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Aeroelasticity and Structural Dynamics

The fourteenth issue of AerospaceLab Journal is dedicated to aeroelasticity and structural dynamics. Aeroelasticity can be briefly defined as the study of the low frequency dynamic behavior of a structure (aircraft, turbomachine, helicopter rotor, etc.) in an aerodynamic flow. It focuses on the interactions between, on the one hand, the static or vibrational deformations of the structure and, on the other hand, the modifications or fluctuations of the aerodynamic flow field.

Aeroelastic phenomena have a strong influence on stability and therefore on the integrity of aeronautical structures, as well as on their performance and durability. In the current context, in which a reduction of the footprint of aeronautics on the environment is sought, in particular by reducing the mass and fuel consumption of aircraft, aeroelasticity problems must be taken into account as early as possible in the design of such structures, whether they are conventional or innovative concepts. It is therefore necessary to develop increasingly efficient and accurate numerical and experimental methods and tools, allowing additional complex physical phenomena to be taken into account. On the other hand, the development of larger and lighter aeronautical structures entails the need to determine the dynamic characteristics of such highly flexible structures, taking into account their possibly non-linear behavior (large displacements, for example), and optimizing them by, for example, taking advantage of the particular properties of new materials (in particular, composite materials).

This issue of AerospaceLab Journal presents the current situation regarding numerical calculation and simulation methods specific to aeroelasticity and structural dynamics for several applications: fan damping computation and flutter prediction, static and dynamic aeroelasticity of aircraft and gust response. Moreover, articles present results on smart morphing structures for airplanes. Other papers present the latest progress in terms of structure design and critical load assessment. Finally, articles present recent results relating to structural damping modelling and the non-linear behavior of structural assemblies, to the development of structure optimization algorithms taking into account uncertainties, to the development of vibration control devices and to the crashworthiness of aeronautical composite structures.

Structural dynamics is a wide scientific domain covering a very large range of applications such as structure vibrations, crash and impact, structure damping, vibroacoustics and so on. Aeroelasticity is strongly linked to the subdomain of the structural dynamics dedicated to the low frequencies. It can be briefly defined as the study of the dynamic behavior of a structure (aircraft, turbomachine, helicopter rotor, etc.) in an aerodynamic flow, or, according to the author of the famous aeroelastic triangle [3] (Figure 1), as "*the study of the mutual interaction that takes place within the triangle of the inertial, elastic and aerodynamic forces acting on structural members exposed to an airstream, and the influence of this study on design*" (A. R. Collar, 1947). Though Dutch windmill manufacturers empirically solved blade aeroelastic problems four centuries ago by moving the front spar from the mid-chord to the quarter-chord position [5], aeroelasticity is a rather recent discipline that arose with the first flight attempts (e.g. the second attempt of S. Langley in 1903 failed probably due to a static torsional divergence instability) [5]. After the success of the Wright flight, it was mainly biplanes that were developed in order to ensure a high torsional stiffness of the wings, but some aircraft as the Handley Page 0/400 bomber and the DH-9 still experienced tail flutter instabilities. One of the earliest documented cases mentioning failure resulting from the static interaction between the air flow and the wing deformation is that of the monoplane Fokker D-8, developed for its superior performance compared to biplanes during World War 1.

The aeroelasticity scientific domain has grown up alongside the aviation boom, especially during and after World War 2, with the increasing flight speed of the aircraft. It now concerns all aeronautical applications (aircraft, turbomachines, helicopters, launchers, missiles) as well as others such as wind turbines, bridges and buildings [4].

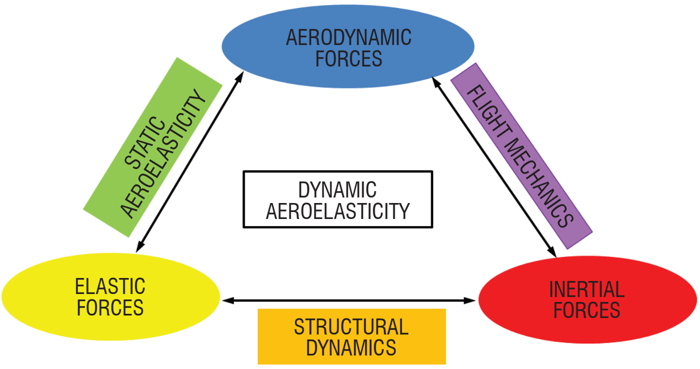

Figure 1 – Collar's representation of forces occurring in aeroelastic phenomena

Aeroelasticity used to be taken into account at a late stage of an airplane design, to check its stability. But today aeronautics has to drastically reduce its impact on the environment. One way to reach this goal is to decrease fuel consumption. For this purpose, a considerable effort is made to decrease the weight of the structures, which thereby tend to become more flexible. Furthermore, numerous new concepts of aircraft such as low sweep angle and high aspect ratio wing, laminar wing, highly flexible wing and strut braced wing, to mention just a few, are being developed to improve aerodynamic performance. But these new concepts tend toward lighter and more flexible wings. Therefore today aeroelasticity has an increasing influence on the design and has to be taken into account at earlier or even preliminary stages, not only to check the stability of the airplane design but also to compute its actual aerodynamic performance, the control surface effectiveness, and so prevent its reversal, and of course to verify both the static (static divergence) and dynamic (flutter) stabilities. Multi-disciplinary design and optimization methods are currently being developed to simultaneously determine the aerodynamic shape and the structural stiffness taking into account interactions between the aerodynamic flows and the structure [8] [1]. Garrigues *et al.* (AL14-09) presents a review of the aeroelastic practices at Dassault Aviation and shows the evolution of the role of aeroelasticity in aircraft design.

