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Some Comments on Nonlinear Aeroelastic Typical Section

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Abstract: The Aeroelastic typical section, also known as three degrees of freedom Aeroelastic model, is a great way to study nonlinearities in Aeroelastic systems in an isolated way. There is a lack of research using cubic spring commanding the aileron deflection and considering Peters' unsteady loading acting on the model. The model presented here have two linear springs (one commanding the vertical displacement and the other commanding the pitch angle) and one cubic spring for aileron deflection. With the numerical simulated time series, the 0-1 test is performed as well as the Takens' reconstruction and the Lyapunov exponent determination. The 0-1 test result is compared to the Lyapunov exponent, as part of their validation for aeroelastic systems subjected to structural nonlinearities.

Keywords: Aeroelastic system, structural nonlinearity, unsteady aerodynamics

1. Introduction

The typical section with three degrees of freedom, is largely used for various cases in Aeroelasticity, like isolate a specific phenomenon or deal with less and known degrees of freedom. This model, shown in Figure 1, is subjected to unsteady aerodynamic loads, calculated considering Peters' unsteady aerodynamic model [1]. Also, a cubic nonlinear spring is considered in the aileron actuation, which adds the known structural nonlinearity.

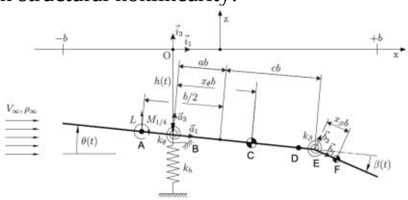

Fig. 1. Three degrees of freedom aeroelastic mathematical model, adapted from [2] by the autors.

The mathematical model in Figure 1 and the unsteady aerodynamic loads are defined in state-space. The unsteady loads consider the inflow as added states, which means that the three degrees of freedom are only the structural states.

2. Results and Discussion

The Aeroelastic system presented in Figure 1 is numerically simulated for various conditions. The time series presented here is only an example of a result and considers an initial vertical displacement of 0 mm, and initial pitch angle (also known as angle of attack) of 2° and an initial aileron deflection of 1°. The airflow speed is also varied, but only one (215m/s) will be shown here for brevity:

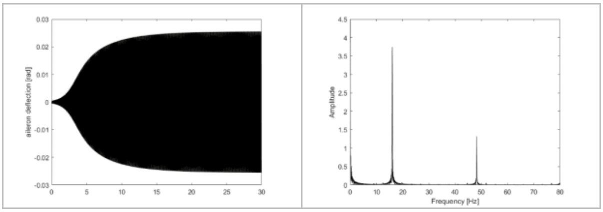

Fig. 2. Time serie and FFT.

Figure 2 shows a cubic nonlinearity in FFT and the time series looks a limit-cycle oscillation. The 0-1 test of the time series presented in Figure 2 is:

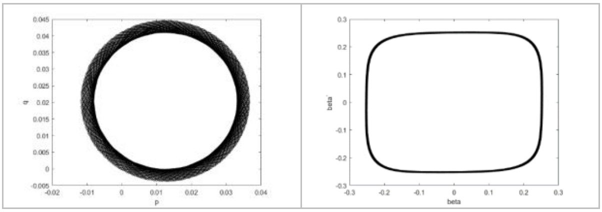

Fig. 3. Shows the 0-1 test result and reconstructed attractor.

The 0-1 test shows a bounded figure, which represents a quasi-periodic system behaviour, since there is mode coupling when dealing with aeroelastic system. The reconstructed attractor also characterizes a limit-cycle. This comparison is also available for a different aeroelastic system in [3].

The Lyapunov exponent compared to 0-1 test also resulted in quasi-periodic system behaviour:

Table 1. Lyapunov exponent x 0-1 test

Lyapunov Exponent	0-1 Test
-8.5884	-0.0216

3. Concluding Remarks

For both 0-1 test and Lyapunov exponent, the Aeroelastic typical section has quasi-periodic behaviour. It is extremely important to highlight that the state-space model also considered three additional states related to the inflow, and their derivatives, totalizing nine states. This system was simulated for three angles of attack, three aileron deflections, eight velocities and two cubic spring parameters and the result presented here is only a representative result. Below 175m/s the aileron deflection amplitude reaches the same value and, by increasing the velocity, the movement amplitude also increases. Lower values of cubic spring parameter resulted in higher amplitudes.

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