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From Davenport's wind loading framework to contemporary practice: Stathopoulos' role in wind load evaluation for low-rise buildings and their attachments

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SUMMARY

This paper presents a contemporary perspective on wind load evaluation in wind engineering, viewed through the lasting contributions of Prof. Theodore Stathopoulos. Beginning with his early studies in the 1970s, Stathopoulos played a pivotal role in extending and advancing the fundamental framework for wind load evaluation across more than five decades of experimental and computational research. The paper revisits key factors influencing wind loads on low-rise buildings and their attachments, with emphasis on developments in wind pressure measurements, CFD-based wind load evaluation, performance-based design approaches and data-driven techniques. Applications to cladding and structural systems, wall- and -rooftop mounted elements are discussed, together with their incorporation into design guidance and wind loading provisions in current building codes and standards. The paper serves as both a technical synthesis and a collective reflection on Stathopoulos' role in bridging wind engineering research from its foundational era to the present day.

Keywords: *Wind load evaluation, low-rise buildings; wind tunnel testing; pressure coefficients; computational wind engineering; performance-based wind design; wind codes and standards*

1. INTRODUCTION AND MOTIVATION

Structural wind engineering emerged as a distinct discipline in the mid-20th century through the pioneering contributions of Jack E. Cermak and Alan G. Davenport. Cermak built one of the first boundary-layer wind tunnels to simulate atmospheric winds on structures (Cermak, 1971), while Davenport introduced probabilistic and statistical approaches to wind loading. Davenport's work framed wind effects as a "wind loading chain" linking meteorology, aerodynamics and structural response, with the local wind climate described in statistical terms (Davenport, 1961a, 1961b). These advances enabled realistic simulation of wind-structure interaction and moved the discipline beyond uniform-flow assumptions.

Theodore Stathopoulos has played a unique and sustained role in carrying and advancing this framework forward over more than five decades. Extensive investigations carried out in the mid-1970s, involving atmospheric boundary-layer wind tunnel testing of a range of low-rise building geometries (Davenport et al., 1977, 1978), were instrumental in establishing early guidelines and provisions for the evaluation of wind pressures on such buildings. In parallel, the work of Surry &

Stathopoulos (1978) on the estimation of instantaneous area-averaged pressure coefficients using the pneumatic averaging technique provided important advances in the characterization of wind pressure distributions over building surfaces. Collectively, these contributions provided experimental and methodological foundation for the development of wind loading provisions in current wind codes and standards for low- and medium-rise buildings and their attachments, and continue to inform experimental, computational and codification developments in structural wind engineering.

This paper presents a technical reflection on wind load evaluation, viewed through the long-standing contributions of Theodore Stathopoulos. It is written as a collective perspective from researchers who were among the most recent graduate students he supervised or worked with, highlighting how his methodological principles continue to shape contemporary research and practice in wind engineering.

2. KEY ADVANCES IN STRUCTURAL WIND ENGINEERING

Stathopoulos' contributions to wind engineering extend beyond structural wind loading to include a broad range of environmental wind effects. The establishment of the Boundary Layer Wind Tunnel at Concordia University in the early 1980s provided a reliable experimental facility for studying wind-structure and wind-environment interactions. Since then, this facility and its research group have supported extensive investigations into wind effects on buildings and their surroundings.

2.1. Experimental wind pressure and structural force coefficients

The measurement and interpretation of wind-induced pressures represent a critical link between flow characteristics, building geometry and design-relevant structural loads. Stathopoulos made significant contributions to advancing the understanding of pressure coefficient distributions on low- and medium-rise buildings and their attachments, as well as the role of spatial and temporal averaging in translating localized pressure fluctuations into structural actions. These concepts remain fundamental in contemporary studies of cladding elements, primary roof and wall structural systems, and roof- and wall-mounted attachments. Research on flat roofs established pressure distributions and loading zones patterns fundamental to cladding and structural design (Baskaran & Stathopoulos, 1989; Alrawashdeh & Stathopoulos, 2015). Investigations on gable, monoslope and sawtooth roofs addressed the influence of roof slope, asymmetry and industrial configurations on pressure coefficients (Stathopoulos & Mohammadian, 1991; Stathopoulos & Saathoff, 1994; Chavez et al., 2023). More studies addressed complex roof shapes (L-, U-, T- and X-) and stepped roof geometries, highlighting the impact of plan irregularity and setback configurations in wind-induced pressures (Stathopoulos & Luchian, 1990; Shao et al., 2019; Aldoum & Stathopoulos, 2025a). Experimental studies on parapets, canopies and rooftop solar panels focused on establishing design surface and net pressure coefficients (Stathopoulos & Baskaran, 1987; Stathopoulos et al., 2014; Alrawashdeh & Stathopoulos, 2023; Sakib et al., 2025).

