Nonlinear thermoelastic modeling and uncertainty quantification in cylindrical structures

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Abstract. Input uncertainties and their effects on the linear and nonlinear response of a cylindrical structure subject to thermal loads with clamped-clamped boundary conditions are studied. The von-Karman nonlinearity is considered in the modeling of this system due to the mid-plane stretching nonlinearity of the end-constrained structure. The proposed system represents a simplified version of more complex systems with numerous practical applications, such as weapon systems, rockets, and more [1, 2]. To demonstrate forward propagation of uncertainty due to system inputs, this study focuses on variations of the predicted thermal load due to environmental factors. The thermal load variations are represented as input uncertainties that aim to overcome output inaccuracies that arise from assuming idealized systems. Specifically, the outcome refers to the linear and nonlinear dynamic responses of the proposed system. Thus, studies are performed computationally following a convergence analysis that aids in the reduction in the number of needed trials while maintaining the accuracy and reliability of the predicted response.

Introduction

The motivation of this research effort is to study the effects of input uncertainties in a dynamical system on the output uncertainty of the system's nonlinear dynamic response. Doing so will help improve the reliability of the obtained output of the system through its lifetime. The proposed system is a simplified model of a cylindrical weapon system, represented as a cylinder subject to thermal loads with clamped-clamped boundary conditions. Clearly, uncertainty in any system input, such as the thermal load will alter the system output, i.e. the buckling and nonlinear dynamic response due to von Karman nonlinearity [3]. Having that said, as the complexity of the system increase, so too will the number of input uncertainties. These input uncertainties can propagate through the system, leading to significant output uncertainties. It is especially important for complex systems, such as weapon systems to have reliable predicted outputs [2]. From this idea, it is necessary to improve the understanding of the nonlinear dynamic responses through system input uncertainties. The inputs for the cylindrical structure will contain the uncertainty of the thermal load and geometric/material properties of the cylindrical structure utilizing multiple probability density function distributions around the expected value. In terms of the output uncertainty, studies will be conducted on the buckling loads and post-buckled amplitudes, linear natural frequencies, and mode shapes. Finally, simplified analytical models will be utilized to perform a convergence analysis to reduce the number of needed computational trials, while maintaining the accuracy of the expected output ranges. This will replace previously conducted lengthy experimental and computational trials and the need for complex analytical parametric studies.

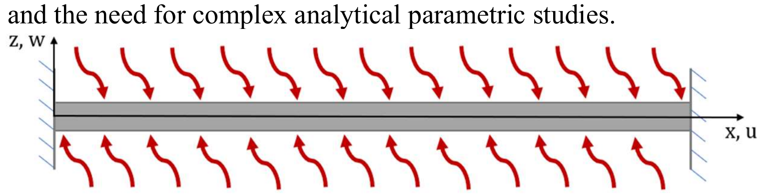

Figure 1: Cylindrical structure subject to thermal loading.

Results and discussion

In consideration of the results from this research effort, techniques and strategies will be developed to minimize uncertainties beginning with input uncertainties in simple systems, eventually progressing to more complex systems. This will allow for decreased risk probability and will increase the accuracy of the safety factor and for repairable systems, the mean time between failures (MTBF) [1]. Additionally, the needed computational trials will be reduced following an analytical convergence analysis of the needed trials.

References

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