

# NONLINEAR AEROELASTIC SIMULATIONS OF A QUADRATIC DAMPER WITH FREEPLAY IN A 3-DOF TYPICAL SECTION

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## ABSTRACT

Simulations of nonlinear aeroelastic systems are necessary both for aircraft development needs and certification purposes. These simulations can be carried out either using frequency domain or time domain analyses. Frequency domain analysis of nonlinear systems requires the use of describing functions for the specific nonlinearity and, similarly, time domain approach is based on a description (or model) of the nonlinearity with respect to one or more states of the system.

The purpose of the present work is to simulate a three-degree-of-freedom typical section, the one presented in the work of Wayhs-Lopes et al. [1] and depicted in Figure 1, both in frequency and time domains. The describing function for the quadratic damper with freeplay is presented and its derivation was based on the methodology described in Castro et. al. [2]. A nonlinearity is assumed to exist in the degree of freedom associated with the control-surface rotation ( $\beta$  degree of freedom in Figure 1) and its description, for time domain computations, is also presented in the article.

Figure 2 contains an illustration of the damping force as a function of the nonlinear damper displacement. This model is the basis for obtaining the specific describing function and for implementing the time integration procedure, which uses a 4<sup>th</sup>-order Runge-Kutta method. Time integration is enhanced by using the Hénon technique [3].

Unsteady aerodynamics relies on the Theodorsen's model, which is used directly in frequency domain analyses. Additionally, to use this model in time simulations, Roger's rational function approximation is used to obtaining a state-space description of the system. Equations of motion in state-space form are used to perform the time marching process.

Limit cycle oscillations (LCO), which are typical responses of this type of nonlinear systems, are evaluated in both approaches. LCO maps, showing amplitudes and frequencies as functions of flight velocity, are calculated. The comparison between both approaches reveal that the results match rather well. Additionally, Hénon's technique improves the predictions of the displacements computed during the time integration.

This work is especially relevant because it uses a recently developed model, discussed in Ref. [2]. The new model allows the nonlinear damper to enter the deadzone region based on the velocity and not on the position of the damper arm, which is different from preceding studies. In previous models for a damper with freeplay, the criterion for reaching the deadzone is based on the displacement (or position) of the damper's arm.

As a conclusion, the present model can capture the behaviour of a nonlinear damper with quadratic damping and freeplay in both frequency and time domains and it appears to capture characteristics (amplitude and frequency) of eventual LCO in a more accurate fashion.

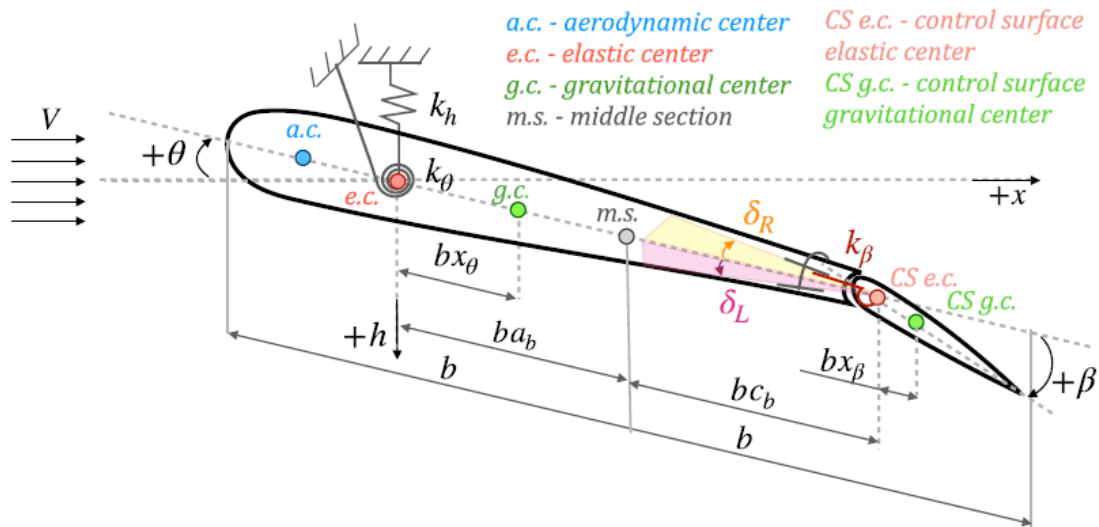


Figure 1 – Typical section with three degrees of freedom.

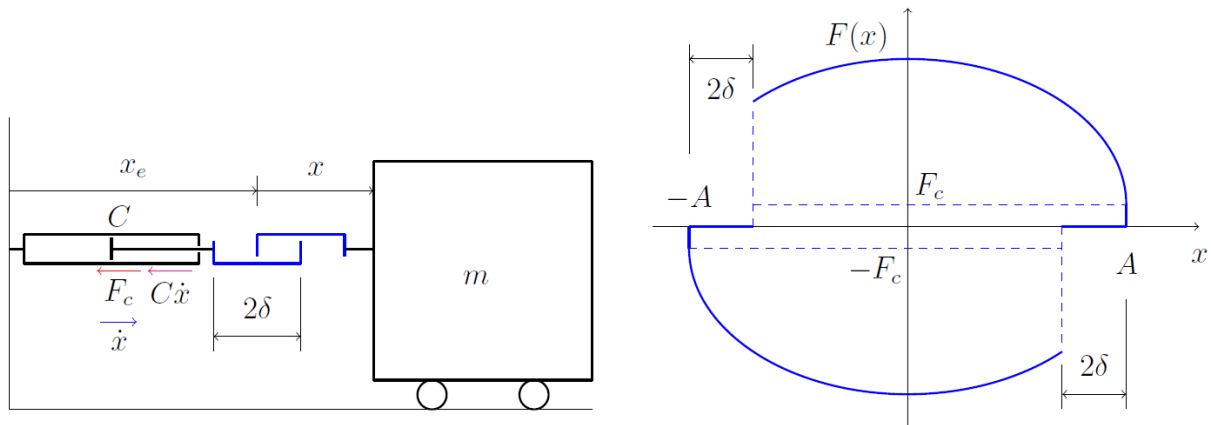


Figure 2 – Idealization of a quadratic damper with freeplay and friction.

#### References:

- [1]. L. D. Wayhs-Lopes, E. H. Dowell and D. D. Bueno. “Influence of friction and asymmetric freeplay on the limit cycle oscillation in aeroelastic system: An extended Hénon’s technique to temporal integration”. *Journal of Fluids and Structures*, 96 (2020).
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- [4]. Roger, K. L. “Airplane Math Modeling and Active Aeroelastic Control Design”. AGARD-CP-228, 4.1-4.11 (1977).