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UNCERTAINTY DESIGN AND OPTIMIZATION OF SMALL HYBRID LAUNCH VEHICLES BASED ON POLYNOMIAL CHAOS EXPANSION

Abstract

With the rapid growth of the demands on small satellites in commercial and military fields, small launch vehicle(SLV) with the advantages of low cost and quick response develops quickly recent years. The hybrid rocket motor(HRM) has the merits of easy throttling, simple structure, multiple-start, high-reliability and environmental friendly, and it gradually becomes a selected propulsion system for SLV. However, it involves strongly-coupled multidisciplinary parameters and lots of uncertain factors in the design of SLV powered by HRMs which have both a liquid feeding system and a chamber with solid fuel grain. Therefore, efficient design optimization methods under uncertainty are needed for the overall design of small hybrid launch vehicles. In this paper, an uncertainty analysis method based on polynomial chaos expansion(PCE) is carried out to improve calculation efficient in uncertainty analysis and optimization. Based on random spectrum expansion theory, Wiener-Askey polynomials are selected to solve the expansion coefficients of non-embedded polynomials through regression method, then an analysis method for simulating uncertainty propagation in complex systems is obtained. Based on HRM and other disciplines including aerodynamic, trajectory and structure, the overall design model of a small hybrid launch vehicle is obtained. The performance parameters of Minotaur launch vehicle are selected as the reference, then a deterministic design optimization of a small hybrid launch vehicle is carried out. According to the design results and sensitivity analysis, the uncertainty design and optimization is adopted using PCE method and Monte Carlo simulation. The characteristics of the two design results are compared while the efficiency and precision of uncertainty analysis methods are analyzed. The results show that the small hybrid launch vehicle has good performance and meets the launch requirements of small payload. Compared to deterministic one, the uncertainty design optimization methods improve the reliability and robustness obviously, but have a little performance loss. Comparing to Monte Carlo method, the computing efficiency of PCE method is obviously improved under the circumstance of the same precision. Thus, the PCE-based uncertainty analysis method can efficiently improve calculation efficiency in complex systems while ensuring high computational accuracy, and has a good application prospects in launch vehicle fields.