ANALYSIS OF NONLINEAR DYNAMIC CHARACTERISTICS OF LARGE FLEXIBLE WINGS BASED ON STRUCTURAL REDUCED ORDER MODEL

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ABSTRACT

Large flexible aircraft represented by high-altitude long-endurance UAVs and flying wing UAVs have broad application prospects in many fields. Due to specific requirements for flight performance, such aircraft has large structural flexibility. Under the aerodynamic loads, large flexible aircraft will undergo large elastic deformation, which will bring geometric nonlinear aeroelastic problems. Traditional linear aeroelastic analysis methods cannot meet the aeroelastic analysis requirements of large flexible aircraft. Patil and Hodges[1-2] introduced geometric nonlinearity into aeroelastic analysis for the first time. They proposed a fully coupled approach that employed a mixed variational principle for nonlinear structural modelling and finite-state inflow theory to describe unsteady aerodynamics. Since then, many researchers have developed various geometric nonlinear aeroelastic analysis methods with different accuracies and applicable problems to accurately predict geometric nonlinear static deformation and flutter calculations[3-5].

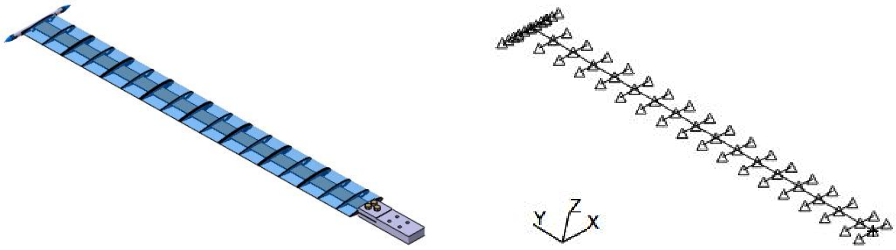
However, the nonlinear dynamic characteristics of the aeroelastic system of large flexible wings deserve further study. Most of the existing studies are limited to the research on the instability near the static equilibrium point and the characteristics of the limit cycle oscillation (LCO), while there is relatively few research on the geometric nonlinear aeroelastic bifurcation characteristics and even the entry paths into chaotic. This is of great significance for analyzing the aeroelastic characteristics of large flexible wings and ensuring the safety of large flexible aircraft Such research requires efficient and high-precision aeroelastic prediction models.

In this paper, the nonlinear reduced order model based on the implicit condensation and expansion (ICE) method[6] is used for structural modelling, and sparse regression technology is introduced to enhance the rationality and accuracy of identification of nonlinear stiffness coefficients. Dynamic equations of nonlinear reduced order model have formulation as Eq.(1). A non-planar UVLM formulation is accommodated to construct generalized aerodynamic forces. Based on the structural and aerodynamics model, the geometrical nonlinear aeroelastic analysis frameworks are established. A large flexible wing model is used as a numerical example. The approach enables static aeroelastic, flutter, and gust response analysis of large flexible wings. Comparison with the full-order model and test results show that the proposed method is effective and accurate.

$$M_{mn}\ddot{q}_n + K^{(1)}_{mn}q_n + K^{(2)}_{mnl}q_nq_l + K^{(3)}_{mnlp}q_nq_lq_p = f_m \tag{1}$$

Based on the efficient geometric nonlinear aeroelastic modelling method introduced in this paper, the complex nonlinear aeroelastic characteristics of the large flexible wing model have been calculated and will be demonstrated. After going through a series of processes such as LOC, double periodic bifurcation, and quasi-periodic bifurcation, the wing response enters a chaotic state rapidly. Meanwhile, as the angle of attack (AOA) of the large flexible wing increases, the unstable speed of wing becomes smaller and smaller, and the path from the

appearance of the LCO response to entering chaos also becomes shorter and shorter. All these will have adverse effects on the safety of large flexible aircraft.



(a) 3-D CATIA model (b) FE model

Figure 1 . Model of large flexible wing

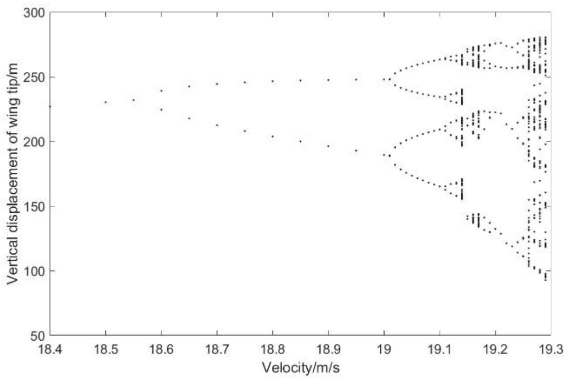


Figure 2 . Nonlinear dynamics characteristic of wing under 3 Deg AOA

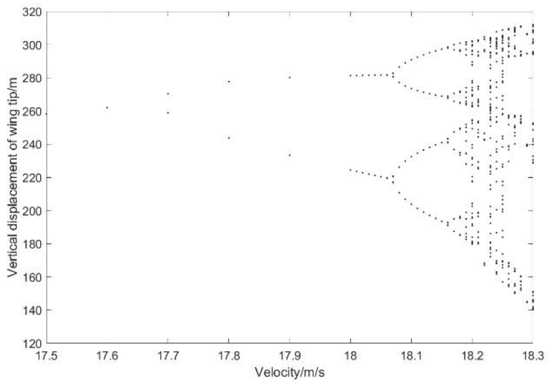


Figure 3 . Nonlinear dynamics characteristic of wing under 4 Deg AOA

Key words： Large flexible aircraft, Aeroelasticity, Geometric nonlinearity, Reduced order modeling, Bifurcation, Chaos

References

[1] Patil MJ, Hodges DH, Cesnik CES. Nonlinear aeroelastic analysis of aircraft with high-aspect-ratio wings. 39th structures, structural dynamics and materials conference, 1998.

[2] Patil MJ, Hodges DH, Cesnik CES. Nonlinear aeroelasticity and flight dynamics of high-altitude long-endurance aircraft. J Aircraft (2001);38(1):88–94.

[3] Ritter M, Jones J, Cesnik CES. Free-flight nonlinear aeroelastic simulations of the X-HALE UAV by an extended modal approach. 17th international forum on aeroelasticity and structural dynamics, 2017.

[4] Y. Meng, Z. Wan, C. Xie, C. An, Time-domain nonlinear aeroelastic analysis and wind tunnel test of a flexible wing using strain-based beam formulation, Chinese Journal of Aeronautics, 34 (2021) 380-396.

[5] Frederico Afonso, José Vale, Éder Oliveira, Fernando Lau, Afzal Suleman, A review on non-linear aeroelasticity of high aspect-ratio wings, Progress in Aerospace Sciences 89 (2017) 40–57.

[6] C. An, C. Yang, C. Xie, L. Yang, Flutter and gust response analysis of a wing model including geometric nonlinearities based on a modified structural ROM, Chinese Journal of Aeronautics 33 (2020) 48–63.