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Effects of the time-varying wind angle of attack on the aerodynamic loading of a two-dimensional square cylinder

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SUMMARY:
A sudden change in the direction angle of the wind is one of the peculiar characteristics of non-synoptic phenomena such as thunderstorm outflows. Referring to 10-site full-scale events acquired by the GS-WinDyn research group in the High Tyrrhenian Sea, simulations of the effects induced by the transient angle of attack on the aerodynamics coefficients of a two-dimensional sharp-edged square cylinder are carried out in the "Giovanni Solari" Wind Tunnel at the University of Genoa. The first part of the results is related to the stationary experiments, which are the reference for transient tests, and are shown to be consistent when compared with the relevant literature. The second phase is instead devoted to non-stationary tests, whose preliminary analysis suggests discrepancies from the stationary reference values. In particular, both the initial incidence between the wind and the body and the temporal duration of the change of the angle of attack appear to affect the aerodynamic loading. Due to the strong non-stationary characteristics of the results obtained, Wavelet-based techniques are adopted to study the data in the transients, aimed at making comparisons between aerodynamic coefficients in steady and unsteady conditions, thereby questioning the applicability of the quasi-stationary theory under these conditions.

Keywords: Time-varying angle of attack, Transient aerodynamics, Thunderstorm outflows.

1. INTRODUCTION

Along with the increasing occurrence of extreme weather conditions in recent years, possibly related to ongoing climate change, the number of disasters induced by non-synoptic winds is increasing, and the Wind Engineering community has begun to realize the importance of their impact on the safety of communities. Therefore, improving the current wind-load design codes represents a crucial task for wind engineering scholars. With the advancement of technology, many high-sensitivity and accuracy apparatuses are available (e.g., LiDAR profilers or scanners), which allow gathering full-scale data associated with wind events. Since 2012, the Giovanni Solari Wind Engineering and Structural Dynamics Research Group (GS-WinDyn, University of Genoa) has recorded more than 250 wind events with non-stationary characteristics in the High Tyrrhenian Sea through an extensive monitoring network. They allowed the group to start a line of research about thunderstorms, involving site detection, physical and numerical simulations, as well as analytical modeling of the aerodynamic loading. At the same time, some novel wind simulators have also been designed and built (e.g., WindEEE Dome, at Western University in Canada), which can reproduce the downbursts through an impinging jet. On the other hand, it is possible to reproduce partial aspects of the phenomenon by adequately modifying the traditional concept of wind tunnel. This is the case of multiple-fan wind tunnels, conceived in Asia at the end of the last century. They are able to reproduce accelerating flows in a straight channel thanks to the action of small fans installed before the inlet section, allowing to conduct studies on bluff-body aerodynamics in transient conditions (e.g., Brusco et al., 2022).

The present study concerns the transient aerodynamics of 2D sharp-edged square cylinders through a wind tunnel test campaign. In particular, the focus of the campaign is set on one of the peculiar characteristics of thunderstorms, the sudden-change in the wind direction (e.g., De Gaetano et al., 2014), aiming at understanding the effects on drag and lift forces, and questioning the quasi-steady theory hypothesis. Generalities about this experimental campaign are provided in the following Section.

2. EXPERIMENTAL CAMPAIGN

This study was performed in the “Giovanni Solari” Wind Tunnel at the University of Genoa (Fig. 1a). It is a closed-loop facility, characterized by a low level of turbulence. Moreover, it is equipped with actively controlled motors to reproduce instantaneous changes in the wind angle of attack (AoA, α). This is possible by controlling 3 parameters, namely the initial angle, the target angle, and the rotation speed (as shown in the scheme in Fig. 1b). The investigation cases use as reference the full-scale thunderstorm registration database of the GS-WinDy group (Brusco and Solari, 2021; De Gaetano et al, 2014; Xhelaj et al, 2020). Specifically, the ten events picked by Brusco and Solari (2021) are selected. From them, the wind velocity U, the wind direction α and the rotational speed α' (i.e., the temporal derivative of the wind direction) are extracted.

