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Enhancing the Wind Performance of Civil Infrastructure Through "Online" Cyber-Physical Wind Tunnel Simulation

Pedro L. Fernández-Cabán, Ph.D.[a]

[a]*Assistant Professor, Clarkson University, Potsdam, NY*

ABSTRACT

Boundary layer wind tunnels (BLWT) remain the primary tool used in wind engineering for characterizing surface pressures on bluff bodies and fluid-structure interaction effects on wind sensitive civil infrastructure. Despite significant advancements in computational fluid dynamics (CFD) over the past few decades, the reliance on BLWT testing is partly attributed to the inability of numerical CFD models to accurately simulate the three-dimensional and highly turbulent features of atmospheric boundary layer flows near the earth's surface, and their interaction with the built environment. While the wind loading acting on a structure can be more accurately quantified in the BLWT, structural design and optimization procedures can only be performed numerically using high-level optimization algorithms. These algorithms can rapidly evaluate a wide range of competing designs to meet specified objectives. Therefore, the development of new cyber-physical approaches can couple the exploration of the design domain through numerical optimization algorithms with the accuracy of physical testing in the wind tunnel. Cyber-physical systems (CPSs) bridge the cyber world of computing and communications with the physical world to monitor, coordinate, and control physical processes. CPS components include sensing, actuation, communication interface systems, computational models or algorithms, and a physical system of interest.

This talk will present recently developed cyber-physical approaches that combine high-fidelity experimental BLWT testing, mechatronic building models, and numerically driven optimization strategies to autonomously improve the performance of civil infrastructure in the BLWT. The mechatronic models can bring about physical changes and adjust their aerodynamic or dynamic properties (through actuation) to enable exploration of a wide range of candidate designs in the BLWT. Two proof-of-concept studies of a low- and high-rise building are illustrated to demonstrate the potential of the CPS framework. Lastly, future opportunities in cyber-physical modeling and integration of novel optimization, machine learning, and decision-making strategies for evaluating and predicting wind-induced effects on structures will be discussed.