Parametric Distribution Reconstruction Methods for Uncertainty Propagation and Reliability Assessment

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Density estimation methods play a critical role in inferring probability distributions and form the foundation of structural reliability analysis. Among the various density estimation techniques, moment-based parametric methods have garnered considerable attention due to their fundamental nature and practical applicability. A significant advantage of moment-based methods is their non-intrusive nature: on the one hand, they do not require the computation of the gradient information of the performance function; on the other hand, they avoid complex iterative processes, thereby greatly simplifying the treatment of implicit functions in engineering problems. Despite their many advantages, moment-based density estimation methods still face two major challenges in practical applications. The first is how to efficiently and accurately compute the statistical moments of the performance function; the second is how to accurately reconstruct the probability distribution of the performance function based on limited moment information, particularly achieving high accuracy in modeling the distribution tails. The focus of this presentation is on the second challenge, providing an in-depth analysis of improved strategies for reconstructing probability distributions using moment-based density estimation methods.

This presentation first provides a systematic introduction to several four-parameter probability distribution models that are widely applied in practical engineering. It then offers an in-depth discussion of maximum entropy methods based on continuous random variables, which are further categorized according to the nature of the imposed constraints into methods with integer moment constraints, fractional moment constraints, and fractional exponential moment constraints. Following this, the presentation systematically reviews and elaborates on polynomial transformation models extensively used in the field of structural reliability, establishing a comprehensive and in-depth foundational framework for the audience. Building upon this foundation, a polynomial transformation model based on probability-weighted moments is introduced to enhance the applicability and performance of traditional approaches. Finally, the presentation focuses on one-dimensional continuous mixture distributions, providing a detailed analysis of their concepts and properties and exploring their applications in uncertainty propagation and structural reliability analysis.