AERODYNAMIC AND AEROELASTIC CHARACTERIZATION OF A FORWARD-SWEPT, LAMINAR AIRCRAFT WING UNDER REALISTIC FLIGHT CONDITIONS

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ABSTRACT

The need for reducing one's emissions is commonly shared among many organizations within the aerospace industry. Among other strategies, one approach is to develop novel wing designs that may offer improved lift and drag characteristics, thus being aerodynamically more efficient. In that regard, forward-swept wing (FSW) configurations are receiving renewed attention [1], [2], [3] owing to their potential advantages in aerodynamic performance – e.g., improved lift distribution, delayed stall, lower induced drag – compared to conventional backward-swept wings. In particular, when combined with airfoil shapes that feature a naturally laminar flow (NLF), these benefits can be amplified: by minimizing skin friction drag associated with maintaining extensive laminar boundary layers, an FSW configuration may achieve higher aerodynamic efficiency, overall. At this stage, it is worth noting however that FSWs come with aeroelastic challenges, specifically the risk of torsional divergence due to outboard bending-torsion coupling. To investigate these aerodynamic and aeroelastic characteristics, a forward-swept wing configuration with a naturally laminar flow design has been experimentally tested under realistic flight conditions. A wide range of advanced metrology means were employed to capture aerodynamic loads, accelerations, as well as flow characteristics (e.g., transition behavior), whether the model is kept at a steady angle of attack or is applied a forced dynamic pitch motion using a state-of-the-art pitching oscillator. The work presented here is part of the German Aerospace Research Programme (Luftfahrtforschung, LuFo) VI/1 and VI/2 projects "Wing Technology Validation for Ultra Green Aircraft" (ECOWING-D) and "Ultra High Efficient Wing and Movables for Next Generation Aircraft" (ULTIMATE).

As part of these projects, several experimental campaigns are conducted in the European Transonic Windtunnel (ETW), which is a closed-vein, closed-circuit wind tunnel whose test section extends over 2.0 m (H) × 2.4 m (W) × 9.0 m (L) – see Fig. 1. Within the test vein, transonic, high-Reynolds-number flow conditions can be achieved on a model-scale aircraft wing due to the cryogenic nature of the wind tunnel. More specifically, the tunnel is operated using nitrogen gas, which is injected downstream of the test section in its liquid form with temperatures of approximately $T = 110$ K (see Fig. 1-a). Owing to these low gas temperatures, and coupled with the high-speed flows, a scaled-down aircraft wing model can realize realistic, full-scale flow conditions (i.e., in both, Mach number and chord-based Reynolds number). The so-called *NLF-ECOWING-FSW* configuration tested here is a forward-swept, semi-span wing model with naturally laminar flow design that is mounted on the tunnel wall via a fuselage and belly fairing (see Fig. 1-b). The wing is equipped with large number of sensors, among which steady and unsteady pressure sensors as well as acceleration and temperature sensors. In addition, the planform is coated with four patches of cryogenic temperature-sensitive paint (cryoTSP [4]), which are employed to capture laminar-to-turbulent transition characteristics. In

addition, several stereo pattern tracking (SPT) markers are placed onto the model surface to capture wing deformations. An extensive test matrix was explored, including various Mach numbers, ambient temperatures and pressures, thus resulting different chord-based Reynolds numbers. In addition, the model incidence was varied in a static as well as dynamic fashion.

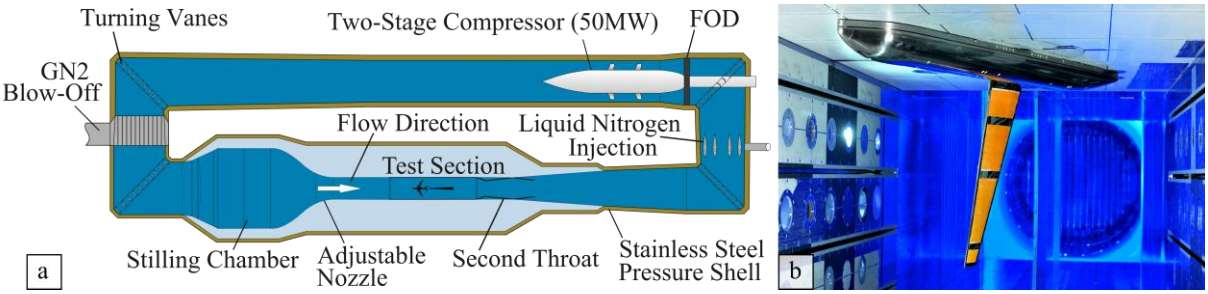

Figure 1: Schematic of the ETW (left, copyright ©ETW) and the FSW-NLF wing model with a fuselage and belly fairing installed in the test section (right, copyright ©ETW/Airbus/DLR).

