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50 years of Computational Wind Engineering: Past, present and future ☆

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ABSTRACT

In the past 50 years, Computational Wind Engineering (CWE) has undergone a successful transition from an emerging field into an increasingly established field in wind engineering research, practice and education. This paper provides a perspective on the past, present and future of CWE. It addresses three key illustrations of the success of CWE: (1) the establishment of CWE as an individual research and application area in wind engineering with its own successful conference series under the umbrella of the International Association of Wind Engineering (IAWE); (2) the increasing range of topics covered in CWE; and (3) the history of overview and review papers in CWE. The paper also outlines some of the earliest achievements in CWE and the resulting development of best practice guidelines. It provides some views on the complementary relationship between reduced-scale wind-tunnel testing and CFD. It re-iterates some important quotes made by CWE and/or CFD researchers in the past, many of which are still equally valid today and which are provided without additional comments, to let the quotes speak for themselves. Next, as application examples to the foregoing sections, the paper provides a more detailed view on CFD simulation of pedestrian-level wind conditions around buildings, CFD simulation of natural ventilation of buildings and CFD simulation of wind-driven rain on building facades. Finally, a non-exhaustive perspective on the future of CWE is provided.

Contents

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1. Introduction

Computational Wind Engineering (CWE) is primarily defined as the use of Computational Fluid Dynamics (CFD) for wind engineering applications, although it also includes other approaches of computer modelling and in the broadest sense also field and wind-tunnel measurements supporting CWE model development and evaluation (Murakami, 1990a, 1990b, 1993a, 1997, 1998; Meroney, 1997; Stathopoulos, 1997, 2002; Baker, 2000; Murakami et al., 2008; Huber and Blocken, 2011). In the present paper however, I will restrict the definition of CWE to the use of CFD and other computer approaches in wind engineering. Wind engineering itself is best defined as "the rational treatment of interactions between wind in the atmospheric boundary layer and man and his works on the surface of Earth." (Cermak, 1975). CWE has come a long way. 50 years ago, the present extent of achievements and applications in CWE could hardly have been imagined.

At the occasion of the 6th European and African Conference on Wind Engineering (6EACWE) in Cambridge in July 2013, the International Association of Wind Engineering (IAWE) celebrated the 50th anniversary of the historical meeting in Teddington in 1963. Also the historical starting point of CWE could also be situated around 1963, when Smagorinsky (1963) developed one of the first successful approaches to Large Eddy Simulation (LES), the Smagorinsky–Lilly model, which is still intensively used in many areas of fluid mechanics today. Which is the actual historical starting point of CWE depends on the spatial scale considered (see Section 2). The main research area of Smagorinsky was Numerical Weather Prediction (NWP), applied at the synoptic scale or meteorological macroscale. However, the practical deployment of NWP already started in the 1950s (e.g. Charney et al., 1950; Smagorinsky, 1953, 1958; Charney, 1955; Phillips, 1956).

In meteorology, the 1960s and later years were characterised by the continued development and application of NWP (e.g. Phillips, 1960; Smagorinsky, 1963, 1969; Kasahara and Washington. 1967; Shuman and Hovermale, 1968; Kasahara, 1974). In addition, there was the emergence of mesoscale analyses in 2D (i.e. in a vertical section) of phenomena such as sea breezes with and without prevailing (synoptic) winds (e.g. Pearce, 1955; Fisher, 1961; Estoque, 1961, 1962; Magata, 1965), convective motions over mountain ridges (e.g. Fosberg, 1967, 1969) and flow over (simplified urban) heat islands with and without prevailing winds (e.g. Estoque and Bhumralkar, 1969; Delage and Taylor, 1970; Meroney and Yamada, 1971, 1972). Other numerical studies addressed the microscale flow around explicitly modelled surface-mounted obstacles such as buildings (e.g. Yamada and Meroney, 1972; Hirt and Cook 1972; Frost et al., 1974) and complex terrain (e.g. Hirt and Cook 1972; Deaves, 1975; Derickson and Meroney, 1977). Of particular importance for CWE were the pioneering studies by Meroney and his co-workers in which the so-called hybrid approach was pursued: systematic comparison of numerical simulations with dedicated wind-tunnel measurements in an atmospheric boundary layer wind tunnel (e.g. Meroney and Yamada, 1971, 1972; Yamada and Meroney, 1972; Derickson and Meroney, 1977).

In Aerospace Engineering, the T3 group at the Los Alamos National Laboratories in 1963 first used computers to model the 2D swirling flow around an object, using the vorticity stream function method, followed by the first 3D application by Hess and Smith (1967) using the so-called panel method.

Driven by these early achievements, later efforts in CWE focused on the determination and analysis of the wind velocity and pressure fields around buildings (e.g. Vasilic-Melling, 1977; Hanson et al., 1986; Paterson and Apelt, 1986, 1989, 1990; Murakami 1990a, 1990b, 1990c, 1993a, 1993b; Murakami et al., 1987, 1990, 1992; Murakami and Mochida, 1988, 1989; Baskaran and Stathopoulos, 1989, 1992; Stathopoulos and Baskaran, 1990; Baetke et al., 1990; Wu et al., 1992; Mochida et al., 1993; Nicholls et al., 1993). A strong impetus to CWE was provided by the organisation of a new symposium in 1992 by S. Murakami in Tokyo, Japan: the International Symposium on Computational Wind Engineering (CWE). The importance of this symposium cannot be overemphasised (Stathopoulos, 2013): For the first time, it joined wind engineering delegates with classical aerodynamicists, who were using CFD rather routinely to address and solve aeronautical problems. As these problems are very different from wind engineering problems, the first CWE symposium led to a very fruitful interaction between the different groups of delegates. It also marked the beginning of a period of impressive growth in CWE developments and applications, and the beginning of a whole new series of symposia, demonstrating not only the growing importance of CWE, but also the pioneering and visionary character of their founder, S. Murakami.

The difference in time between the earliest CFD developments in the 1950s and the later application of CFD in CWE for wind velocity and pressure fields around buildings is attributed to the specific difficulties associated with the flow field around bluff bodies with sharp edges, many of which are not encountered in CFD computations for simple flows such as channel flow and simple shear flow (e.g. Ferziger, 1990; Leschziner, 1990, 1993; Stathopoulos, 1997; Murakami, 1998). Murakami (1998) meticulously outlined the main difficulties in CWE: (1) the high Reynolds numbers in wind engineering applications, necessitating high grid resolutions, especially in near-wall regions as well as accurate wall functions; (2) the complex nature of the 3D flow field with impingement, separation and vortex shedding; (3) the numerical difficulties associated with flow at sharp corners and consequences for discretisation schemes; and (4) the inflow (and outflow) boundary conditions, which are particularly challenging for LES. These difficulties were directly linked to limitations in physical modelling and in computational requirements at those times, but many of those limitations are still to some extent present today.