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Robust optimization of structural–acoustic coupled system with random parameters

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ABSTRACT

Aircraft noise has become an important factor that endangers public health and acoustic navigability. Reducing the noise and optimizing the structural–acoustic system in an effective way is of great importance. Because of the uncertainty existing in the structural or acoustic parameters, traditional deterministic optimization may be unfeasible when the parameters are subject to fluctuations. When the structural or acoustic parameters have uncertainty, the design scheme obtained from the deterministic optimization may be beyond the scope of the method. Therefore, we must develop an optimization method that can consider the uncertainties in the involved parameters. To accomplish this, a robust optimization method of structural–acoustic coupled systems with random parameters is proposed based on the traditional optimization method. Two methods of robust optimization for structural–acoustic systems are introduced including the objective function robustness and the constraint condition robustness. The multi-objective optimization problem is transformed into a single objective problem using a weight factor. The results of the two numerical examples illustrate the efficacy of the proposed robust optimization method.

1. Introduction

The structural–acoustic problem has become an important issue in the design of aerospace craft. The magnitude of the structural borne noise strongly influences the habitability, comfort, and perceived quality of these vehicles. A high level of vibration and noise can cause structural fatigue damage of the aerospace. In many cases, the airplane must meet strict vibro-acoustic standards. Many technologies can be used to achieve significant noise and vibration suppression, such as optimizations, passive isolation and active control. In particular, design optimization methods have gained wide attention in the literatures. However, in structural–acoustic coupled systems, some uncertain factors are inevitably in almost all structures due to the randomness of loading conditions, material properties and simulation modelling [1]. Traditional deterministic optimization of the structural–acoustic coupled system does not consider the impact of these uncertain factors on the structural–acoustic system. As a result, the design scheme obtained with the deterministic optimization method may have low reliability and robustness. If the design scheme of the deterministic optimization is used for design directly, the quality of the results is at great risk and it may be beyond the constraint conditions when considering the uncertainties. The uncertainties can be regarded as random variables. The difference between the actual value and the nominal value of the structural or acoustic performance may occur in the design process of structural–acoustic systems, manufacturing/service stage and material aging. Thus, it is necessary to propose an optimization method considering the uncertainties in the design of structural–acoustic systems.

Robust optimization is a feasible method for dealing with uncertainties and it has been widely used in structural design optimization. Taguchi [2] originally proposed a robust design concept to handle the uncertain optimization problem. Kang and Chen [3] studied the nonlinear structural robust design problem using the perturbation-based stochastic finite element analysis incorporating structural optimization techniques. The problem was formulated as a multi-criteria optimization problem, in which both the expected value and the standard deviation of the objective function were minimized. The robustness of the feasibility was also accounted for by involving the variability of the structural response in the constraints. Chen [4] introduced the basic concept, mathematical description and implemental process of the six sigma-based robust design optimization. Based on the robust optimization design of traditional statics, Xiao and Jian [5] studied the dynamic problems by optimizing the robustness of the objective function and con-

