INFLUENCE OF UNCERTAINTIES ON THE RESPONSE AND RELIABILITY OF SELF-ADAPTIVE COMPOSITE ROTORS

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ABSTRACT

Recently, advanced composite materials have become a popular alternative to traditional metallic alloys in marine applications, including marine rotors such as propellers and turbines. A typical marine rotor is constructed from nickel-aluminum-bronze (NAB) or manganese-aluminum-bronze (MAB) alloys. Composite materials are significantly lighter and provide improved corrosion resistance. In addition, composite rotors can provide improved hydroelastic and structural performance through passive tailoring of the coupled bend-twist deformations. Through proper design, the load-dependent deformations of a composite rotor can be tailored to maintain a more optimal pitch angle distribution over a range of flow conditions, and hence improved performance compared to its rigid counterpart.

Compared to metallic alloys, composite materials tend to be more susceptible to geometric and material imperfections due to the complex manufacturing process which results in random variations in material stiffness and strength parameters. Moreover, there is a level of modeling uncertainty when quantifying the initiation and evolution of material failures due to the complex, multi-scale failure mechanisms. Additionally, the geometry of a rotor can be highly complex, as shown in Figure 1. Slight variations in the blade pitch, rake, and skew distributions can affect overall performance. For a composite rotor, random variations due to fiber misalignments, voids, and laminate properties will also change the overall performance.

The objective of this research is to quantify the effects of material, geometric, and loading uncertainties on the response of self-adaptive composite propellers and overall system reliability. In doing so, safe operating envelopes can be developed and design tolerances can be recommended for a safe and reliable structure. A fully-coupled, 3-D, boundary element method-finite element method will be used to evaluate the fluid-structure interaction response [1,2]. The reliability of the structure can be estimated by considering the random variations in stiffness and strength parameters, as well as modeling uncertainties through use of different mechanistic-based failure models. Random variations in material strengths based on Gaussian distributions are implemented and a Monte Carlo analysis of the failure initiation indicators allows for a probabilistic estimate of the structural reliability. Figure 2 shows a sample plot of the probability of exceeding a specific percentage of blade failure for the three dominant failure modes. Variability in laminate fiber angles and material stiffness parameters is addressed by randomly varying the blade's equivalent unidirectional fiber angle, which is

used to simplify the analysis of the rotor blades [3], by $\pm 3^\circ$. The results are obtained by randomly varying the propeller pitch, rake, and skew by $\pm 2\%$. Figure 3 compares the results of the random variations on the performance for the rigid (NAB) and the adaptive composite (CFRP) propellers. The results indicate a much wider spread in the performance for the adaptive composite propeller due to the added material uncertainties. This is significant because it demonstrates that an adaptive composite structure that depends on fluid-structure interaction is more sensitive to natural, random variations than an equivalent rigid structure. Hence, there is a need to quantify the effects of material, geometric, and loading uncertainties on the response of self-adaptive composite propellers and overall system reliability.

Figure 1: Optimized adaptive composite and rigid metallic propellers.

Figure 2: Probability of exceeding specific percentage of blade failure initiation for matrix, delamination, and general ply failure criteria.

Figure 3: Variability in hydroelastic and structural performance (left) and resulting natural frequencies (right) as a function of random variations in geometric parameters (rake, skew, pitch, and fiber angles).

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