady effects in shock wave-induced separation (UFAST). Seventy-six oral presentations and six poster sessions were included in this Symposium. A "best-poster award" was attributed by the Scientific Committee during the gala dinner, held in the Achilleion Palace and Museum.

The presentations consisted of Invited Keynote Lectures, and papers in the topical sessions listed on the previous page. Some of these presentations, duly updated, may be found in this Special Issue.

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The significant outcomes of the symposium are the following.

Advances in the physical knowledge of the unsteady separated flows are achieved by means of particle image velocimetry (PIV) (especially the three-component PIV and time-resolved PIV as well as simultaneous combination of both) that provides a detailed physical analysis of the unsteady separation and of the detached flow around fixed and moving body configurations.

A great number of theoretical, numerical and experimental studies were devoted to the instability, transition and control of unsteady separation, including also the physics of compressibility. Among these aspects, the instability and transition related to vortex-induced vibrations (VIV), wall rotation effects and dynamic stall were an important issue in the topic, as well as analytical approaches that are able to capture and evaluate the separation. Configurations of cylinders in tandem, of elliptical cross-section cylinders, of oblate freely rising bodies, of impulsively starting motion around bluff bodies, and of flows around curved or tapered cylinders and spheres were considered. An original issue of the symposium related to this topic was the numerical study of flexible bodies leading to a very complex wake structure in the context of fluid–structure interaction.

A detailed insight of the sensitivity to external disturbances has been presented for separated boundary layers, leading edge separation on slender airfoils at incidence, separation associated with wall jets and in channels enforced by suction. Asymptotic analysis in the limit of large Reynolds number proved that the marginal-separation equations govern these vastly different situations. A novel separating shear layer scaling has been deduced from the unsteady motion and the first analytical and numerical results were produced, representing the rotational/irrotational interaction of the separating shear layer with the external potential flow. Furthermore, amplitudes causing bubble bursting have been evaluated and found to increase with increasing forcing frequencies, as observed experimentally. The transverse instabilities in separating boundary layers have been studied based on the perturbed Navier–Stokes system using Floquet theory. The stability and sensitivity of separated flows past freely moving disks, orbiting cylinders and in lid-driven cavities have been investigated, as well as the axisymmetric absolute instability of swirling jets. New analytical approaches in 2-D and 3-D and Navier–Stokes simulations have been presented for flows in vascular vessel bifurcations involving wall flexibility, and the role of separation associated with the longer or shorter length scales has been studied. The influence of 3-D perturbations in the stability of 3-D-separated flows has been analytically studied for subsonic and supersonic flows, as well as the receptivity of separated boundary layers to external sound waves.

Furthermore, compressibility effects on unsteady separation have been investigated by experimental, theoretical and numerical approaches, for transonic and supersonic flows. In particular, the unsteady shock–boundary layer interaction (SBWLI) and consequent separation have been analysed. The proper orthogonal decomposition (POD) approach has been of significant impact in analysing the organised modes yielded from SBWLI. The buffeting phenomenon was the object of a number of successful presentations. Efficient reduced order modelling (ROM) for compressible and incompressible flows have also been presented. The organised modes development due to the compressibility effects and the Bénard–von Kármán instabilities interacting with buffet modes and their control have been studied in detail. The analysis of these effects is an important outcome of the symposium, contributing to the fundamental research of compressibility phenomena arising in aeroelasticity.

Significant advances in the flow physics of unsteady separation have also been achieved by using direct numerical simulation (DNS) and LES in the low and moderate Reynolds number ranges. A number of DNS studies have analysed the unsteady separation and instability modes around bluff bodies and wings, as well as separation in biomechanical flows (aneurysms).

Concerning turbulence modelling, in the context of LES, the regularisation subgrid modelling approach and the Variational Multi-Scale approach (VMS) have been investigated, as well as applications of LES and DNS for SBWLI analysis. Considerable achievements in the prediction of high Reynolds number unsteady separated flows have been made by using the DES and adapted/modified statistical turbulence modelling approaches in the context of unsteady Reynolds averaged Navier–Stokes (URANS) concerning both academic unsteady flows around bodies as well as flows around real aircraft configurations. Advanced statistical turbulence modelling was presented, sensitive enough to capture the coherent structures (organised eddy simulation (OES)) and involving the anisotropic eddy-viscosity concept. In the context of hybrid approaches, the embedded hybrid RANS–LES, the hybrid RANS–VMS and the DES involving algebraic-stress modelling for the RANS part were investigated. Among the configurations considered, the Boeing 777 nose-gear cavity, wing–body junction flows, dynamic stall wings as well as cavity flows including those of the stratospheric observatory (infrared astronomy—American–German research program SOFIA) were presented.

