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Non-stationary wind effects estimation using LES: the case of a large-span roof

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SUMMARY:
Non-stationary winds are attracting increasing attention in the Wind Engineering community. For instance, the modification of the vertical wind profiles with respect to the classical ones used for synoptic winds is well-known, and, for flexible structures, the pseudo-impulsive excitation might lead to significant differences in the response with respect to the typical stationary wind excitation. In this contribution, we focus on the aerodynamic consequences of non-stationary winds, considering structures for which the expected time-scale governing the aerodynamic behaviour might become comparable to the gust time-scale. In particular, using Large Eddy Simulations, we consider a large-span stadium roof and apply non-stationary winds characterized by different ramp-up and decay times. The global forces acting on the roof are calculated and compared to those obtained for a stationary wind, showing the modifications induced by the transient nature of the incoming gust.

Keywords: non-stationary wind, transient aerodynamics, large-span roofs

1. INTRODUCTION

Extreme wind events such as thunderstorm outflows have strong non-stationary features, being characterized by a slowly time-varying mean speed in addition to turbulent fluctuations. The effects of this transient variation of wind velocity on buildings and structures have been widely investigated using analytical methods, experiments and numerical simulations (Le et al., 2020; Gurley and Kareem, 1997; Li et al., 2019).

An aspect of the phenomenon which currently received relatively little attention, is the analysis of cases in which the pseudo-impulsive nature of the incoming wind might have consequences from the aerodynamic point of view (Li et al., 2022). In particular, when the time-scale characterizing the aerodynamic behaviour of the structure is comparable to that of the incoming non-stationary wind (i.e. ramp-up time or duration), significant transient aerodynamic effects might develop. In particular, this might be the case for large-span roofs, especially with enclosures. In the present contribution, using LES, simulations are performed modelling a stadium roof within an urban environment. A stationary wind as well as non-stationary ones are applied and global forces measured for each sector of the roof. The non-stationary wind characteristic time-scale is varied, keeping all other parameters fixed, so highlighting the role played by the wind transient nature.

Figure 1. An overview of the computational mesh adopted for the simulations.

2. NON-STATIONARY INFLOW

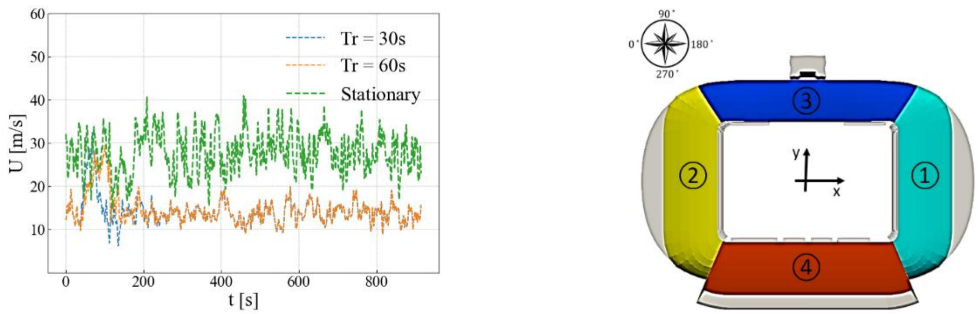
In the present study, aiming at isolating only the effects due to the transient nature of the aerodynamic response, we do not consider the effects due to the modifications of the wind profiles with respect to the classical ones used for stationary winds. In particular, aiming at keeping the case as simple as possible, the only modification we introduce with respect to studies conceived for stationary winds is that we scale the incoming wind field applied at the inflow patch (mean values and turbulence) by a time-varying factor.

In particular, such factor is defined so that the overall slowly-varying mean velocity starts from a background value, U_b, representative of the meteorological structure convection speed. At the time T_s, the velocity starts increasing during a ramp-up time, T_r, and, then, it decreases approaching the background value at a time T_d after the peak. The ratio between the peak value of the slowly-varying time averaged velocity and the background value is denoted as F.

A synthetic turbulent inflow condition obtained using the PRFG[3] method and applied with the VBIC technique to avoid spurious pressure fluctuations is used to generate the incoming turbulent velocity fluctuations. Turbulence is generated, for the sake of simplicity and comparability, in agreement with procedures used for ABL flows.

In particular, in the following the background velocity, U_b, is set to be 12.5m/s. The ramp-up is assumed to start at T_s =35s and the ramp factor, F, is set to be 2. Both the decay time, T_d, assume the same value. The ramp-up time, T_r, is selected to be 30s and 60s. In addition, a stationary wind, characterized by a mean velocity equal to the one measured at the peak of the non-stationary cases, is considered for reference.

Figure 2 (a) shows the time-histories of the velocity measured at the stadium roof height in an empty computational domain. As it can be seen, turbulent fluctuations superimpose to the slowly-varying mean wind speed. As expected, the measured peak velocity obtained in the case of non-stationary flow is higher than the slowly-varying mean, but overall higher peaks are observed for the stationary case due to the longer persistence of high speeds.



