JOURNAL OF AIRCRAFT
Vol. 46, No. 5, September–October 2009

Identification of a Nonlinear Wing Structure Using an Extended Modal Model

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DOI: 10.2514/1.42024

The nonlinear resonant decay method identifies a nonlinear dynamic system using a model based in linear modal space comprising the underlying linear system and a small number of additional terms that represent the nonlinear behavior. In this work, the method is applied to an aircraftlike wing/store/pylon experimental structure that consists of a rectangular wing with two stores suspended beneath it by means of nonlinear pylons with a nominally hardening characteristic in the store rotation degree of freedom. The nonlinear resonant decay method is applied to the system using multishaker excitation. The resulting identified mathematical model features five modes, two of which are strongly nonlinear, one is mildly nonlinear, and two are completely linear. The restoring force surfaces obtained from the mathematical model are in close agreement with those measured from the system. This experimental application of the nonlinear resonant decay method indicates that the method could be suitable for the identification of nonlinear models of aircraft in ground vibration testing.

I. Introduction

THE identification of nonlinear dynamic systems is a topic of considerable current interest, given that many real systems exhibit nonlinear characteristics [1]. Methods range from those that allow detection of the presence of nonlinear effects, through indicating the classification of the type of nonlinearity present, to methods that seek to identify a mathematical model for the nonlinear system under test. The latter class of methods is of most interest, as they allow the response of the system to be predicted and they potentially enable structural modification studies or other interventions to be carried out.

It is generally accepted that recent developments in aerospace engineering, such as active control systems and increasingly flexible structures, have rendered aircraft more nonlinear. Furthermore, traditional sources of nonlinearity such as backlash in bearings and store pylons are still present. Therefore, the true vibrational characteristics of an aircraft can only be obtained if the nonlinearity present in the structure and control system is quantified and identified.

Because of these considerations, there is increasing interest in ground vibration tests (GVTs) for aircraft that can detect, characterize, and identify nonlinearity. Current GVT methodologies can only readily detect nonlinearity using stepped sine or phase resonance [2] tests. Several extensions to this methodology have been proposed, such as the nonlinear resonant decay method (NL-RDM) [3,4], phase-separation techniques [2,5], nonlinearity detection by wavelet transforms of impulse responses [6], describing functions [7] (also called linearity plots [8] or modal characterizing functions [9]), identification of nonlinearities by time-series-based linearity (INTL) plots [10], neural networks [11], expert systems [12], and Hilbert transforms [9].

Nonlinear system identification can be performed in physical space (i.e., using measured inputs and responses for parameter estimation) or in modal space (using modal responses). Aircraft-specific work usually focuses on modal models due to the high level of complexity of aircraft structures [3–5,8,10]. The usual assumption is that aircraft are mostly linear dynamic systems that contain some weakly nonlinear modes. These modes behave nearly linearly under small amplitudes of excitation. Consequently, a linear modal model is a good approximation of the true aircraft at low excitation levels and a good basis for a nonlinear model.

The focus in this paper is on a particular approach to identifying a nonlinear aircraft model based in linear modal space. The NL-RDM was first proposed in 2001 [3] and further detailed in subsequent publications [4,13]. It aims to identify a model based in linear modal space, the so-called extended modal model. It is fundamentally based upon a development of the original restoring force surface approach in modal space [14] and takes advantage of the methodologies for normal mode force appropriation [15]. In fact, the NL-RDM was the first approach to propose the application of appropriated excitation to nonlinear systems to limit the number of responding modes [3]. It seeks to consider modes as being in one of several categories: namely, 1) modes that behave linearly, 2) modes that behave nonlinearly but are not nonlinearly coupled to other modes, and 3) modes that are nonlinear and are nonlinearly coupled to other modes. Each of the modes behaving nonlinearly (i.e., categories 2 and 3) may then be identified using a relatively-low-order model in which a limited number of nonlinear modal terms (usually, but not necessarily, of polynomial type) extend the linear modal equation for that mode to account for the nonlinear effects. The use of appropriated force patterns provides a coarse filter in which each mode of interest is

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Received 5 November 2008; revision received 2 June 2009; accepted for publication 11 June 2009.

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