

CONTROL SURFACE MODELING: ANALYSIS OF UNSTEADY EFFECTS OF SPANWISE GAPS USING LINEARIZED FREQUENCY-DOMAIN SOLVERS

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ABSTRACT

Control surfaces dynamically modify the geometry of an aircraft, altering the surrounding flow field and inducing unsteady aerodynamic loads. Accurately predicting these effects is essential for reliable flight-load assessments. However, incorporating control-surface deployment in high-fidelity computational fluid dynamics (CFD) simulations remains challenging, particularly due to the presence of small geometric gaps. While streamwise gaps are typically sealed, spanwise gaps are not, as closing them would require advanced morphing technologies. These spanwise gaps generate complex circulation patterns and large vortical structures that convect downstream [1], making their aerodynamic impact non-negligible [2].

This work investigates these effects using NASA's Benchmark Active Controls Technology (BACT) model [3], a rectangular wing with a NACA 0012 section equipped with upper and lower spoilers and a trailing-edge control surface. Extensive experimental data exist for harmonically oscillating trailing-edge surfaces, covering variations in frequency, initial position, and amplitude. The sensitivity of in-phase and out-of-phase pressure coefficients to control surface oscillation amplitude (Figure 1) and initial position makes this configuration an excellent candidate for assessment with linearized frequency-domain (LFD) solvers.

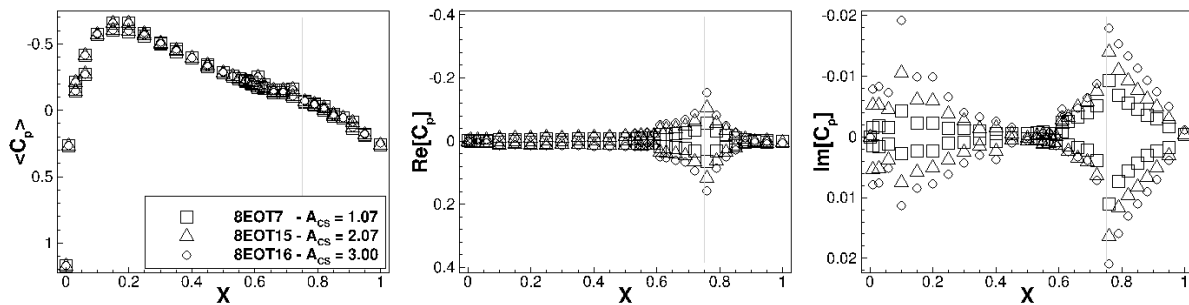


Figure 1: Experimental coefficient of pressure C_p distribution for the wing section at $\eta = 0.4$ (spanwise midpoint of the control surface). From left to right, the mean, real, and imaginary parts of C_p are shown. The light gray vertical line indicates the location of the control surface hinge line. The control surface is initially undeflected and oscillated with a frequency of 9.9 Hz and amplitudes of 1.07° , 2.07° , and 3.00° for test cases 8EOT7, 8EOT15, and 8EOT16, respectively.

Two numerical configurations are studied: a clean wing and a wing including the spanwise gaps (Figure 2). The clean-wing mesh is easily generated, and control-surface motion is modeled using mesh deformation with a blending approach. In contrast, the gapped configuration requires significantly more complex meshing due to the narrow gaps and the need to generate boundary-layer elements in this constrained region. An overset-grid strategy is employed, with separate grids for the lifting and control surfaces coupled via sliding-interface boundaries. Control-surface motion is obtained through a mesh-deformation algorithm applied exclusively to the control-surface grid, with sliding-interface nodes constrained to tangential movement to maintain the alignment between the lifting and control-surface grids.

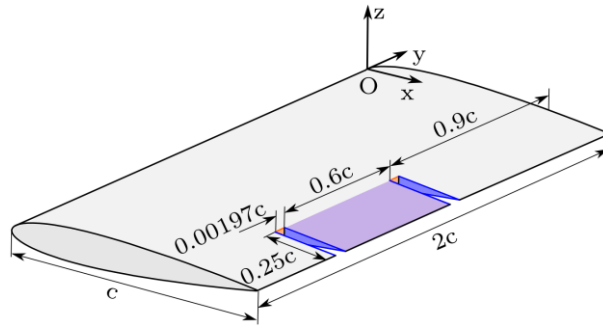


Figure 2: BACT configuration with trailing-edge control surface (in pink) and spanwise gaps (not to scale). The gap surfaces normal and parallel to the free-stream flow are illustrated in orange and blue, respectively. The chord length c is 0.4064 m.

Steady-state simulations of the baseline deflection angle are first performed using the well-validated DLR TAU code and the CFD software by ONERA, DLR and Airbus (CODA), and compared with available experimental data. Unsteady simulations are then conducted using the LFD solver variants of CODA [4] (for both configurations) and TAU [5] (for the clean wing). The numerical results are analyzed against experiments to assess the predictive capabilities of the solvers and to quantify the influence of explicitly modeling the spanwise gaps on the unsteady aerodynamic response.

Acknowledgments. CODA is the computational fluid dynamic (CFD) software being developed as part of a collaboration between the French Aerospace Lab ONERA, the German Aerospace Center (DLR), Airbus, and their European research partners. CODA is jointly owned by ONERA, DLR and Airbus.

Bibliography

- [1] L. B. Streher, *Control surface modeling and large-eddy simulation: Enhancing accuracy and efficiency in aerodynamic analysis*, PhD thesis, University of Groningen, 2024.
- [2] N. Liggett and M. J. Smith, "The physics of modeling unsteady flaps with gaps," *Journal of Fluids and Structures*, pp. 255-272, 2013.
- [3] R. M. Bennett, R. C. Scott and C. D. Wieseman, "Test case for the benchmark active controls model: spoiler and control surface oscillations and flutter," in *Verification and validation data for computational unsteady aerodynamics, Report of the Applied Vehicle Technology Panel (AVT) Task Group AVT-010, RTP Technical Report 26*, 2000, pp. 201-224.
- [4] U. S. Vevek, S. Timme, J. Pattinson, B. Stickan and A. Büchner, "Next-generation computational fluid dynamics capability for aircraft aeroelasticity and loads," in *International Forum on Aeroelasticity and Structural Dynamics, IFASD 2022, IFASD-2022-025*, 13-17 June 2022, Madrid, Spain, 2022.
- [5] R. Thormann and M. Widhalm, "Linear-frequency-domain predictions of dynamic-response data for viscous transonic flows," *AIAA Journal*, pp. 2450-2557, 2013.