Nonlinear analysis of the longitudinal flight dynamics of a transport airplane

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Some phenomena affecting the longitudinal flight dynamics of a transport airplane cannot be analysed by a classical linear approach and need a nonlinear dynamical system theory. The bare or augmented aircraft may be concerned. In this study, our attention is focused on deep-stall and pilot-aircraft coupling.

On the one hand, deep-stall consists in a stable equilibrium at high angle of attack, which unfortunately proves to be difficult to leave. It is thus interesting to determine the different equilibria and their stability for a range of controls and then to diagnose the configurations leading to stabilisation at such a hazardous state.

A civil transport aircraft with T-tail is considered. This type of aircraft can meet deep-stall because the wake of the main wing can flow over the tail and render it ineffective. The flight dynamics models under study are based on the identification of the global aerodynamic coefficients or on the sommation of the contribution of all the elements. The locus of equilibrium points (bifurcation diagram) is first calculated and shows the elevator deflexions for which the aircraft is prone to deep-stall. Then the basin of attraction can be determined amongst others by computing the stable manifold of the saddle-node equilibrium (at medium angle of attack) in the (α, q) phase portrait as illustrated in the figure (1).

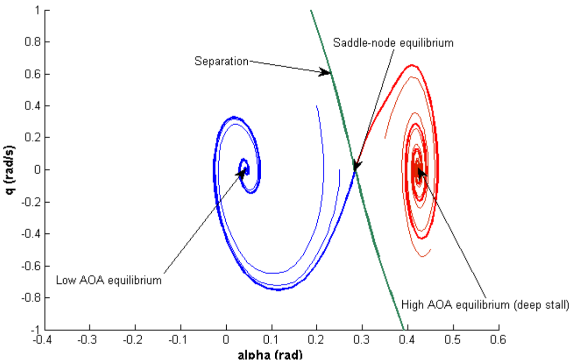

Figure 1: Phase portrait and basin of attraction associated with the deep-stall phenomenon

Knowing the dynamics for nose up and nose down elevator position, it is possible to distinguish some dangerous situations and to give some advices for the aircraft design or the recovery procedure. A parametric study towards physical or conception parameter can also be performed in order to assess their influence on the overall dynamics.

On the other hand, nonlinear elements such as rate limiting of an actuator can be responsible for flying qualities cliffs and pilot-induced oscillations which may surprise the pilot. Diagnosing the configurations for which a limit cycle appears suddenly helps conceiving an aircraft with adequate flying qualities and avoiding disastrous situations.

At the end of this study, it is shown that the nonlinear system theory provides us with effective and concrete results concerning the T-tail airplane flying qualities.

References

[1] R. T. Taylor and E. J. Ray. A systematic study of the factors contributing to post-stall longitudinal stability of t-tail transport configurations. In *AIAA Aircraft Design and Technology Meeting*, Los Angeles, USA, November 1965.

[2] R. C. Montgomery and M. T. Moul. Analysis of deep stall characteristics of t-tailed aircraft configurations and some recovery procedures. *Journal of Aircraft*, 3 (6):562 – 566, 1966.

[3] M. G. Goman, G. I. Zagainov, and A. V. Khramtsovsky. Application of bifurcation methods to nonlinear flight dynamics problem. *Progress in Aerospace Scineces*, 33:539–586, mars 1997.