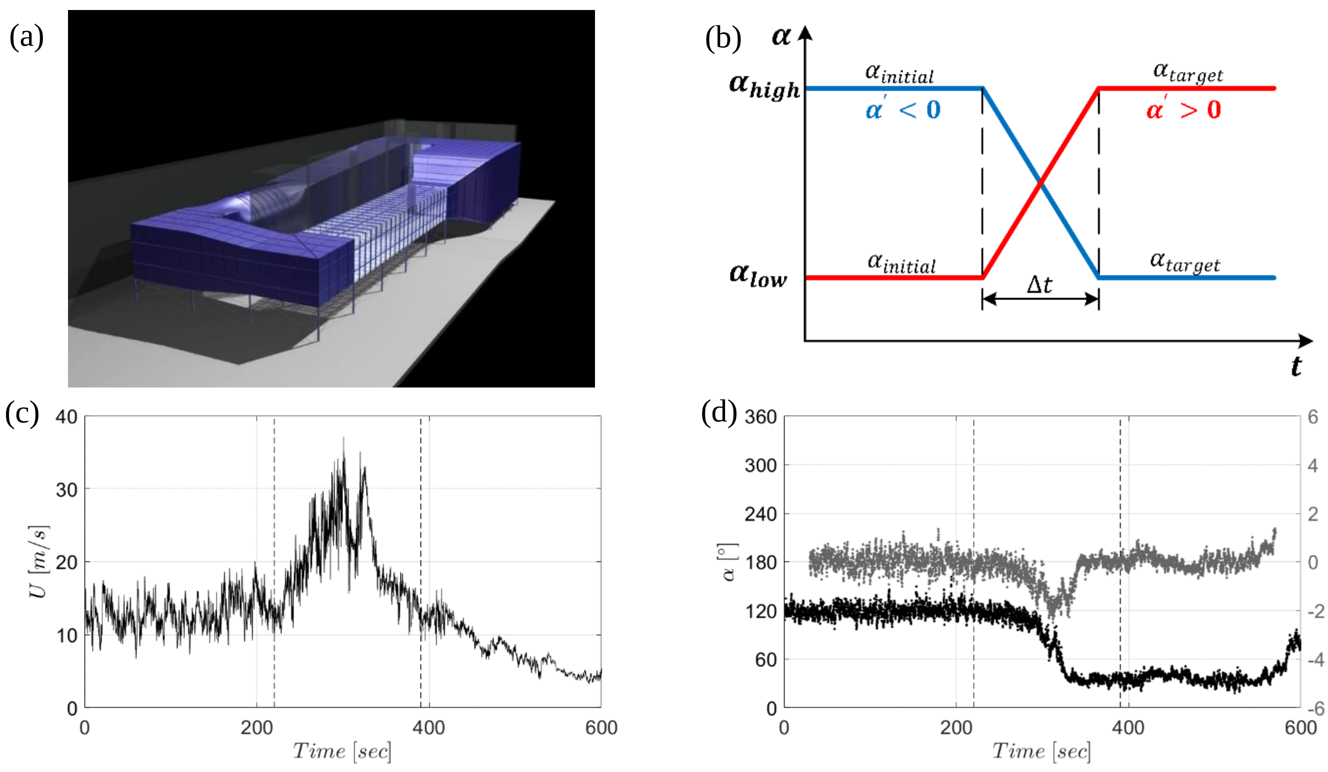

Figure 1. (a) Sketch of Giovanni Solari Wind Tunnel; (b) Scheme of one cycle time-varying angle condition; Time history from one of the thunderstorm events in Brusco and Solari (2021) (c) Wind speed U; (d) Wind direction α (black) and rotational speed α' (grey).

Fig. 1c and Fig. 1d show the time-histories for one of the selected events. The quantities presented in Fig. 1d will be used to calibrate the action of the controlled motors, which are to rotate a sectional wind tunnel model. Since the simulated variations of the angle of attack are scaled 1:1 from full-scale ones, the effects that will be observed are supposed to be valid for structures which have the same geometric dimension of the wind tunnel model.

Body geometry, wind speed and AoA are all important factors controlling the aerodynamic behavior. The traditional predictive tools to assess aerodynamic loading are based on stationary conditions, which means that each factor is considered as constant. On the other hand, research about the transient effects (variation of wind speed and/or wind AoA) is still scarce. This research adopts a square cylinder with sharp corners to discuss the transient aerodynamics induced by a sudden change of the AoA. The study data were acquired through the pressure measurement system PSI using the Digital Temperature Compensation (DTC), allowing the connection of 8 individual scanners, each one featured by 32 ports that can simultaneously register data. The maximum sampling frequency is 650 Hz. The incidence between the body axes and the wind ones follows the clockwise direction, and a total of 46 measurements have been carried out (from 0 degrees to 45 degrees, with a step of 1 degree) for stationary conditions. To ensure the goodness of this first batch of aerodynamic data, the estimated aerodynamic coefficients have been compared with available data from literature references (Carassale et al., 2014; Lee, 1975; Tamura and Miyagi, 1999; Yen and Yang, 2011). As an example, Fig. 2 shows the comparison between the mean drag and lift force coefficients for different AoA, unveiling a similar trend between the different references. In particular, it is possible to note around 10 ~ 15 degrees the presence of the critical region typical of square cylinders. This condition will be deeply investigated within this research, with the aim of observing the discrepancies of the along-wind and cross-wind force for stationary and transient AoAs.

