Physics-Based Digital Twinning

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A digital twin usually refers to a digital replica of an asset – whether a physical platform or a process – that can be used, for example, to optimize in near real-time the operation and/or life cycle management of this asset; or more generally, to drive the Intelligent Enterprise by linking engineering and operations such as maintenance. The advocated enabler of such a computational capability is the integration of artificial intelligence, machine learning, and software analytics with data, to create living digital simulation models capable of updating themselves as their physical counterparts evolve. Preliminary forms of such digital twins are often described as the result of the integration of data analytics with the model-based prediction of a few, scalar, quantities of interest (QoIs). This lecture however will first question whether a few QoIs can be identified to represent the critical state of a newly designed then deployed physical platform. Next, it will present a more robust approach for realizing digital twins based on adaptable, stochastic, low-order but high-fidelity computational models grounded in physics – that is, partial differential equations. The proposed approach features novel mathematical ideas for integrating the modeling and quantification of model-form uncertainty with probabilistic reasoning, projection-based model order reduction, and machine learning. It constructs stochastic, physics-based computational models that self-adapt using information extracted from sensor data; and operate in real time. Finally, the lecture will demonstrate the potential of the proposed approach for digital twinning using three sample realizations: a digital twin for a small-scale replica of an X-56 type aircraft; another one for a three-dimensional MEMS device; and a third digital twin for an automotive system.