Nonlinearities in off-diagonal GAF matrix elements in the scope of T-tail flutter

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Abstract:

Assessment of T-tail flutter requires unsteady aerodynamic forces beyond the scope of the conventional DLM, usually accounted for by means of correctional terms computed by external methods and superposed with the DLM aerodynamics. Alternatively, unsteady CFD methods inherently capture the aerodynamic forces to their full extent. However, literature has shown that the full description of the unsteady aerodynamic terms in combination with a linear modal approach for the representation of the dynamical system may lead to spurious stiffness terms (van Zyl & Mathews, 2011). For a physically more accurate flutter assessment of T-tails, it is suggested to include quadratic deformation components in the modal representation.

While the effect of the quadratic mode shape components on the stiffness of the vertical tail plane (VTP) out-of-plane bending mode shape is known from literature, their impact on the aerodynamic coupling terms has not been studied in depth so far. As these are driving factors for flutter, this paper will work out the impact of quadratic mode shape components on the aerodynamic coupling terms with regard to frequency of oscillation and deformation amplitude.

Nowadays, as a result of continuously increasing computational power and advance in computational methods, CFD approaches for computing unsteady aerodynamic forces for flutter assessment are well established. In this work, the converged solutions to simple harmonic excitation are represented in the form of hystereses, which enables the evaluation of aerodynamic stiffness and damping in terms of their inclination and area, respectively. Fourier transformation of the input and output signals is used to address the frequency content of the aerodynamic response.

The flutter mechanism observed for a generic T-tail configuration without sweep and taper involves the first out-of-plane bending mode shape of the VTP in addition to its first torsional mode shape (Murua, van Zyl, & Palacios, 2014). Both mode shapes are approximated as rigid body rotations of the horizontal tail plane (HTP) w.r.t. the longitudinal and vertical axes, respectively. This allows for an analytical description of the linear, quadratic, and fully nonlinear deformations. Furthermore, the analytical description of the deformation can be used to evaluate the generalized aerodynamic force (GAF) values subject to linear as well as nonlinear deformation in time domain (TD) (Ritter, 2019). In order to exclude aerodynamic interference between HTP and VTP, only the isolated HTP is studied. The aerodynamics are restricted to inviscid flow.

Figure 1 shows the aerodynamic response due to HTP roll motion generalized with respect to an HTP yaw motion (GAF_{21}) over sinusoidal deformation input for varying amplitudes and reduced frequencies. This GAF represents one of the aerodynamic coupling terms relevant for the flutter mechanism to occur. The quadratic deformation appears to be sufficiently accurate in comparison to the fully nonlinear one. As can be observed, a striking impact of the nonlinear deformation on the

shape and inclination of the hystereses and, hence, on aerodynamic stiffness and damping is notable. In addition, a dynamic nonlinearity of this GAF term with regard to the deformation amplitude is evident, as is a higher harmonic content in the GAF signal due to the deviation of the hystereses from an elliptical shape.

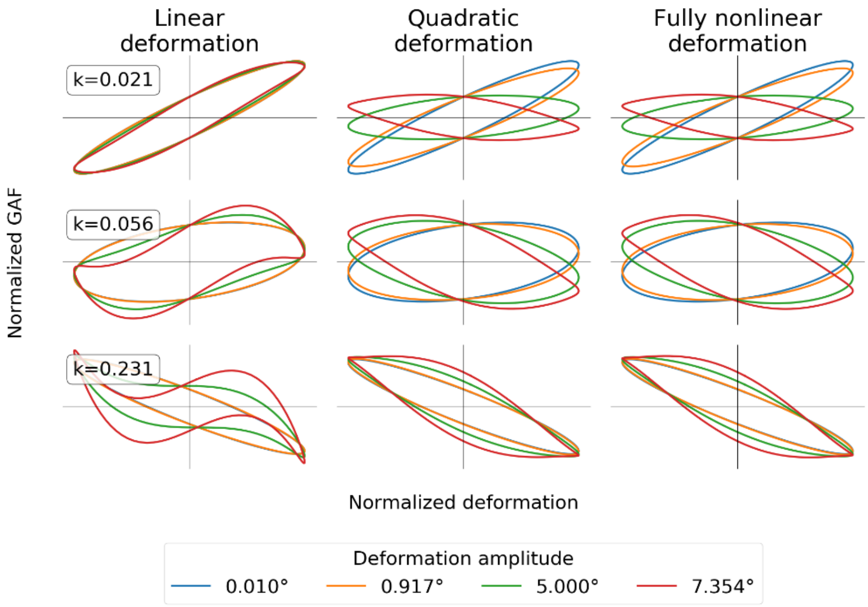

Figure 1: Hystereses of GAF_{21} for linear and nonlinear deformations as well as varying deformation amplitudes and reduced frequencies

For T-tail flutter onset prediction, these findings indicate a potential dependency of the flutter velocities on deformation amplitude, which will be content of future research activities.

References

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