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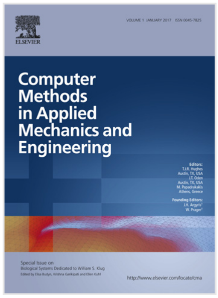

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Algorithms and analyses for stochastic optimization for turbofan noise reduction using parallel reduced-order modeling

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Abstract

Simulation-based optimization of acoustic liner design in a turbofan engine nacelle for noise reduction purposes can dramatically reduce the cost and time needed for experimental designs. Because uncertainties are inevitable in the design process, a stochastic optimization algorithm is posed based on the conditional value-at-risk measure so that an ideal acoustic liner impedance is determined that is robust in the presence of uncertainties. A parallel reduced-order modeling framework is developed that dramatically improves the computational efficiency of the stochastic optimization solver for a realistic nacelle geometry. The reduced stochastic optimization solver takes less than 500 seconds to execute. In addition, well-posedness and finite element error analyses of the state system and optimization problem are provided.

Keywords: stochastic Helmholtz equation, conditional value at risk, proper orthogonal decomposition, turbofan noise reduction

1. Introduction

Aircraft noise is a major constraint on expanding and improving the air transport environment throughout the world. With the popularization of air transportation, aviation noise mitigation has always been an interesting topic for researchers and engineers [39, 4]. Noise emission at take-off and landing from the high-bypass turbofan, the only choice of engine for commercial aircrafts because of its lower fuel consumption [2], is mainly contributed by the engine fan noise [19]. At take-off, the fan rotational speed is supersonic and this makes the noise (known as "buzz-saw" noise) propagate upstream the inlet [26]. During landing, the fan speed is low and the noise is caused by the interaction of the blades with the inlet flow.

The fan noise radiation can be effectively damped by the equipment of an optimally designed acoustic liner in the engine nacelle. To this end, one needs to address some design challenges including but not limited to the choice of acoustic liner material and layer structure. The performance of acoustic liners can be evaluated in experiments by means of ground tests [33] or in dedicated experimental test rigs [11]. Simulation-based optimization on the liner design, however, can dramatically reduce the experimental cost and time. In particular, simulations have been performed in [5] for the search of liner impedance factors, by solving an optimization problem towards minimizing fan noise radiation. In this paper, we still focus on the estimation of optimal liner impedance factors.

Mathematical models governed by partial differential equations (PDEs) often contain coefficients (or boundary condition data), such as the acoustic wavenumber in the Helmholtz equation for sound propagation, that are not exactly known due to incomplete knowledge or an inherent variability in the system. These uncertainties should be introduced into the model by treating the parameters as random variables. Optimization of the resulting stochastic system would be more complex than the deterministic one, but its accommodation to model uncertainties provides a more robust and realistic tool for practical application. In this paper, we take into account uncertainties on the acoustic wavenumber due to variability in the weather, and on the fan noise source due to incomplete knowledge. We formulate the optimization on the conditional value-at-risk (CVaR) measure [32], which quantifies the conditional expectation of the sound energy provided that the sound is above a certain threshold. The optimization based on CVaR measure

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