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Bifurcations in flight dynamics and aeroelasticity: Nonlinear analysis and numerical simulations

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SUMMARY

In aeronautics some phenomena require a nonlinear approach because the linear analysis is not suffient to catch the underlying physics. Some issues met in the fields of flight dynamics and aeroelasticity are concerned with this feature. This study aims at showing so-called bifurcations implying unpredictable behaviours in the linear frame such as jumps or appearances of limit cycles and thus for which a nonlinear analysis is mandatory in order to catch the real behaviour. The methodology and practical aspects necessary to perform such an analysis are here exposed.

The first topic concerns the longitudinal flight of a F-18 fighter. The results of the computation with the numerical bifurcation analysis toolbox *matcont* are shown and the angles-of-attack α (equilibria and limit cycles) are given in function of the elevator deflection δ_e with a fixed throttle. A Hopf bifurcation is diagnosed and gives raise to periodical orbits which may surprise the pilot. This can be a hazardous situation to manage (especially with a nonzero flight-path angle during a landing phase). Moreover there is a range of elevator deflections δ_e for which there are multiple equilibria for the same elevator deflection. A pitchfork bifurcation is responsible for a hazardous stabilization at a nonzero bank angle.

The other topic deals with the aeroelasticity of an airfoil. The nonlinear physics come from the pitch stiffness (torsion), the plunge stiffness (flexion) or the aerodynamics (stall) amongst others. Several approaches are used so as to assess the flutter properties. On the one side, a continuation algorithm (*matcont* toolbox of *matlab*) allows the nonlinear analysis by computing the equilibria and the envelope of the periodical orbits. On the other side, a software of numerical simulation (*star-ccm+*) is exploited with a method of *overset mesh* so as to take into account easily the motions of plunge and pitch of the airfoil and may help investigating some types of nonlinear behaviour.

For example, the plunge stiffness can be hardened $k_h(h) = K_h\left(1+\xi h^2\right)$. The Hopf bifurcation associated to $\xi = 50$ is supercritical and the one associated to $\xi = 0.09$ is subcritical (more dangerous) as observed in the bifurcation diagrams. Thus the hardening of the plunge stiffness seems to have a favourable effect.

To put in a nutshell several ways to analyse these nonlinear phenomena met in aeronautics are shown, diverse mathematical tools are used and reveals to be helpful for the design of an airplane.

Keywords: bifurcation theory, flight dynamics, aeroelasticity, overset mesh

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