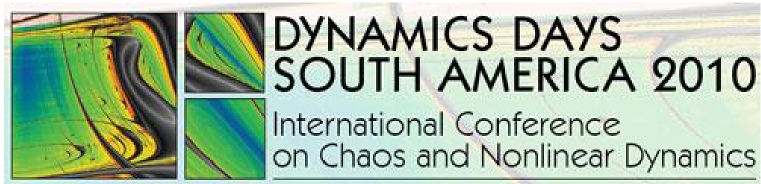

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BIFURCATION ANALYSIS OF A TYPICAL SECTION WITH CONTROL SURFACE FREEPLAY

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A bifurcation analysis of a typical section airfoil with control surface freeplay nonlinearity is carried out. Two approaches are used to evaluate the limit cycle behavior: time marching numerical integration and harmonic balance method. Also, the sensitivity to the initial condition is discussed. Linear analyses are conducted to provide guidance for the nonlinear analysis. The universal scaling law for the dependence of limit cycle oscillations and bifurcation parameters, elucidated by Tang, Dowell, and Virgin (Ref. [2]) are confirmed. Comparisons between the bifurcation diagrams generated by the harmonic balance and the numerical integration show good agreement, considering the hypotheses adopted.

The typical section aeroelastic equations are cast in state-space form with the freeplay nonlinearity represented as feedback loop (Fig. 1), where freeplay is defined mathematically by a nonlinear stiffness arising from the piece-wise linear relationship between torque and flap motion (Fig. 2).

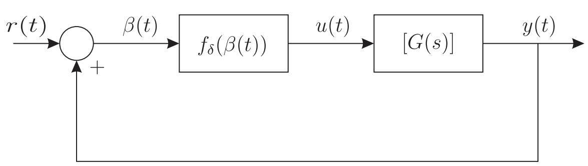

Figure 1 – Nonlinear Aeroelastic System Block Diagram

The effects of unsteady aerodynamic modeling are also object of study. State-space models are derived from Peters'[1] finite-state induced flow model and rational function approximation of Theodorsen[3] airloads. Thus, the initial condition problem is solved by means of numerical integration.

Alternatively, the harmonic balance method is used to obtain the linearized solution. A linear equivalent stiffness is obtained as function of the flap amplitude using the describing function. The basic premise of the method is to assume sinusoidal response of the aeroelastic system. Fourier series terms are used describe the system response, assuming the hypothesis that the system has low-pass characteristics.

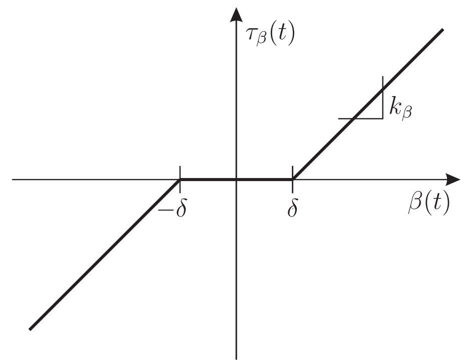

Figure 2 – Freeplay Nonlinearity

Bifurcation diagrams are plotted with airflow speed as parameter. The Fig. 3 shows the comparison among the methodologies. The stability of the LCOs is evaluated through time-marching.

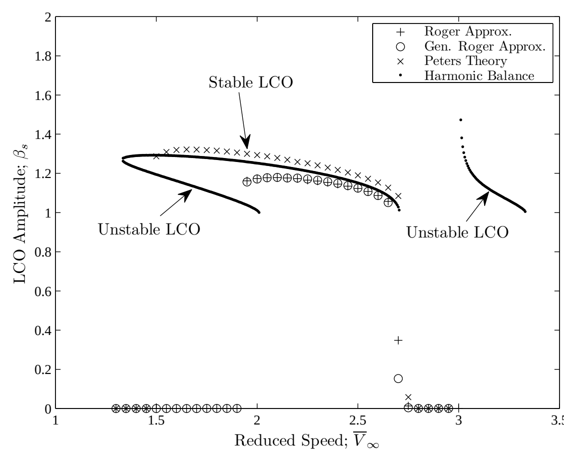

Figure 3 – Bifurcation Diagram

Regions with high sensibility to initial conditions are found. The effect of aerodynamic modeling is accentuated at those regions. The generalization of Roger rational function approximation does not present significant changes when compared to the conventional approach. Additional investigations shall be performed with different aeroelastic systems in order to validate the conclusion. The use of p Transformation method together with classical flutter solution techniques is suggested for future works.

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