INNOVATIVE COMPUTATIONAL TECHNOLOGIES FOR CHALLENGING ENGINEERING PROBLEMS

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Grand Challenge problems in Aeronautical, Astronautical, Automotive and Naval Engineering abound. Examples include problems pertaining to advanced technology concepts for N+3 subsonic and supersonic commercial transport aircraft, advanced spacecraft propulsion systems for accessing space more routinely, light-weight supersonic inflatable aerodynamic decelerators for robotic missions to Mars, optimal design under uncertainties, and autonomous systems with decision making capabilities. Addressing these problems requires, in addition to flight tests, at-sea tests, and other experiments, multiscale computational models and algorithms. It also necessitates the development of advanced solution methods that can operate in practical amounts of CPU time, while getting informed by observational data in a manner that can manage uncertainties and quantify them during predictions. By far however, the biggest challenge is to break the stalemate position in which all but a select group of industries are as far as embracing high-fidelity computational models, due to the usual concerns about their reliability and computational cost. To this effect, this lecture will present some new directions and capabilities that are needed for rising to these challenges. They include, among others, parametric, nonlinear, Stochastic, Hyperreduced, Projection-based Reduced-Order Models (SHPROMS) that can extract from numerical or experimental data fundamental information or knowledge that otherwise they do not capture, in order to quantify uncertainties and enable real-time predictive simulations. Such capabilities are potentially a game changer for computational design and optimization, embedded computing, model predictive control, and most importantly, dynamic data-driven applications systems. Specifically, the lecture will begin with a progress report on the real-time solution of complex, parametric engineering problems in aeronautics, automotive, and naval engineering using HPROMs. Then, it will present a nonparametric probabilistic approach for modeling model form uncertainties in a nonlinear HPROM and quantifying uncertainties in its associated high-dimensional counterpart. This approach features three ideas: substituting the deterministic Reduced-Order Basis (ROB) underlying an HPROM with a stochastic counterpart that depends on a small number of hyperparameters; constructing the probability measure of the stochastic ROB on a subset of a compact Stiefel manifold in order to preserve linear independence and the satisfaction of the boundary conditions; and solving a reduced-order statistical inverse problem to determine the hyperparameters. These innovative ideas will be demonstrated in this lecture through the solution of several realistic problems in computational analysis and design.