Ship Multidisciplinary Robust Design Optimization under Multidimensional Stochastic Uncertainties

Dong-qin Li, Zhi-yong Jiang, Xin Zhao
School of Naval Architecture & Ocean Engineering, Jiangsu University of Science and Technology
Zhenjiang, Jiangsu, China

ABSTRACT

Generally the multidisciplinary design optimization in ship design only considers the impact of certainties with ignoring the existence of uncertainties in the design. The results of the optimization obviously cannot really guarantee the feasibility of ship hull and excellence of sailing performance. Currently, uncertainty multidisciplinary design optimization of ship focuses on one dimension of uncertainty analysis. To obtain the optimal solution of ship design, the problem of Multidisciplinary Robust Design Optimization (MRDO) under multidimensional uncertainties is studied in the paper by analyzing and considering uniform distribution and normal distribution of random uncertainties. It deduces a new multi-dimensional polynomial chaos approach based on Legendre polynomials and Hermite polynomials. It is established the mathematical models of multi-dimensional uncertainty quantification while considering the speed reducer and bulk carrier optimization as the research objects. By analyzing the influence of multi-dimensional stochastic uncertainties to the ship design optimization, the research of ship robust multidisciplinary design optimization is completed. The possibility of failure in ship design optimization is effectively reduced and avoided.

KEY WORDS: Stochastic uncertainty; multidisciplinary robust design optimization; multi-dimensional polynomial chaos; uncertainty quantification

INTRODUCTION

Over the years, optimization has been playing an increasingly important role in engineering. Complex systems like ships and other marine structures must fulfill multiple, often conflicting objectives (Knight Joshua T., 2014). Multidisciplinary Design Optimization (MDO) can be used to evaluate multiple, conflicting objectives simultaneously and reveal useful tradeoff information for decision-making purposes (Dong Suzhen, 2014). However, real world applications are affected by uncertainty and require uncertainty analysis and uncertainty quantification (UQ). Uncertainty exists in many of the design variables and system parameters for ship and marine structure design. This is especially true in the early stages of design. For this reason and others, optimization of a ship's performance characteristics is often delayed until later in the design process, after uncertainties have been at least partially resolved.

At present, most of the ship multidisciplinary design optimization model is built on the basis of the deterministic Multidisciplinary Design Optimization theory. In fact, the choice of optimum will be affected by many uncertainty factors, which may lead to the failure for the ship design; the optimization results obviously cannot really guarantee the feasibility of ship hull and excellence of sailing performance (Diez M, 2014). To overcome this limitation, the optimization problem may be solved under a probabilistic standpoint with uncertainty. That is to say, deterministic MDO can be augmented in an ad hoc formulation that include uncertainties, leading to the development of a Multidisciplinary Robust Design Optimization framework (MRDO), with the goal of producing optimal designs relatively insensible to the stochastic variations of environment and operations, and safe with respect to degradation of the performances in off-design conditions. MRDO method is actually an effective way to solve the problem of multidisciplinary design optimization problem considering the uncertainty factors (Leotardi C., 2015). The core idea is to consider the coupling effect among different disciplines through uncertainty quantification, and to obtain the overall optimal solution of the system.

From the mathematical standpoint, the application of statistical decision theories to deterministic analysis requires the Uncertainty Quantification as a pre-requisite to Robust Design Optimization. This paper will present and discuss some of the fundamental aspects in building a MRDO framework; this article will also demonstrate how multidimensional uncertainties can be directly incorporated into optimization using a new hybrid polynomial chaos method which is used to evaluate the expected value and the standard deviation of the objective functions in the process of Uncertainty Quantification. In addition, the expected value and standard deviation of the original (deterministic) objective can be included in the optimization, and the problem can be solved as a two kinds of objectives minimization procedure. Finally the proposed hybrid polynomial chaos method has been verified by the uncertainty optimization of speed reducer and bulk carrier.