Unsteady pressure coefficients are measured at three spanwise wing cross-sections when the model is applied a pitch oscillation of ±0.5° at an inflow speed of $M = 0.78$ and a chord-based Reynolds number of $Re_c = 10\times10^6$, which are depicted in Fig. 2. As can be seen, the wing model exhibits different shock behavior (in location and strength) across the span, which is indicated by the abrupt drop in pressure coefficients, as well as the increased pressure fluctuations. The influence of these shock characteristics alongside the pressure fluctuations will be discussed in comparison with the wing's dominant structural eigenfrequencies which are shown next.

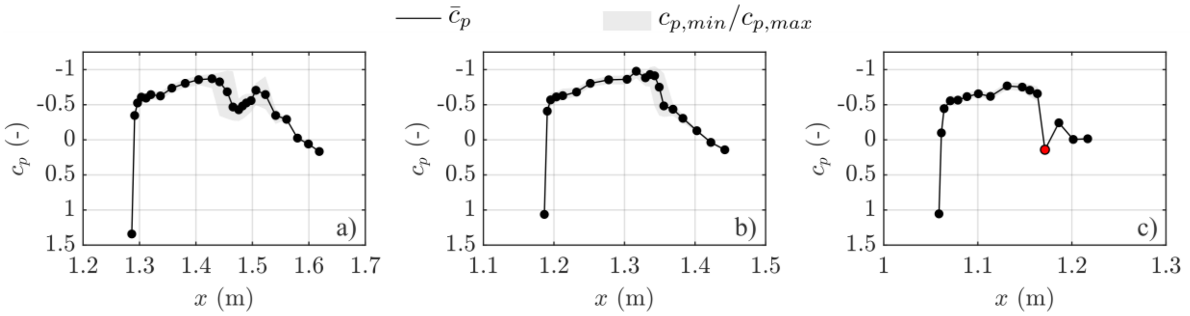

Figure 2: Chordwise unsteady pressure coefficients obtained at an inboard (a), midboard (b), and outboard (c) spanwise position when the model is set at an incidence of 1°, applied a forced pitch oscillation of ±0.5°, and exposed to flow conditions of Mach number $M = 0.78$ and Reynolds number $Re_c = 10\times10^6$. The red marker indicates a defective sensor.

Figure 3 depicts the frequency spectrum corresponding to the FSW model for the above test conditions, indicating its dominant structural eigenfrequencies. For instance, the first and second bending mode are seen to occur at $f_{s1} \approx 26$ Hz and $f_{s4} \approx 116$ Hz, whilst the first torsion mode is found at $f_{s6} \approx 272$ Hz. A more detailed investigation of the aeroelastic properties of the FSW configuration under various test conditions will be discussed in the paper to come.

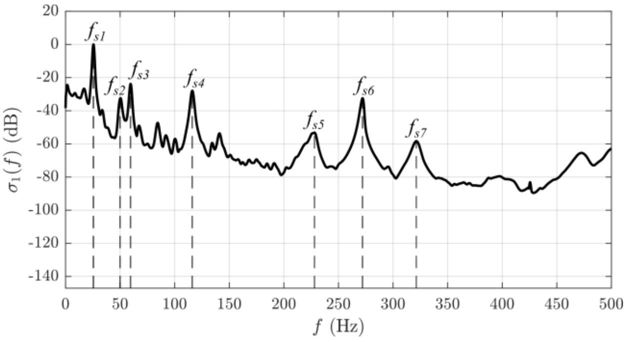

Figure 3: Frequency spectrum of the wing model indicating its dominant structural eigenfrequencies (here shown from $f_{s1\text{-}7}$), as obtained from the acceleration sensors installed across the wing planform.

References

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