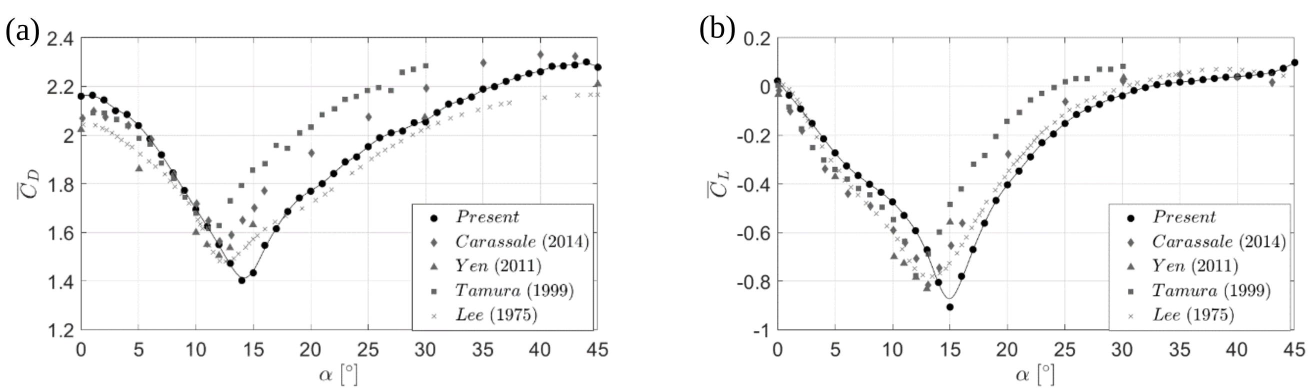

Figure 2. Comparison with literature (a) Mean Drag force coefficient; (b) Mean Lift force coefficient.

3. ANALYSIS METHODOLOGY

Because of the strongly non-stationary characteristics of these experiments, time-frequency analyses (based on continuous Wavelet transform) are employed. These represent a good tool for separating slowly-varying parts of data from fluctuating ones through an energetic approach (Brusco et al, 2022). For instance, Figures 3a and 3b show in light grey two time-history of the time-varying AoAs from two of the tested repeats. The quantity α_W is its slowly-varying component, while α'_W represents the corresponding rotational speed, being the subscript W generically related to quantities obtained following the Wavelet filtering procedure. In particular, the Wavelet-based signals (characterized by an evident smoothness) will be employed for an easier retracing of the stationary references within the transients, and thus will be employed to compare steady and transient conditions.

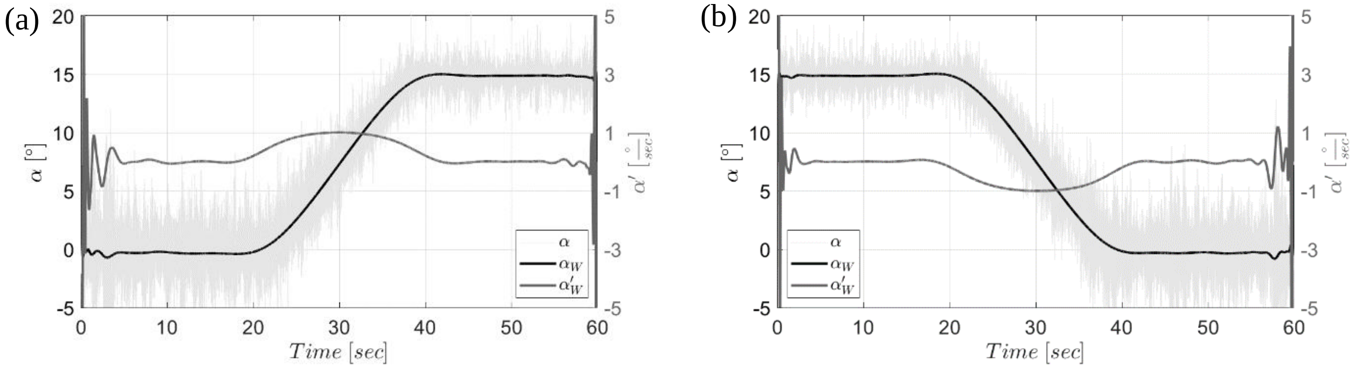

Figure 3. Time series of the AoA (α) and rotation speed α': (a) $\alpha' > 0$; (b) $\alpha' < 0$.

4. PRELIMINARY RESULTS

As far as the stationary tests are concerned, the results are in good agreement with the classical references for different AoAs. Preliminary results of the transient tests show discrepancies compared with the stationary reference values. In particular, the initial angle of the body (i.e., the initial condition) and temporal duration of the variation appear to play a crucial role in the results. This implies that AoA transient conditions can lead to not negligible differences in the aerodynamics of the bluff bodies.

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