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Testing in Aerospace Research: Introduction

The ONERA's 70th anniversary is an opportunity to ask ourselves about the place and evolution of research in the field of aerospace, especially in terms of needs and means. A key topic of these reflections is obviously the contribution of testing activities. Originally involved in all of the developments, they progressively had to face more complex requirements, as well as the emergence of competing approaches, mainly based on computation capacities and engineering methods. In this context, the 12th issue of *AerospaceLab Journal* offers an overview of the evolution of testing in various scientific domains concerned by aerospace developments: facilities, methods, instrumentation, processing, performance, exploitation of data, new fields of research involved, etc. The purpose is to assess the future use of testing, either as the best or as the only way to meet a specific requirement, such as equipment certification for instance, or as a complementary approach to other methods, including their validation or hardware in the loop analysis.

As quoted by Henri Poincaré in *La Science et l'hypothèse* (1908): "The man of science must work with method. Science is built up of facts, as a house is built of stones; but an accumulation of facts is no more a science than a heap of stones is a house". Such a quote is a good introduction to this special issue, which strives to illustrate both the primary need for experiments in aerospace research and also the need to stand back from the experiences: in conceiving it and in exploiting its results as well. This also encompasses all of the efforts and imagination that have to be deployed in order to build measurement or observation instruments, and to gain more benefit from the experiments by using or deriving improved methods for data or signal processing. Contributions using the inverse problem approach must also be recognized. Beyond the response to the need for understanding, modeling, establishing reference physical parameter values, etc., the development of more accurate instruments, more precise data processing techniques and even new physically-based devices has led over the last years to a great transfer towards industry.

This special issue dedicated to testing in aerospace contains fifteen papers gathering the contributions of more than ninety researchers. It covers the research and development activities of the four branches at ONERA: Materials and Structures, Fluid Mechanics and Energetics, Physics and Information Processing, and Systems, through numerous research projects and overviews covering several scientific Branches.

The first paper [*Inverse Problems and Experiments: a Fruitful Symbiosis*] strives to identify the mutual benefits that experiments and inverse problems have gained by working together, and exemplifies it with general linear problems in signal processing and two examples of image-based identification problems.

Then, a set of four papers addresses the field of mechanics. In the first one [*On Recent Advances in Microstructural Characterization and In-Situ Testing Techniques to Study Material Behavior*], an overview is provided of recent experimental techniques to characterize the microstructure and to measure the deformation of metallic materials. Some of the most promising characterization, measurement and identification techniques and methods used to develop, calibrate and validate physics-inspired constitutive models are discussed, with examples. Notably, the individual use of traditional interferometry is now clearly on the way to be replaced by the combined use of techniques based on image correlation (2D and 3D), *in-situ* and *ex-situ* scanning electronic microscopy (SEM), or EBSD, among others. The great potential offered by the combination of in-situ techniques at different scales with real-time computations is presented. The next paper [*Combined Experimental and Modeling Approaches for Strength Analysis of 3D Woven Composites: From Elementary Coupons to Complex Aeronautical Structures*] illustrates the combined approach of experimentation and modeling for strength analysis of composite materials and structures. Namely, dealing with new generation woven composites; it shows how multi-instrumented tests at various scales can be used in order to understand, model and validate the various damage mechanisms encountered both at the material level and at the structure level, up to the scale of industrial components. The thermal and mechanical fatigue of single crystal superalloys is addressed in the third paper [*Complex Thermo-Mechanical Approaches to Study the Behavior of High-Temperature Alloy*], based on complex torsional thermomechanical fatigue testing, including thermal gradient, which enables the severe thermomechanical in-service conditions acting on thermal barriers and modern air cooling gas turbine blade technologies to be reproduced. Thanks to a precise control of induction heating, it is possible to validate a complex constitutive model for thermal and mechanical fatigue,

including overheating effects, and to address the creep-fatigue interaction mechanism. The last paper [*Aircraft Ground Vibration Testing at ONERA*] describes the ground vibration testing techniques, past, present and future, deeply involved in the development of new aircraft, especially for avoiding (or determining the flight domain without) flutter.