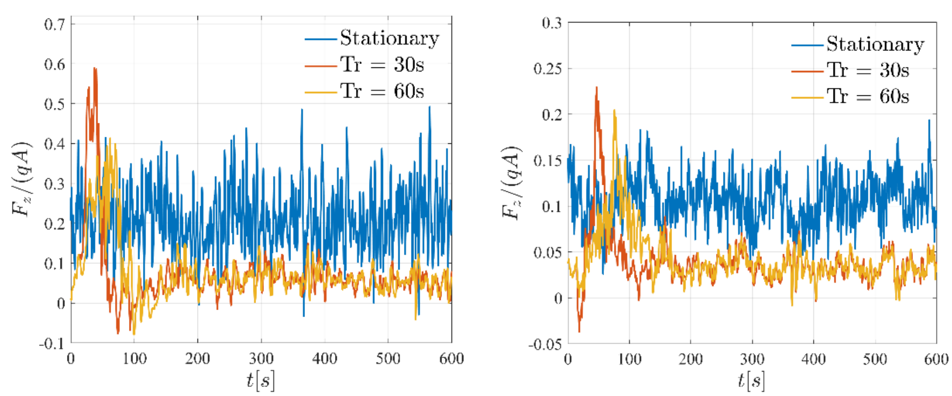
(a) (b)

Figure 2. The adopted model: (a) time-history of along-wind velocity for the considered wind fields, measured at the roof height, (b) the subdivision of the roof in sectors.

3. GLOBAL FORCES OVER THE ROOF

For wind forces calculation, the roof is subdivided into four sectors, as shown in Fig. 2 (b). The incoming wind is directed along the positive *x*-direction. The global forces in the *z*-direction are obtained by integrating the pressure on the roof surfaces. Such quantities are made non-dimensional with respect to the dynamic pressure $q = 0.5 * \rho * u_{ref}^2$, where u_{ref} is the reference wind speed taken as the peak of the slowly-varying mean for the non-stationary cases and as the mean wind speed for the stationary case, measured at the roof height.

The forces for each roof sector for the three analyzed cases are presented in Fig. 3 and 4. Expectedly, the variation of the vertical force displays a ramp-up and ramp-down behavior, like the wind speed. Nevertheless, it is interesting to notice that slight overshoots with respect to the peak value obtained in the stationary case are observed for *Sector 1* and *Sector 2,* which are impinged by the wind orthogonally. In particular, such slight overshoots appear to be more marked when the time-scale of the gust is decreased, keeping all other parameters fixed. On the contrary, for *Sector 3* and *Sector 4* results do not appear to be sensitive to the time-scale of the gust, and values are compatible to those obtained in the stationary case.



Sector 1 *Sector 2*

Figure 3. Time-histories of vertical forces for the analyzed cases: *Sector 1* and *Sector 2*.

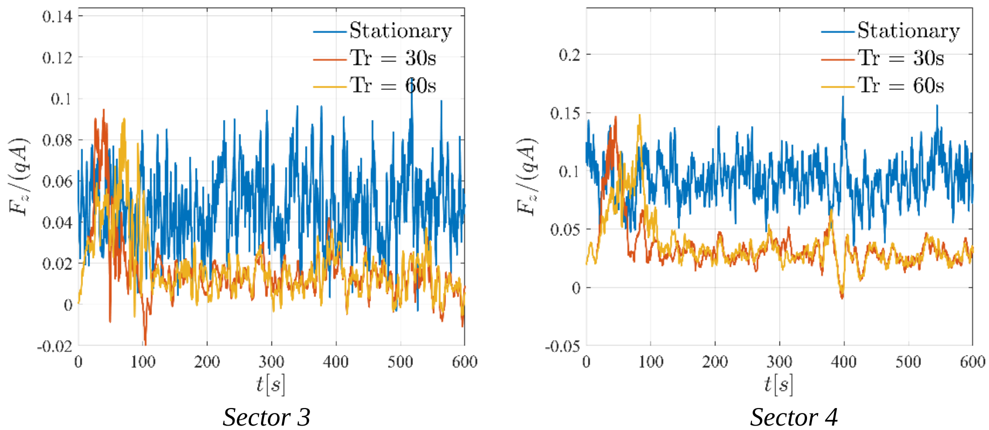


Figure 4. Time-histories of vertical forces for the analyzed cases: *Sector 3* and *Sector 4*.

4. CONCLUSIONS

In this study, some preliminary considerations regarding the unsteady aerodynamic behaviour of large roofs with enclosures have been presented. Numerical simulations indicate that a slight increase of the aerodynamic loads might be expected with respect to the stationary case, due to the transient nature of the applied wind. Further research will help in clarifying the role played by non-stationarity in the aerodynamic response of large-span roofs and further characterize their response in the case of downburst events.

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