Overview of Reliability Analysis and Design Capabilities in DAKOTA

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Abstract

Reliability methods are probabilistic algorithms for quantifying the effect of uncertainties in simulation input on response metrics of interest. In particular, they compute response function distribution statistics (probability, reliability, and response levels) based on specified probability distributions for input random variables. Thus, these reliability methods provide a capability for uncertainty quantification, which may be used either for stand-alone probabilistic analysis or as a foundation for reliability-based design optimization algorithms. In this paper, capabilities developed at Sandia National Laboratories for reliability analysis and design [1, 2] are overviewed.

From the reliability analysis side, both the forward reliability analysis of computing probabilities for specified response levels (the reliability index approach (RIA)) and the inverse reliability analysis of computing response levels for specified probabilities (the performance measure approach (PMA)) are of interest. Algorithm options include the use of limit state approximations with first-order local (AMV, AMV+), second-order local (AMV^2, AMV^2+), or multipoint (TANA) surrogate models in x-space or u-space; first-order or second-order probability integrations; analytic, numerical, or quasi-Newton limit state Hessians; most probable point search algorithm selections; and warm-starting approaches.

From the reliability-based design optimization side, design formulations may be broadly characterized as bi-level (in which the reliability analysis is nested within the optimization), sequential (in which iteration occurs between optimization and reliability analysis), or unilevel (in which the design and reliability searches are combined into a

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single all-at-once optimization). In the sequential case, trust-region surrogate-based methods are of particular interest. In each case, sensitivity analysis can be used to provide analytic derivatives of reliability, probability, and response levels with respect to design parameters, where the design parameters may either define distribution parameters of the uncertain variables or be separate from the uncertain variables. Within these top-level characterizations, additional algorithm options include the selection of RIA or PMA mappings for probability or reliability metrics as well as each of the approximation, integration, MPP search, and warm-starting options of the reliability analysis described above.

This suite of capabilities for reliability analysis and design has been developed at Sandia National Laboratories as part of the DAKOTA software [3], a freely available open source toolkit focused on analysis of large-scale engineering applications on high-performance parallel computers. Computational experiments have been explored for an expanding suite of benchmark problems using DAKOTA. Relative performance of these reliability analysis and design methods is presented and algorithm recommendations are given.

References

[1] Eldred, M.S., Agarwal, H., Perez, V.M., Wojtkiewicz, S.F., Jr., and Renaud, J.E., Investigation of Reliability Method Formulations in DAKOTA/UQ, (to appear) *Structure & Infrastructure Engineering: Maintenance, Management, Life-Cycle Design & Performance*, Taylor & Francis Group.

[2] Eldred, M.S., and Bichon, B.J., Second-Order Reliability Formulations in DAKOTA/UQ, (in preparation) *Structure & Infrastructure Engineering: Maintenance, Management, Life-Cycle Design & Performance*, Taylor & Francis Group.

[3] Eldred, M.S., Giunta, A.A., van Bloemen Waanders, B.G., Wojtkiewicz, S.F., Jr., Hart, W.E., and Alleva, M.P., DAKOTA, A Multilevel Parallel Object-Oriented Framework for Design Optimization, Parameter Estimation, Uncertainty Quantification, and Sensitivity Analysis. Version 3.1 Users Manual. Sandia Technical Report SAND2001-3796, Revised April 2003, Sandia National Laboratories, Albuquerque, NM.