This leads naturally to aerodynamics, again with four papers. In [*Testing in Aerodynamics Research at onera: the Example of the Transonic Buffet*], thirty years of combined experiments, modeling and computations at ONERA are detailed. It recalls the progress made in the deep understanding of the fundamental phenomenon of transonic buffet and the development of simulation capabilities. Among the different perspectives, the use of data assimilation techniques is identified as the most promising for the experiment-computation dialogue. Then, the paper [*Planar Particle Image Velocimetry for Aerospace Research at ONERA*] addresses the technique with the most striking progress for the study of aerodynamic flows in experimental setups over these last years. However, environmental conditions are also of primary importance to manage, and Lidar is a very precious tool to understand and measure atmospheric hazards, such as turbulence, wind shear or wind gust, and also induced hazards such as wake vortices. The paper [*Doppler LIDAR Developments for Aeronautics*] exposes recent developments at ONERA, giving some insight into the state of the art, as well as perspectives for future applications in aeronautics, such as the optimization of the separation distance between aircrafts in runways. The last paper [*Experimental Fluid Mechanics goes 3D: New Numerical Methods for Quantitative Instantaneous 3D Imagery of Fluids*] emphasizes the pointwise character of particles in PIV, in contrast with classical Tomo-PIV approaches, namely on the modeling of the imaging process, reconstruction of the 3D volume of particles and estimation of the 3D motion field between two time instants. Next, the 3D-BOS (Background Oriented Schlieren), which is aimed at estimating the instantaneous 3D density field of a moving fluid, is addressed in a new one-step numerical approach. Finally, important perspectives are drawn, especially for the study of compressible flows by combining both techniques

Turning now to physics, the first of a sequence of three papers [*Ro-Vibrational Spectroscopy in Hybrid fs/ps-CARS for N₂ Thermometry*] addresses the coherent anti-Stokes Raman scattering methodology for the thermometry of N₂ in combustion chambers of aeronautics gas-turbines. The method and instruments have been enhanced, both with regard to robustness, which now enables real-life combustion chambers to be dealt with, and with regard to the repetition rate, which now reaches 1 kHz, a magnifying factor of 10 to 100 with respect to existing devices. The second paper [*Gravitation and Geodesy with Inertial Sensors, from Ground to Space*] reminds us of the dramatic change in the perception of Earth's gravity that has taken place since

the beginning of this century. Thanks to past spatial missions like CHAMP, GRACE and GOCE, we have changed our mind in considering the Earth's gravity field and its measurement, using dedicated sensors and adequate data processing, revealing the changes of the Earth's field as a true signal, rather than perturbing terms added to the geostatic reference field. The development of ultraprecise instruments at ONERA has given rise to fundamental science applications like in the MICROSCOPE mission, where Einstein's Principle of Equivalence will be tested with an unprecedented accuracy, or to ground applications with the atomic interferometer for positioning marine vessels within the gravity field on the globe. The last article of this series [*Radiation Testing of Electronics Systems: How Can Simulation Tools Help in the Definition and Optimization of Test Plans in Labs?*] addresses a major concern related to on-board space systems: exposure to harsh environmental conditions, including radiation, extreme temperatures and a high vacuum. The wide diversity of observed disruptions, potential anomalies (and thus physical-chemical mechanisms behind them) and the large set of technologies involved, require the development of modeling tools to support experimentation, in order to achieve a representative simulation of device response and a reliable prediction of life mission, and to limit costly ground testing.

The interaction between modeling and experiment, between sensing the environment and acting on systems, can be exemplified by the last set of three papers. The paper [*Dealing with Complexity through Advanced Control Techniques*] deals with the control of complex dynamic systems encountered in aerospace, both with regard to their behavior and to their mission, through the implementation of multi-loop control architectures based on information on the system internal state and on its environment. In order to design "task" level control primitives, which take place just above the previous control loops, it is essential to combine sensor-based robust and non-linear control techniques, together with information on the environment, extracted from exteroceptive sensors in order to adapt system behavior to uncertainties and perturbations. The paper [*Surrogate Models for Aircraft Flight Control: Some Off-Line and Embedded Applications*] focuses on the need for surrogate models for applications that cannot afford high-fidelity simulation, and the various techniques that enable these models to be built from HF simulation results or sensing data. Beyond the environment, the last paper [*Component-Based Simulation for Real-Time Experiments of Advanced Aerospace Systems*] addresses concerns about the role of the human arising in human-in-the-loop system architecture.

After this quick overview of the articles in this issue, the extent of the spectrum of the applications and the importance of experiments in the aerospace domain now appears clear, although it cannot claim to be exhaustive ■