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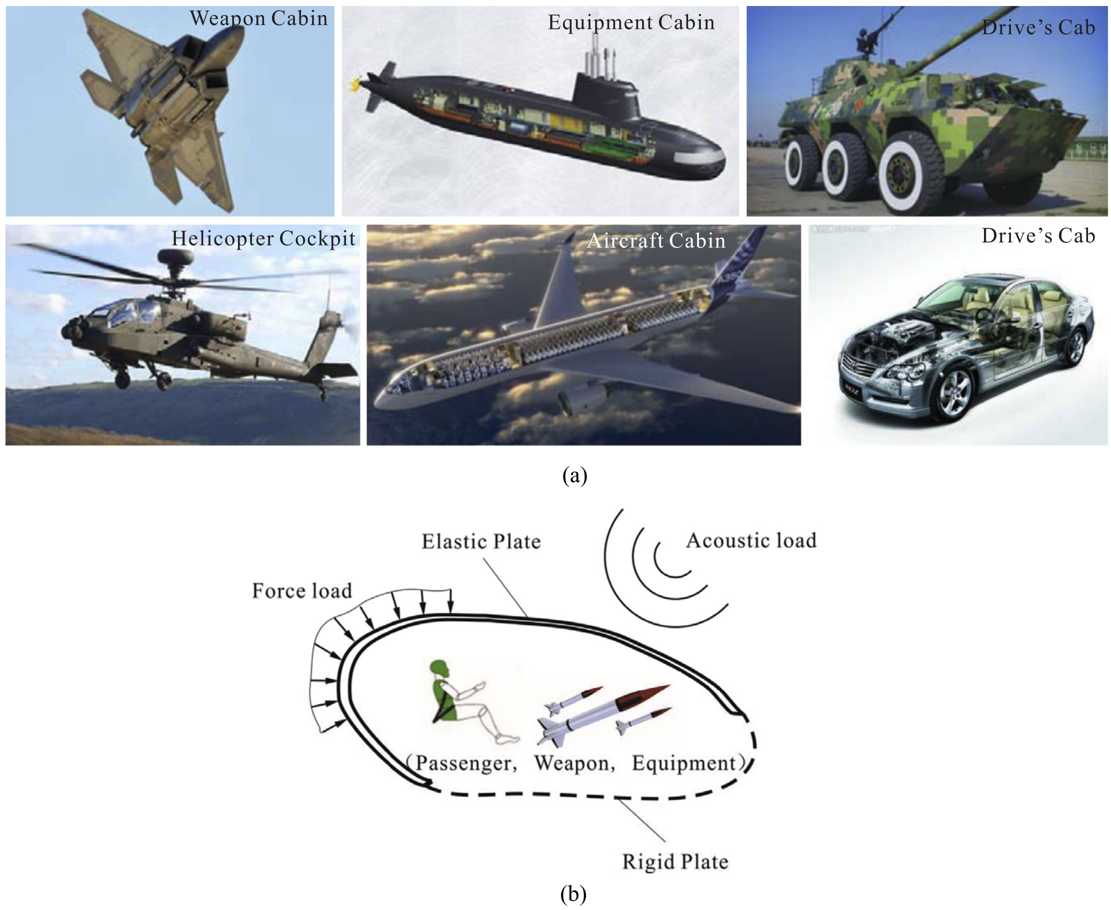

Fig. 1. The structural–acoustic system. (a) Typical military and civilian products with structural–acoustic coupled systems (from the Internet). (b) A schematic of a structural–acoustic coupled system.

straints condition. Zhang et al. [6] presented a robust optimization design method for the advanced grid composite cylindrical shell with initial-imperfect. Liu [7] constructed the 6σ robustness optimization design method based on product quality engineering and achieved the 6σ quality of the design target by combining it with the NSGA-II algorithm and the Monte Carlo simulation technique. Wang and Wei [8] discussed the reliability, optimum design, reliability-based optimization and robust optimization for laminated composites.

Some scholars have studied the structural–acoustic optimization problem. Structural–acoustic optimization often takes the minimum structural weight as an objective function and the acoustic pressure at the design domain points and either the total acoustic radiation pressure of the structures as or the minimum acoustic response as a target while the structural weight as the constraint condition. Zhang et al. [9,10] performed the optimal geometric design of the structures to reduce the acoustic pressure at positions and frequencies of interest using the feasible direction method and the acoustic response characters were evaluated based on the 3-D FEM model with the direct method. Chen et al. [11] presented the finite element equations for a low-frequency acoustic–structural coupled system and developed their optimization model. Other scholars have also examined structural–acoustic optimization, but the majority were deterministic optimization [12–18].

All of the above structural optimization methods are deterministic and do not consider the uncertainties in the structural–acoustic system. In fact, uncertainties are inevitable in the structural–acoustic systems of aerospace structures. Stochastic, interval and fuzzy methods are the three most commonly used approaches to solve uncertainty problems. The stochastic method is the most popular method for dealing with the uncertainties in structural–acoustic systems. From the literature, we can see that deterministic optimization is widely used in the structural–acoustic system. However, few papers can be found regarding the optimization of the structure with random parameters. Thus, it is essential to study the influence of stochastic uncertainties in the optimization of structural–acoustic systems.

Our aim in this paper is to apply the robust design method to structural–acoustic systems to consider the uncertainties in the structural or acoustic parameters. The goal of robust optimization is to reduce the sensitivity of the random variables and to improve the structural and acoustic performance. In this paper, two robust optimization methods of structural–acoustic coupled systems are established. Deterministic optimization and robust optimization are compared and the results demonstrate the advantage of the robust optimization. The multi-objective functions of the optimization are processed using the weight factor method.

2. Physical problem and concept of robust optimization in structural–acoustic coupled system

Vibration and noise is an important branch of mechanics and has been widely recognized in engineering, which affects not only public daily life but also national defense, engineering and technology. Cavity structures are commonly used in advanced fighter aircraft, submarines, helicopters, tanks, civil aircraft, vehicles and other types of civil and military equipment, as shown in Fig. 1(a). The most important mechanical consideration of the cavity structure is the structural–acoustic coupled problem, which consists of an elastic structure in the fluid under the influence of externally