Aeroelastic limit cycle oscillations due to multi-element control surface with freeplay

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Abstract. Single control surface (CS) freeplay has been well investigated in the aeroelastic field and several studies describe its effect on the limit cycle oscillations (LCO). Airworthiness regulations establish that this discontinuous nonlinearity needs to be considered in both CS and trailing-edge tab, if the latter one exists. In this context, the present study introduces the effects of freeplay from both CS and tab on the LCO. The four degree-of-freedom typical section is considered, highlighting the main differences when compared with the freeplay of a single trailing-edge surface. The results show that higher amplitudes are identified for this configuration when compared to the classical case.

Introduction

Discontinuous nonlinearities as freeplay are commonly present in hinge connections. The piecewise linear torque of a hinge with freeplay (gap of amplitude 2δ in which the stiffness has no action) depends discontinuously on the rotation angle β, such that $T_\beta = k_\beta(\beta \pm \delta)$, if $|\beta| > \delta$ and $T_\beta = 0$, if $|\beta| < \delta$. Since this is a topic addressed by airworthiness regulations (MIL-A-8870C, by United States Military Standard; AC 23.629-1B and AC 25.629-1B by Federal Aviation Administration), the literature review for aeroelastic systems with freeplay is dense and one of the main effects observed is the appearance of LCO [1]. The effect of freeplay in a single control surface is largely studied [2], for example using the three degree-of-freedom (3-DOF) typical section based on Theodorsen's unsteady aerodynamics [3], even though the regulations highlight the need of considering the freeplay not only in the main control surfaces but also in the corresponding tabs. Mashhadani et al. [4] studied the airfoil typical section with an added fourth DOF, a tab attached to the trailing edge of the CS. The authors consider freeplay on the tab only. A recent work is found to examine freeplay in both leading and trailing control surfaces [5], showing how considering simultaneous freeplay in different CS is a new topic in the field. In this context, this work presents the effect of freeplay acting in both CS and tab for the LCO of the 4-DOF typical section (plunge, pitch, CS, and tab), employing the Hénon's technique for time marching.

Results and discussion

Figure 1 shows the bifurcation diagrams for the CS (left) and the tab (right) inversion points ($\dot{\beta} = 0$ and $\dot{\gamma} = 0$) for three scenarios regarding the freeplay inclusion: i. CS only, ii. tab only, and iii. both CS and tab. In general, the scenarios can be compared in terms of the flight speed where the LCO start, the maximum magnitude of the LCO, and their complexity, usually related to the amount of inversion points at certain speeds. Comparing the scenarios with CS freeplay (i. and iii.), the maximum CS magnitudes are of similar order whereas the maximum tab magnitudes are intensified by the presence of simultaneous CS element freeplay. Also, the scenario i. presents higher complexity around the freeplay boundary for CS motion. Comparing the scenarios with tab freeplay (ii. and iii.), the scenario ii. has more complex LCO in the range from $V/V_f = 0.24$ to $V/V_f = 0.56$ and the presence of multiple freeplay produces higher magnitudes, for both CS and tab motions. This latter conclusion is an important motivation to consider freeplay in various elements of a control surface.

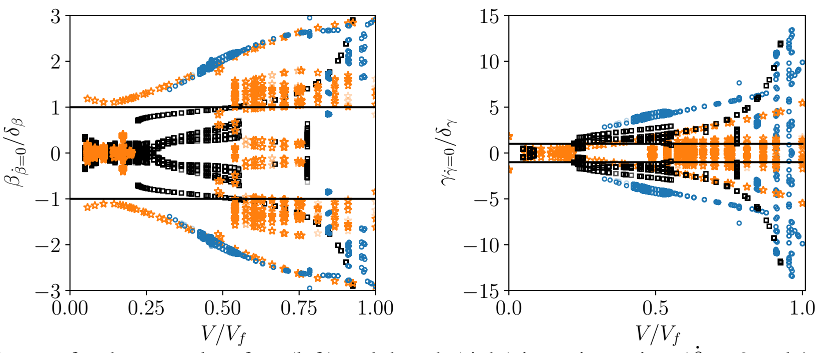

Figure 1: Bifurcation diagram for the control surface (left) and the tab (right) inversion points ($\dot{\beta} = 0$ and $\dot{\gamma} = 0$). Three scenarios of freeplay: i. (⋆) CS only, $\delta_\beta = 0.2$ deg; ii. (□) tab only, $\delta_\gamma = 0.4$ deg; iii. (o) both CS and tab, $\delta_\beta = 0.2$ deg and $\delta_\gamma = 0.4$ deg.

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