Characterizing Epistemic Uncertainty for Launch Vehicle Designs

Abstract

NASA Probabilistic Risk Assessment (PRA) has the task of estimating the aleatory (randomness) and epistemic (lack of knowledge) uncertainty of launch vehicle loss of mission and crew risk and communicating the results. Launch vehicles are complex engineered systems designed with sophisticated subsystems that are built to work together to accomplish mission success. Some of these systems or subsystems are in the form of heritage equipment, while some have never been previously launched. For these cases, characterizing the epistemic uncertainty is of foremost importance, and it is anticipated that the epistemic uncertainty of a modified launch vehicle design versus a design of well understood heritage equipment would be greater. For reasons that will be discussed, standard uncertainty propagation methods using Monte Carlo simulation produce counter intuitive results and significantly underestimate epistemic uncertainty for launch vehicle models. Furthermore, standard PRA methods such as Uncertainty-Importance analyses used to identify components that are significant contributors to uncertainty are rendered obsolete since sensitivity to uncertainty changes are not reflected in propagation of uncertainty using Monte Carlo methods.

This paper provides a basis of the uncertainty underestimation for complex systems and especially, due to nuances of launch vehicle logic, for launch vehicles. It then suggests several alternative methods for estimating uncertainty and provides examples of estimation results. Lastly, the paper shows how to implement an Uncertainty-Importance analysis using one alternative approach, describes the results, and suggests ways to reduce epistemic uncertainty by focusing on additional data or testing of selected components.

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