

On-Line Robust Aeroservoelastic Stability Margin Analysis from Wavelet-Processed Flight Testing Data

Hongchao Li, Zhongke Shi and Wei Tang

Abstract—An on-line method based on robust μ analysis is presented to evaluate the stability margin of multi-loop aeroservoelastic system from flight testing data. The flight data is preprocessed to remove noise by wavelet filter in time-frequency domain. The method for stability analysis is described and the classical stability margin used for single-input-single-output (SISO) system has been extended to multi-loop system. With the present definition for uncertainty, the guaranteed bounds on gain and phase margin can be calculated for a specified μ value. A nonparametric identification is applied to determine the open-loop transfer function from testing data. This method enables us to implement on-line stability evaluation without theory model. Finally, the analysis results are compared with return difference matrix method to illustrate the efficiency of the new method.

I. INTRODUCTION

Modern combat aircrafts are designed to meet the two objectives of low structural weight and high maneuverability. They employ advanced metallic and composite materials in their structure design and full authority of fly-by-wire automatic control system (FCS) for their control. This design has resulted in lowering of aircraft structure modal frequencies because of increasing structure flexibility and an increase of FCS bandwidth to meet high response requirements. As a consequence, the overlap or proximity in the structural and control dynamic response ranges has increased, resulting in a strong possibility of structure and control coupling in the total aircraft response. This mutual interaction between the FCS and the airframe dynamic response due to inertial and unsteady aerodynamic forces is technically known as aeroservoelasticity (ASE).

Envelope expansion of new modified aircrafts often requires structural stability testing to prevent against ASE instability. In-flight testing allows determination of ASE effects as a function of flight parameters. With the aid of flight testing data, on-line stability margins analysis is

implemented for safety of flight. The ASE system including airframe and FCS can be regarded as a typical multi-loop system. The classical stability margin analysis method, such as Bode and Nyquist techniques, work well for SISO system but are inadequate for multi-loop system. In the past, return difference matrix (RDM) with singular value has been proposed for multi-loop system stability analysis [1]–[3]. And this method has been employed successfully to provide flight-determined stability for X-29A aircraft multi-loop control system in reference [4]. The drawback is that the stability margins result based on singular value is overly conservative. Recent years, robust μ analysis has been used as a promising method for stability analysis of multi-loop system [5]. And R.Lind [6] develops a μ method for ASE stability analysis. However, a theoretical aeroservoelastic aircraft model is required before analysis.

This paper introduces a μ method for multi-loop ASE stability analysis with on-line nonparametric system identification. This method enables us to incorporate flight data into model development and implement μ analysis without theoretical model. The guaranteed bounds on gain and phase margin calculated from a specified μ value are described. In order to improve the signal to noise ratio (SNR) of flight data, a time-frequency filter is applied firstly for data processing. Then the detailed description of μ method and guaranteed bounds on gain and phase margin calculated from a specified μ value will be given in Section IV. And the nonparametric identification with spectrum is discussed in Section V. Finally, the efficiency and effectiveness of this method is validated by real flight test data.

II. AEROSERVOELASTIC SYSTEM AND FLIGHT TEST

The actuators, flexible aircraft and lateral-direction control system comprise a typical multi-loop aeroservoelastic system. In real flight test, an onboard excitation system (OBES) is used to add programmed digital signal to the control system as actuator command for structural excitation. A simplified model for this system has been shown in figure 1, in which, the inputs $r = [r_\phi, r_\psi]$ are commanded to roll and yaw axis to excite aircraft dynamics. $u = [u_\delta, u_r]$ denotes aileron, rudder commands to actuators. y is known as dynamic response of aircraft. And $e = [e_\phi, e_\psi]$ is feedback commands to actuators.

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