DESIGN OF A SWEPT WING MODEL FOR THE INVESTIGATION OF SEMI-ACTIVE FLUTTER SUPPRESSION IN TRANSONIC FLOW

Jens Nitzsche*, Johannes Dillinger, Jan Himisch, Moritz Schmidt, Diliana Friedewald

Institute of Aeroelasticity, German Aerospace Center (DLR), 37073 Göttingen, Germany*
jens.nitzsche@dlr.de

ABSTRACT

Introduction

Future transport aircraft configurations are expected to employ increasingly slender, high-aspect-ratio wings to improve aerodynamic efficiency. In such designs, flutter often emerges as a critical constraint in the transonic regime, which is characterized by the so-called *transonic dip*, i.e. a pronounced local minimum of the flutter boundary as a function of Mach number.

From a design perspective, it is highly desirable to locally alleviate or shift this transonic dip without fundamentally altering the wing geometry or structural layout. In this context, passive (or semi-active) aerodynamic measures offer a compelling alternative to complex active control systems. By modifying the stationary mean flow field, these measures enable a configuration shift from a performance-optimized but flutter-critical wing to a more conservative, flutter-stable configuration at high Mach numbers.

Recent numerical studies based on 2D RANS have shown that localized, small-scale airfoil geometry modifications – specifically contour bumps – can significantly shift the flutter boundary toward higher dynamic pressures [Nitzsche et al., 2022]. However, convincing experimental evidence for such effects remains scarce, particularly for swept 3D wings. Furthermore, the limited availability of high-quality experimental transonic flutter data continues to challenge the validation of advanced CFD-based aeroelastic methods. The present work addresses both gaps.

Experimental Concept

This paper presents the numerical design of a swept, cantilevered wing model intended for a dedicated flutter experiment in the Transonic Wind Tunnel Göttingen (DNW-TWG). The objective is twofold: to establish a reference configuration exhibiting a well-defined transonic dip within the facility's operating envelope, and to demonstrate the potential of adaptive contour bumps to locally increase the flutter boundary at this minimum.

The planned experiments will utilize the 1 m × 1 m adaptive test section of the DNW-TWG. A key feature of this facility is the capability to vary air density, and thus dynamic pressure, at a constant Mach number. This allows for the experimental determination of a continuous flutter boundary in a Mach number–dynamic pressure diagram.

The investigated wing features a trapezoidal planform with 20° sweep angle at the 60% chord line, a 70 cm semi-span, and a root-to-tip chord ratio of 20 cm to 6 cm. The airfoil was specifically designed to combine strong rear loading with a relatively thick trailing edge to limit static aeroelastic deformations.

Constructed as a composite shell with glass-fiber reinforced polymer (GFRP) skins, the wing is tailored to specific modal targets that facilitate flutter coupling between the second bending and first torsional modes. A slender pod beneath the wing at 36% semi-span houses movable tuning masses (Fig. 1); shifting these allows for the adjustment of structural eigenfrequencies and mode shapes. The wing is rigidly clamped to the wind tunnel sidewall to simplify both mechanical integration and aerodynamic modeling; since the structure remains stationary at the

root, no energy transfer occurs between the fluid and the structure in the junction region.

Numerical Design

The design approach employs linearized, frequency-domain flutter calculations. This combines modal-reduced finite element models (ANSYS/MSC Nastran, Fig. 2) with DLM-based unsteady aerodynamics for structural pre-design, and CFD-based aerodynamics for the detailed transonic bump design. For the high-fidelity design phase, motion-induced generalized aerodynamic forces (GAFs) are obtained from unsteady RANS simulations using the DLR TAU solver, employing small Dirac impulse modal grid perturbations. While the frequency-domain approach scales the aerodynamic force level to represent varying dynamic pressure, it does not account for changes in the stationary equilibrium or Reynolds number effects. Therefore, the frequency-domain results at selected operating points are verified using loosely coupled time-domain simulations. Contour bumps are implemented via mesh deformation of the CFD surface grid, parameterized by position, streamwise length (20–40% chord), and height (0.5–1.0% chord).

