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## NOISE MODELING AND RELIABILITY OF BEHAVIOR PREDICTION FOR MULTI-STABLE HYDROELASTIC SYSTEMS

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### ABSTRACT

This paper reviews results of experiments conducted on a simple multi-stable hydroelastic (galloping) oscillator. These results show that noise may cause a multi-stable hydroelastic system to exhibit chaotic behavior, and that in some instances such behavior cannot be predicted reliably unless noise effects are carefully accounted for. We then present results of a theoretical investigation of a simple, paradigmatic multi-stable system, the Duffing-Holmes oscillator. The results of this investigation show that for the system being considered, noise promotes the occurrence of chaotic behavior associated with Smale horseshoes. This theoretical investigation is the first phase of an effort to develop analytical tools for predicting reliably the potential for chaotic behavior of actual hydroelastic systems such as deep-water compliant platforms.

### INTRODUCTION

Overlooking certain types of dynamic behavior can constitute a gross design error with possibly disastrous consequences. It is such an a design error that led in 1836 to the collapse by flutter of the Brighton Chain Pier bridge. Neither this precedent nor the development of flutter theory by Theodorsen (1935) were understood by the bridge design community, and a similar design error led to the well-known collapse in 1940 of the Tacoma-Narrows bridge.

Thompson et al. (1984) noted that experiments and numerical studies conducted on compliant offshore structures can reveal the possible occurrence of unexpected types of dynamic behavior, including deterministic chaos. In those studies the chaotic behavior of the system of interest occurred in a hydroelastic system excited by periodic loads. More recently, experiments and numerical studies performed on a simple, paradigmatic hydroelastic system showed that irregular behavior involving catastrophic jumps between distinct regions of phase space could also be induced by the noise excitation of a multi-stable system (Simiu and

Cook, 1991, 1992). It is this finding that motivated the present work.

Indeed, new types of compliant offshore structures are being envisaged that can be anticipated to exhibit increasingly complex nonlinear behavior, including multi-stability. The hydroelastic studies just alluded to are therefore likely to be relevant in this context. This suggests the need to develop tools for describing and understanding dynamic effects due to the presence of noise. Numerical simulations can be helpful for this purpose. However, as pointed out in the paper, the numerical simulation approach has a number of practical limitations. It is reasonable to expect that theory could overcome some of these limitations, offer valuable fundamental insights, and help to develop reliable prediction capabilities.

Mathematically, a distinction has been made in the literature between chaotic (i.e., irregular) "basin-hopping" behavior with jumps induced by stochastic excitation or noise (Arecchi et al., 1983), and behavior exhibiting jumps associated with deterministic chaos (i.e., behavior that entails the formation of Smale horseshoes and, therefore, sensitivity to initial conditions, at least one positive Lyapounov exponent, basins of attraction with fractal dimension, and the existence of a strange attractor with fractal dimension (Guckenheimer and Holmes, 1983)). Experimental and numerical results (Simiu and Cook, 1992) have shown, however, that these two types of behavior can be indistinguishable phenomenologically.

In this paper we present a theoretical investigation which shows that, for a certain class of systems and for certain regions of parameter space, the mathematical distinction between noise-induced (stochastic) chaos and deterministic chaos can in fact be artificial. That is, what appears to be basin hopping caused by any given realization of a noisy process can be in fact a form of chaotic behavior associated with the formation of Smale horseshoes. Basic theory yields in this case necessary conditions for the occurrence of such chaotic behavior, as well as a useful measure of its strength as reflected,