Mechanical Engineering Doctoral Defense

Multiscale Modeling of Advanced Materials for Damage Prediction and Structural Health Monitoring

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abstract

Advanced aerospace materials, including fiber reinforced polymer and ceramic matrix composites, are increasingly being used in critical and demanding applications, challenging the current damage prediction, detection, and quantification methodologies. Multiscale computational models offer key advantages over traditional analysis techniques and can provide the necessary capabilities for the development of a comprehensive virtual structural health monitoring (SHM) framework. Virtual SHM has the potential to drastically improve the design and analysis of aerospace components through coupling the complementary capabilities of models able to predict the initiation and propagation of damage under a wide range of loading and environmental scenarios, simulate interrogation methods for damage detection and quantification, and assess the health of a structure. A major component of the virtual SHM framework involves having micromechanics-based multiscale composite models that can provide the elastic, inelastic, and damage behavior of composite material systems under mechanical and thermal loading conditions and in the presence of microstructural complexity and variability. Quantification of the role geometric and architectural variability in the composite microstructure plays in the local and global composite behavior is essential to the development of appropriate scale-dependent unit cells and boundary conditions for the multiscale model. Once the composite behavior is predicted and variability effects assessed, wave-based SHM simulation models serve to provide knowledge on the probability of detection and characterization accuracy of damage present in the composite. The research presented in this dissertation provides the foundation for a comprehensive SHM framework for advanced aerospace materials. The developed models enhance the prediction of damage formation as a result of ceramic matrix composite processing, improve the understanding of the effects of architectural and geometric variability in polymer matrix composites, and provide an accurate and computational efficient modeling scheme for simulating guided wave excitation, propagation, interaction with damage, and sensing in a range of materials. The methodologies presented in this research represent substantial progress toward the development of an accurate and generalized virtual SHM framework.

April 20, 2015; 10:00 AM; ERC 490