Results and Outlook

For the clean reference wing, the structural design and mass tuning result in a well-defined flutter boundary within the dynamic pressure range achievable in the DNW-TWG. A pronounced transonic dip is observed. By shifting the tuning masses in the pod, the flutter boundary can be moved globally. Preliminary results indicate that appropriately positioned contour bumps in the mid-board section can locally increase the critical dynamic pressure by 50% or more in the vicinity of the transonic dip, while leaving the subsonic boundary essentially unchanged (Fig. 3).

The wing model is currently being manufactured, with the experimental campaign scheduled for autumn 2026. Future work will focus on validating the predicted flutter boundaries and extending the concept to other localized modifications, such as mini-spoilers.

References

Nitzsche et al. (2022): The Effect of Shock Control Bumps on the Transonic Flutter and Buffeting Characteristics of a Typical Wing Section. IFASD 2022, Madrid, Spain. https://elib.dlr.de/188433/1/IFASD_2022_149.pdf

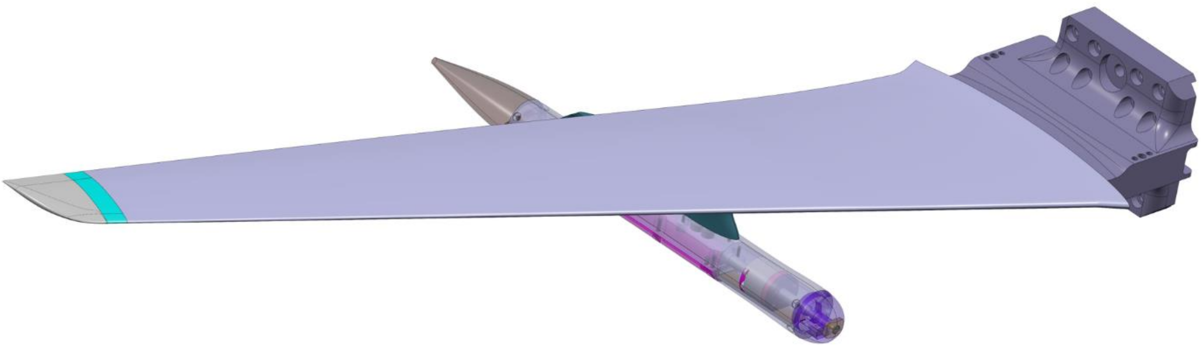

Figure 1: Digital mock-up (CATIA) of the wing model. The removable under-wing pod houses movable tungsten masses.