2.2. Upstream exposure and terrain effects

Accurate representation of upstream exposure and terrain remains fundamental to reliable wind load evaluation for low-rise buildings. Wind tunnel investigations by Wang & Stathopoulos (2007) demonstrated that wind loads are strongly affected by upstream terrain non-homogeneity, with peak loads decreasing rapidly over an upwind fetch of several hundred meters before stabilizing.

Subsequent studies combined experimental and numerical approaches to develop an alternative method for estimating aerodynamic roughness length using remotely sensed data, such as Google Earth imagery, providing a practical and promising tool for exposure assessment in wind engineering applications (Yu et al., 2021, 2024).

2.3. Computational wind engineering and application of Artificial Intelligence (AI)

Throughout CFD evolution, Stathopoulos consistently emphasized a cautious, validation-driven approach to numerical modeling. More recent research has demonstrated a carefully structured pathway for the inclusion of CFD in wind load evaluation through hybrid experimental-computational frameworks. Using large eddy simulation (LES) inflow turbulence was generated from velocity time histories measured in boundary-layer wind tunnel experiments (Potsis & Stathopoulos, 2024, 2026). These approaches showed good agreement with wind tunnel data for pressure coefficients on low-rise buildings, while maintaining computational efficiency. More recently, data-driven and AI approaches have emerged as powerful tools in wind engineering. When grounded in physically meaningful parameters and validated against experimental and numerical data, these methods exhibited excellent predictive performance, offering efficient and cost-effective solutions for wind engineering applications. Stathopoulos has contributed significantly to the application of AI in areas such as urban wind energy, the estimation of wind-driven rain loading and the prediction of wind loads on non-rectangular buildings (Aldoum & Stathopoulos, 2025b).

2.4. Performance-based wind design

Performance-based wind design seeks to move beyond prescriptive wind load specifications by explicitly linking wind actions to structural performance, damage states and risk. In this context, reliable and physically based wind load characterization, consistently emphasized in Stathopoulos' work, is central to performance-oriented design. Figure 1 presents a performance-based framework in which wind effects are evaluated using realistic hazard representations, nonlinear structural modelling and standardized performance metrics (Athanasiou et al., 2022a,b).

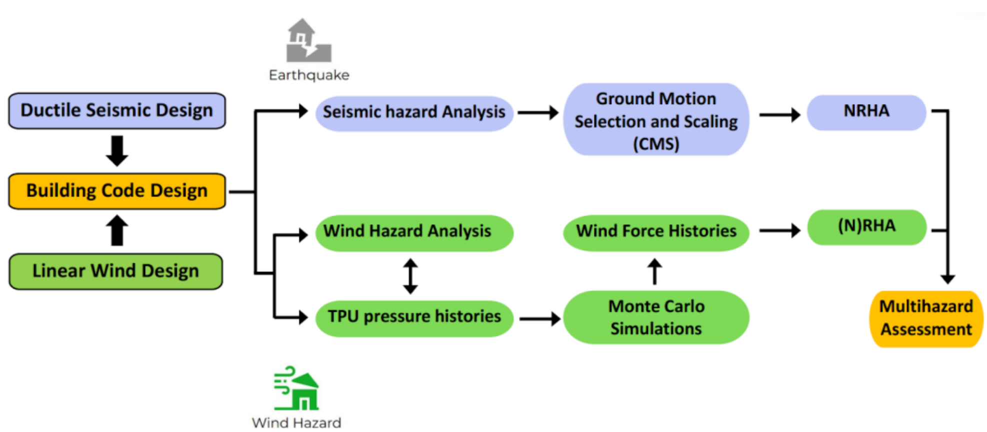

Figure 1: Multi-hazard performance-based design methodology for wind and seismic excitation (after Athanasiou et al., 2022a,b).

Engineering demand parameters obtained from nonlinear response history analysis are assessed against predefined limit states governing safety, serviceability, comfort and collapse prevention. Incremental analyses under increasing wind intensity levels provide a rational basis for evaluating structural performance and resilience under extreme wind events.

3. RESEARCH-PRACTICE AND SCHOLARLY REFLECTIONS

The body of work of Theodore Stathopoulos, which primarily addresses wind effects on low- and medium-rise buildings, their primary structural systems, rooftop solar panel systems and building-mounted attachments, is characterized by a strong continuity between research, design practice and codification. The results of this work have had a significant impact on the development and advancement of wind load standards at both national and international levels, including the NBCC, ASCE/SEI 7, ISO 4354 and GB 50009. This philosophy is reflected in the research themes and methodological approaches adopted by the graduate students and researchers he has supervised, contributing to continuity across successive generations of wind engineering research and practice.

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