"SHIFT THE DIP" — AEROELASTIC EFFECTS OF SHOCK-CONTROL BUMPS ON A SUPERCRITICAL AIRFOIL IN TRANSONIC FLOW

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ABSTRACT

Shock control bumps (SCBs) have been shown to mitigate or even suppress flutter phenomena on transonic wings by shifting the onset of the transonic dip toward higher Mach numbers or pressures, thereby improving the aeroelastic stability margin of the airfoil. Although previous studies have demonstrated the overall effectiveness of SCBs [1], a more detailed understanding of the underlying flow physics is required in order to optimize the bump geometry and its placement on the airfoil for practical aircraft applications. The present work addresses this need by experimentally investigating the aerodynamic and aeroelastic behavior of an airfoil equipped with and without SCBs in transonic wind-tunnel flutter tests.

The experimental setup employed in the Transonic Wind Tunnel Göttingen (TWG) is shown in Figures 1 and 2, respectively depicting the model equipped with the SCB mounted in the tunnel test section and a schematic illustrating the bump geometry. The configuration analyzed in detail features a cosine-shaped surface elevation located at 50% chord (x_b), with a streamwise length of 20% chord (l_b).

Building on the experimental flutter setup and initial qualitative observations reported in [2], the present study provides a comprehensive quantitative assessment of SCB-induced flow–structure interaction mechanisms in the transonic regime. Particular emphasis is placed on the influence of bumps on shock motion, pressure distribution, and unsteady aerodynamic loading, which are directly related to flutter onset, growth rates, and stability margins.

To this end, a broad set of measurement techniques was employed, including high-sample-rate pressure transducers, accelerometers, and optical methods. Particular emphasis is placed on the use of unsteady pressure-sensitive paint (iPSP), which provides time-resolved surface pressure fields associated with shock motion and separation dynamics. These data enable a direct correlation between the global aeroelastic response and the local flow structures.

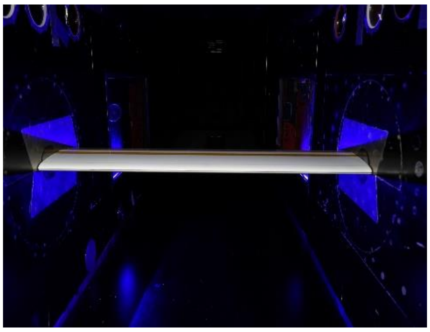

Fig. 1: OAT15A model mounted inside the Transonic-Wind Tunnel Göttingen (TWG)

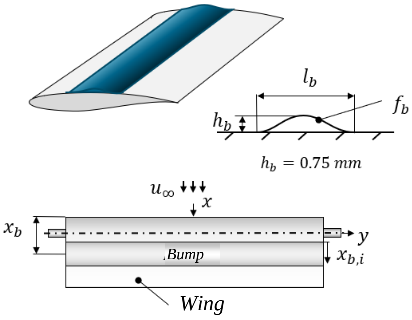

Fig. 2: Bump on the model, Position: 50% chord (x_b); Width: 20% chord (l_b); Form: Cosine – Function (f_b) (Configuration D)

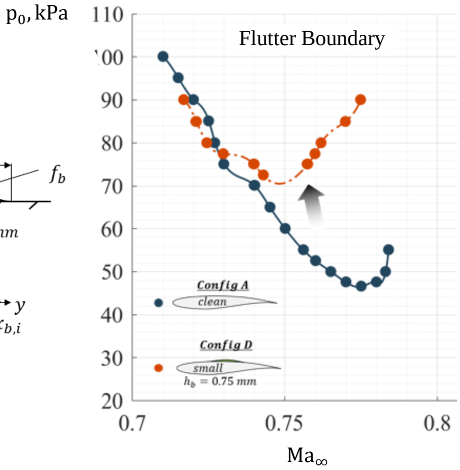

Fig. 3: Transonic dip for the clean configuration (**blue**) and configuration D (**orange**), shown with the ambient pressures over the Mach-Number

The aeroelastic measurements indicate a pronounced dependence of flutter onset on both Mach number and ambient pressure. For the clean configuration, flutter occurred between Mach 0.71 at 100 kPa and approximately Mach 0.775 at 45 kPa (Fig. 3, blue). Within this range, the model exhibited classical shock-induced heave flutter with a dominant frequency of about 29 Hz. In contrast, the bumped configuration showed a significantly altered stability behavior: the transonic dip shifted toward higher pressures (Fig. 3, orange), and no flutter could be detected at pressures below 70 kPa, indicating the stabilizing effect offered by the bump.

