LPV Control Design to Suppress Wing Rock Motion

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Wing rock motion is one type of lateral-directional instability of aircraft revealed as limit circle oscillations mainly in roll. The wing rock problem has received considerable attention for many years. Considerable research has been performed to understand the mechanisms causing wing rock, construct an adequate aerodynamic model and investigate flight dynamics of wing rock. All this is very important for aircraft safety. It is well known that wing rock is a nonlinear phenomenon, so, the aerodynamic model of the aircraft subjected to this instability must be nonlinear and control laws for wing rock suppression must be nonlinear also. Most researches who considered wing rock dynamics theoretically have used an aerodynamic model containing nonlinear roll rate terms which lead to limit circle existence. Very different controllers to suppress wing rock motion where suggested: adaptive, neural network controllers, nonlinear H_∞ controllers applied to restricted problem statement and some others. Nevertheless, wing rock suppression is still an actual problem for certain aircraft due to difficulty of accurate modeling of high angle of attack aircraft aerodynamics and a variety of nonlinearities of different aerodynamic configurations.

The present paper considers a rather simple aircraft aerodynamic model subjected to wing rock motion. A main source of this instability is a strong nonlinear dependence of roll moment on sideslip angle. Wing rock dynamics and its boundaries in this paper are investigated computationally using full system of motion equations and qualitative analysis methods for nonlinear dynamical systems. In continuation process used for dynamics analysis the control surfaces deflections are used as continuation parameters. It is shown that wing rock motion existing in a certain range of stabilator deflections transforms to another dangerous motion known as falling leaf mode with increasing of rudder deflection used as a continuation parameter.

Calculated parameter ranges of wing rock onset are used for generation of quasi-linear parameter dependent model of lateral\directional mode for Linear Parameter Varying (LPV) control law design. The quasi-LPV model captures nonlinearity of roll moment dependence on sideslip angle and dependence of lateral\directional model parameters on angle of attack in the range of wing rock onset. The validity of the constructed LPV model is checked out by the fact that it generates the wing rock motion similar to responses of the aircraft.

A control effector used for wing rock suppression is differential stabilator, while ailerons and rudder are left for traditional roll/sideslip control. A control design procedure is typical in the LPV design framework: stabilize zero equilibrium in lateral\directional motion for the whole range of parameter variations providing a certain error level under specified disturbances, perturbations and under actuator constraints. The design is performed based on LPV synthesis theory which involves Linear Matrix Inequalities (LMIs) optimization technique.

The wing rock suppression with a designed LPV control law is validated based on linear robustness analysis and non-linear time-domain simulations, including simulations for a disturbed aerodynamic model with variations of linear and nonlinear aerodynamic model terms. Linear robustness analysis of the control law performed using μ analysis indicates the closed-loop robustness to variations of aerodynamic coefficients and unmodelled dynamics. The performed analysis confirms the applicability of LPV control design methods for wing rock motion suppression.