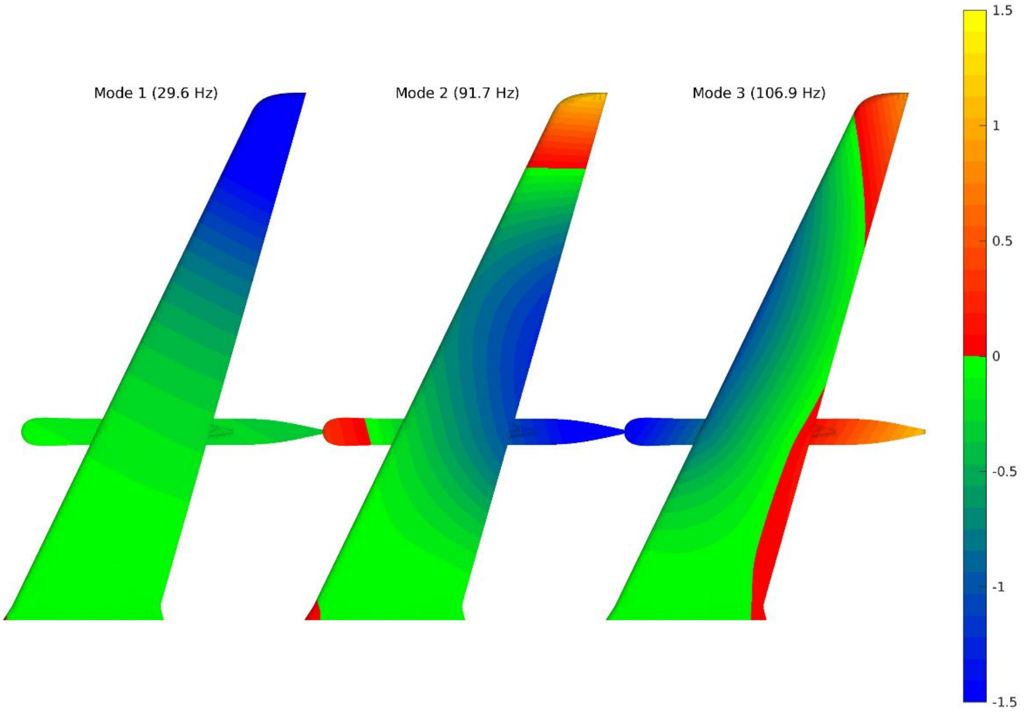

Figure 2: First three structural modes (ANSYS) projected to the CFD surface mesh: vertical component of the modal displacement field. Mode 2 (second wing bending) and Mode 3 (first torsion) interact during flutter.

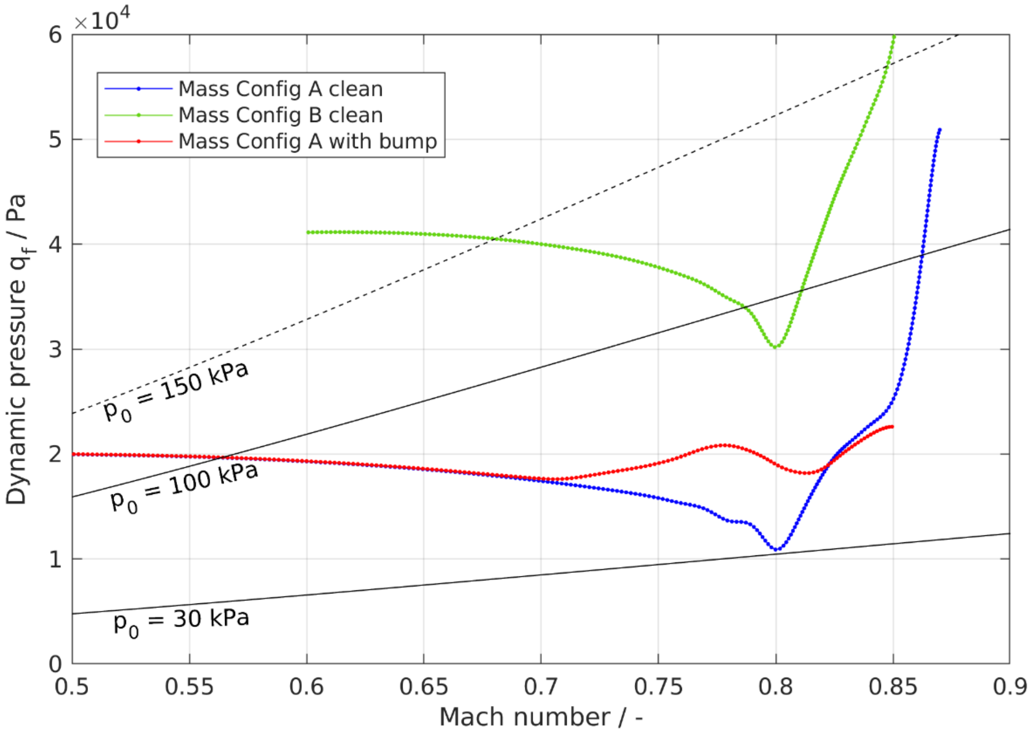

Figure 3: CFD-based flutter boundaries: Effect of pod tuning mass location (config A – max. upstream pos.; config B – max. downstream pos.) and contour bump modification (black lines denote the DNW-TWG operating envelope; wind tunnel total pressure p_0)