The control of flow separation has been achieved by using electromagnetic forcing, plasma actuators, piezoelectric actuators and surface plasma. Vortex shedding control has been achieved by synthetic jets and vortex generators (VGS) and spanwise sinusoidal perturbation (SPPM). Efficient passively controlled studies by means of LES have been presented, concerning transonic cavity flows, as well as passive drag control of turbulent wakes. Biomimetic flows around fish and natural flyers have been studied and optimised by flow control. Flow control of unsteady separation in

bluff bodies undergoing VIV has been achieved by small vibrating rods, active/passive ventilation methods, and rotational control. Small rotating rods have also been used for control of vortex breakdown in a closed cylinder. The flow mechanisms employed in actively controlled, fish-like bodies are investigated to optimise their locomotion and maneuvering performance. Concerning biomimetics, the hydrodynamics of beating cilia has been investigated by DNS involving immersed boundary method and the PALM coupler. This approach is useful for the control (passive or active) of the boundary layer flow for the suction of airfoils using a ciliated wall. Flow-forcing techniques, as well feedback-stabilisation techniques, were also efficiently used for separated bluff bodies. Stochastic feedback flow control has been applied to flexible flapping wing emulating natural flyers, to create thrust and reduce drag. The optimisation of separated flow control has also been achieved by adjoint equations, as well as robust closed-loop control methods applied to high-lift devices and sub-optimal control approaches applied in separated channel flows. In the context of feedback-control strategies, the approach of linear proportional control has been applied in the flow over a sphere. A new strategy, ''Multiscale retrograde estimation and forecasting of chaotic non-linear systems'', concerning multiscale complexity and model uncertainty, has been presented. The ensemble of these aspects constitutes major outcomes of the symposium concerning the state-of-the-art for control devices to attenuate/suppress instabilities and unsteady separation.

A most challenging future direction of research coming from the state-of-the art works examined in this symposium is the prediction of turbulent unsteady separated flows around bodies at high Reynolds number, also involving the complex phenomenon of fluid–structure interaction. By means of the works presented in this symposium, it has been seen that the experimental, DNS and LES approaches of complex unsteady separated flows have proven very promising, despite the fact that the two latter ones are limited in the relatively low Reynolds number range. This difficulty is overcome by having associated URANS and LES in the context of hybrid turbulence modelling. These approaches provide a very useful panel of complex flow physics to model unsteady separated 3-D flows in the high Reynolds number regime, which is of high interest to industrial applications. Therefore, a major outcome of this symposium concerning the future issues is the fact that there is a need for increasing the knowledge of unsteady flow physics by the synergy of well-focused physical experiments in the higher Re-range (e.g., tomographic PIV) and by the knowledge coming from the DNS and LES studies. These efforts will contribute to the improvement of the above-mentioned modelling methodologies in the higher Reynolds number range, to increase the predictive capabilities of strongly detached flows and especially of the fluid–structure interaction phenomena around moving and deformable bodies. These topics are of a significant interest for applications in the domain of Vortex Induced Vibrations (VIV) in unsteady aerodynamics and in aeroelasticity.

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This IUTAM symposium was held in the Chandris Hotel of Dassia-Corfu, in the main conference room "Odysseas" of the hotel, located on a very nice coast of the Ionian Sea at Corfu. A friendly atmosphere was created among the participants, helped by the organisation of two social events, the cocktail and buffet-dinner on Monday 18th June, at the beach, jointly organised by the IUTAM symposium and the statistical-hybrid one and the gala dinner on 20th June in the superb "Achilleion Palace and Museum", that was open for visiting by all the participants.

A general impression from this symposium was that the scientific communities working on experimental, theoretical and numerical approaches related to the unsteady separation and its control have learned a lot from one another and the meeting has brought new research ideas to everyone.

Marianna Braza
Institut de Mécanique des Fluides, UMR-CNRS-No 5502,
Allée. Du Prof. Camille Soula, 31400 Toulouse, France
E-mail address: Marianna.Braza@imft.fr

Kerry Hourigan
FLAIR, Department of Mechanical and Aerospace Engineering,
Division of Biological Engineering, Monash University, Clayton Campus, Victoria 3800, Australia
E-mail address: kerry.hourigan@eng.monash.edu.au

Participants of the IUTAM Symposium "Unsteady Separated Flows and their Control" in the garden of the hotel "Chandris"—Corfu. Friday 22nd June 2007.