This issue of the AerospaceLab Journal presents a global overview of different activities required for aeroelastic analyses. Since aero-elasticity implies fluid-structure coupling, it is necessary first of all to be able to model and analyze the dynamic behavior of structures. The modelling of linear structure using finite element approaches is today of common practice for aeroelastic analyses. But aeronautical structures are most often non-linear owing to clearance and impact or friction for example. Kehr-Candille (AL14-04) is interested in the sources of non-linearities that result from a junction of two substructures, and proposes a numerical model of the damping occurring at such a junction. Stephan *et al.* (AL14-08) develops a new technology of nonlinear energy absorber aimed at mitigating the vibrations of real-life structures, and at thereby improv-ing their behavior in terms of lifetime, stability and user comfort. The last structural aspect addressed by this issue is the growing use of composite material in aeronautics over the last few years.

Such materials imply a different dynamic behavior due to their orthotropic constitutive laws and their low density, than that of structures made of metallic isotropic materials. Deletombe *et al.* (AL14-11) presents a bibliographic review on the crashworthiness of aircraft and helicop-ters made of composite material. This article deals with both numeri-cal and experimental studies.

Aeroelasticity is also concerned with the assessment of loads that apply to an airplane during the different flight phases. The article by Krueger *et al.* (AL14-01) presents the current situation regarding load computations aimed at structure design and certification. The process of identifying and assessing the different loads is complex but necessary to identify those which are critical for the structure sizing. These loads essentially result from flight or ground manoeuvers and from gust or air turbulence. They have to be assessed using numerical simulations and experimental ground and flight tests.

Aeroelastic analyses imply fluid-structure coupling simulations. Most often, in the case of aircraft design, such simulations used to be carried out using a loose coupling formulation: A reduced model of aerodynamic forces is first built from responses to harmonic motions, responses usually computed using low fidelity aerodynamic solvers. This aerodynamic model is then used to compute and update the aerodynamic forces that apply to the structure within the structural equation resolution process. Most of the theories about the aerodynamics of a wing were based on linear or potential flows [2]. However, current aircraft cruise speeds are subsonic but close to Mach 1, a flight regime for which the aerodynamic flows are non linear (transonic regime with shocks on the wing). Therefore, a higher fidelity of aerodynamic modeling is required to capture non-linear phenomena such as shock and flow separation. Fluid-structure coupling is nowadays performed using CFD (Computational Fluid Dynamics) methods and tools for aerodynamic force evaluation. Furthermore, CFD has led to the solving of the coupling in the time domain (also called "strong" coupling), *i.e.* a balance between the structure deformation and the aerodynamic forces is computed within each time step of a time consistent resolution. Dugeai *et al.* (AL14-03) presents a review of aeroelastic simulation methods based on CFD applied to turbomachines. Huvelin *et al.* (AL14-06) describes gust response and gust load alleviation simulations using CFD methods with comparisons with wind tunnel experiments.

Current research is focused on the development of more robust aeroelastic methods aimed at taking into account uncertainties in aeroelastic simulations or optimizations. The origins of these uncertainties may be of a structural nature, for example the manufacturing tolerance or the dispersion of the mechanical characteristics of composite materials, or they may be of an aerodynamic nature (flight angle of attack, velocity or altitude). Chassaing *et al.* (AL14-07) presents advances in the development of aeroelastic stochastic solvers to improve the robustness of the flutter critical velocity evaluation. Poirion *et al.* (AL14-05) proposes a stochastic method for gradient computations aimed at aeroelastic optimization, and thereby at improving the robustness of aeroelastic design.

The last topic addressed in this issue of AerospaceLab Journal concerns the morphing of aeronautical structures. One of the main challenges of the aeronautical community is to reduce its impact on the environment and on climate change. One idea therefore is to imitate birds, and consists in adapting the shape of the structure to the flight conditions and to the aerodynamic load in order to improve the aerodynamic performance for the whole mission and to decrease the structure weight, thus allowing a reduction of the consumption and the release of polluting gases. Liauzun *et al.* (AL14-10) presents an assessment of morphing winglet concepts aimed at decreasing the aerodynamic load that applies to the wings and thereby at improving the aeroelastic behavior of the aircraft. Botez *et al.* (AL14-02) shows recent advances concerning the development of morphing wings with the objective of improving aerodynamic performance.

Only some aspects of aeroelasticity have been addressed in this issue. Although aeroelasticity started with observations that structures sometimes collapsed and mechanical engineers then reinforced their stiffness, it has become a multi disciplinary science that nowadays benefits from advances in numerous scientific domains: aerodynamics, numerical simulations, high performance computing, material and structure modelling, as well as experimental facilities and methods (e.g. large high speed wind tunnels, ground vibration tests [6]) and measurements [7] [9]) as can be seen in Aerospacelab Journal issue 12. All these advances are currently leading and will lead in the future to the identification, understanding and a better knowledge of more complex phenomena resulting from fluid-structure interactions. Notable examples are Limit Cycle Oscillation (LCO), which has an impact on the fatigue of structures, interactions in buffet conditions and structure behavior in a laminar-turbulent transitional flow that occurs on laminar wings, which is studied in order to decrease drag and consumption. On another hand, advances in composite materials allow the aeroelastic tailoring, or in other words the possibility of taking advantage of the structure flexibility instead of fighting it, in order to improve the structure behavior. All these scientific advances will lead to a more optimized aircraft design for the whole flight envelope, especially close to its boundaries ■

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