Regarding the flutter mechanisms, heave-dominated flutter was observed in the lower transonic regime (Fig. 4 left, point **a**). At higher Mach numbers, the instability switched to a torsion-dominated mode at ~49.8 Hz (Fig. 4 left, point **c**). The near-vertical character of the flutter boundary in this region suggests a regime transition from the transonic-dip behavior toward a predominantly single-degree-of-freedom flutter mechanism, as similarly discussed in [3**]**, whose onset becomes primarily Mach-governed and only weakly dependent on ambient pressure. The regime between the transonic dip and this high-transonic instability remained stable (Fig. 4 left, point **b**).

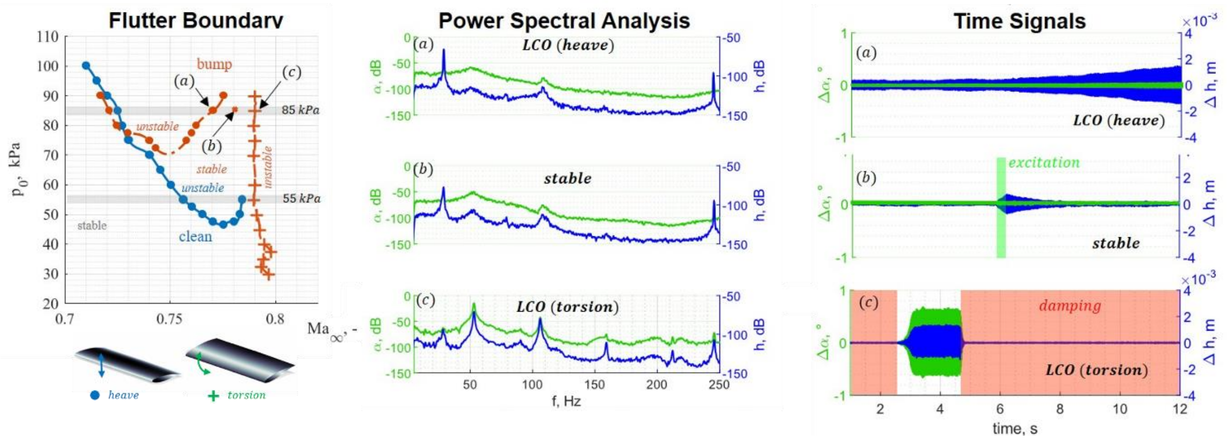

Fig. 4: The **left** figure shows the transonic dips with three selected points. (a) pre-dip, (b) dip and (c) post-dip. On the **right**, the time histories for the bump configuration are shown for cases (a) unstable – heave-dominated flutter, (b) stable, and (c) torsion-dominated flutter; the corresponding PSDs in the **center** of the figure are included alongside each signal.

Overall, the results presented in this study constitute a detailed assessment of SCB-induced flow and aeroelastic modifications. The findings demonstrate the influence of bump geometry on the transonic dip, the flutter boundaries, and the dominant instability mechanisms, thereby establishing the physical framework required for a deeper interpretation of the dynamics behind the transonic-dip. These insights form the basis for the extended analysis to be presented in the full paper, where time-resolved iPSP measurements and complementary datasets will be used to examine the flow structure in greater detail and to more precisely quantify the mechanisms by which shock control bumps contribute to aeroelastic stabilization.

References

[1] Nitzsche, J.; Otte, J.; Kaiser, C.; Hennings, H. (2022) "*The Effect of Shock Control Bumps on the Transonic Flutter and Buffeting Characteristics of a Typical Wing Section*", IFASD 2022, 149

[2] A. Altkuckatz et al. (2024) "*Experimental investigation of shock control bumps on the transonic dip of the OAT15A airfoil*", IFASD 2024, 202

[3] Dowell, E. H. (2024) "*Coupled-Mode Versus Single-Degree-of-Freedom Flutter: The Third Parameter in Flutter*", AIAA Journal, Vol. 62, No. 2, Feb 2024, pp. 864–868. DOI: 10.2514/1.J063255