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OPERATIONAL MODAL ANALYSIS OF IN-FLIGHT SPACE LAUNCH VEHICLES ON USE OF TRANSMISSIBILITY MEASUREMENTS

Abstract

Space launch vehicles are slender and flexible because their structural designs tend to low weight and low aerodynamic drag. The appreciable flexibility leads to the low natural frequency of space launch vehicle structures, which may results in the significant coupling dynamics of rigid-body motions and flexible vibration. Some of the coupling dynamic effects can cause the dynamic instability of space launch vehicles. Therefore, the flexible vibration needs to be filtered from the dynamic measurements commonly by notch filtering, while the rigid-body motions are kept for the flight control of space launch vehicles. In the notch filtering of the flexible vibration, modal parameters, especially the modal frequency, of space launch vehicles are necessary. It is advantageous to estimate modal parameters from the operational measurements of in-flight space launch vehicles in contrast to extracting modal parameters by using analytical approaches, such as finite element analysis, or the experimental modal analysis on the ground, because modal parameters from the operational measurements are real for in-flight space launch vehicles, which include the aerodynamic, thermal, etc. effects. The operational modal analysis of in-flight space launch vehicles is output-only, since the natural excitations, including the thrusts, aerodynamic loads, sloshing loads, etc., are unknown. Unfortunately, current output-only techniques have serious limitations when applied to space launch vehicles. One limiting constraint is that the unknown excitations must be white-noise sequences. To overcome the limiting constraint of the current output-only techniques, this paper presents a transmissibility-based approach for operational modal analysis of in-flight space launch vehicles. Firstly, this paper introduces the parametric model of transmissibility function as well as the non-parametric estimation approach of transmissibility measurements. Secondly, the rational function defined by the difference of two transmissibilities of same output location but different input locations is presented, which is the basic data for modal parameter estimation. Thirdly, the estimation approach of modal parameters is proposed, which replaces the frequency response function (FRF) with the transmissibility-based rational function in the classic least square complex frequency-domain (LSCF) method. Finally, the simulation examples evaluate and validate the proposed transmissibility-based method by comparing with the FRF-based experimental modal analysis methods and the power spectral density (PSD) -based operational modal analysis methods. Comparing with the classic methods, the white-noise assumption is not necessary for the transmissibility-based approach. The unknown operational excitations could be arbitrary (colored noise, impact, etc.) as long as they are persistent in the frequency band of interest.