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UNCERTAINTY ANALYSIS AND ROBUSTNESS-RELIABILITY-BASED DESIGN OPTIMIZATION OF HYBRID ROCKET MOTOR

Abstract

Hybrid rocket motor shows great potential advantages as it is less complex and cheaper than liquid rocket motor, and easier to throttled and restarted than solid rocket motor. However, it has both a liquid oxidizer feed system and a solid fuel thrust chamber, so the system design process of hybrid rocket motor is complicated and contains large numbers of uncertainties. In order to improve the design level, the uncertainties in hybrid rocket motor design are analyzed and a method of probabilistic robustness-reliability-based design optimization with modified Differential Evolution algorithm and Monte Carlo sampling for hybrid rocket motor is proposed. In this method, the system design model of hybrid rocket motor is established to computed the performances from the design parameters. The input uncertainties, parameter uncertainties and model uncertainties of the system design model are researched, then their probability distribution are studied and quantified. The sensitivities of the uncertainties to target function and constraints are analyzed using a second order polynomial response surface model with Uniform Design sampling, and the uncertainty factors with little effect are filtered out. Since the system design model of hybrid rocket motor is a multidimensional and nonlinear system with discrete input design variables, a modified Differential Evolution algorithm is used to improve the efficiency and quality of the optimization solution. The mean value and standard deviation of target function as well as the probability which meet constraint conditions are calculated by Monte Carlo sampling analysis. In this approach, the target function is to minimize the mean value and standard deviation of the total mass of hybrid rocket motor to ensure that the system has a robust performance while confidence-level constraints ensure that system reliability requirements are met with high probability. The modified Differential Evolution algorithm with Monte Carlo sampling optimization method is applied to a hybrid rocket motor concept design, and compared to a modified Differential Evolution algorithm with deterministic optimization approach. The comparison shows that the modified Differential Evolution algorithm with Monte Carlo sampling optimization method produces optimal designs that have low total mass while achieving reliability requirements at specified high confidence levels, while the modified Differential Evolution algorithm with deterministic optimization approach produces heavy total mass designs with excessive redundancy. The uncertainty design optimization method can provide better means for system concept design of hybrid rocket motor.