Part IV

General conclusions

Chapter 9

Final remarks and future perspectives

This chapter briefly summarises the main conclusions of the PhD Thesis.
This Thesis deals with the transient aerodynamics and transient aeroelasticity of slender structures subjected to thunderstorm outflows. Two approaches have been followed to investigate the topics. The first one, described in Part II of the Thesis, has led to the definition of an analytical formulation to study the aerodynamic loading induced by thunderstorm outflows on structures (in time-domain). It takes the time variation of wind speed and of flow direction into account but is based on a quasi-steady approach, neglecting any effects induced on the aerodynamic coefficients by the acceleration and by the change of the flow direction. Moreover, the influence of vortex-shedding is disregarded. The classical formulation for synoptic winds may be found as a particular case. The numerical studies of the dynamic response of different test structures (adopting a pseudo-deterministic approach, the Equivalent Wind Spectrum Technique) highlight the striking role played by the variation of the angle of attack. This quantity, strictly inherent to thunderstorm outflows, seems to play different roles. Indeed, when the buffeting response is investigated (Chapter 3), its variation may induce an increase of the structural dynamic response compared to a more classical non-directional technique. Discrepancies may arise depending on the aerodynamics of the test structure. Indeed, if it is a polar-symmetric structure, differences appear to be modest. Conversely, if the structure is characterised by a cross-section which is sensitive to directionality effects (like Brâncuși's Endless Column in its original configuration), the situation changes. In fact, the effects induced by considering the terms associated with the mean lift coefficient, and with the angular derivatives of the mean drag and lift coefficients, may change the prediction of the dynamic response. It is unlikely that the classical non-directional method may always lead to non-conservative results, as occurred for the Brâncuși Endless Column, because this would depend on the aerodynamics of the body. However, the increase of the spread of the maximum distribution (on 10 wind events) is independent of that, pointing out the importance of the flow direction and its variation. When taking aeroelastic terms into account (Chapter 4), the role played by this quantity appears even more important. In fact, according to the analyses, a sudden variation of the flow direction seems to prevent the building-up of oscillations, which may occur because of the synchronisation between fluid and body, in particular for low-damped structures (Brâncuși's Endless Column in a different configuration). Therefore, the variation of the flow direction does not provide the activation time for the synchronisation, protecting the structure. In any case, the oscillations are eventually mitigated by the drop of the wind speed in the ramp-down phase. These remarks also point out the importance of distinguishing between traveling and stationary downbursts, since their effects on structures may be different.
The second approach has been described in Part III of the Thesis, and is focused on the questioning of the applicability of the strip and quasi-steady theory, on which Part II of the Thesis is based on. The first step has focused on the quantification of the forces directly induced by thunderstorm-induced accelerations (Chapter 5). Analyses carried out on 15 wind events has highlighted that these forces might be significant for low wind speeds only, and thus far from

the design condition. Nevertheless, they may still constitute a meaningful contribution for elongated bodies. Moreover, the estimation of thunderstorm-induced accelerations represent a precious piece of information to define similarity parameters (the acceleration parameter, or the acceleration itself), when reproducing unsteady flows in laboratory.

The extensive wind tunnel testing campaign (Chapters 6, 7 and 8) carried out at the Tamkang University, Taipei, represents the first step towards the validation of the quasi-steady approach. This campaign is not omni-comprehensive of the whole set of cases investigated in the Part II, but is limited to the case of a square cylinder subjected to wind flow with zero incidence. However, the methodologies introduced might well inspire investigations on different shapes and configurations. Taking all the tests into consideration, a loss of aerodynamic drag is seen to occur for high levels of acceleration or deceleration. Moreover, also the difference between the initial and final values of the wind speed is noted as an important parameter. However, the load variations are found to be quite limited (up to 8 %, if compared to the steady reference values). Vortex-shedding seems to occur with discontinuities of the shedding frequency, which appear during the transients and whose number and magnitude seem to be connected with the acceleration. The standard deviation of the lift coefficient connected with vortex-shedding exhibits the most remarkable drop, up to 25 % when compared to the steady reference values. These three facts indicate that the acceleration causes a weakening of the regularity of the alternate vortex-shedding from the body. Consequently, the assumptions made in Part II of the Thesis may partially appear as plausible and justified. In other words, and even if limited to the investigated case, neglecting the variation of the aerodynamic coefficients with the acceleration appears as a satisfactory assumption, and on the conservative side. On the other hand, completely neglecting vortex-shedding effects may be questionable, albeit they are clearly affected by the acceleration.

The information gathered with the wind tunnel testing campaign seems to be directly applicable on the classical non-directional method described in Chapter 3 for the definition of the dynamic response of Brâncuși's Endless Column, leading to a reduction of the results there presented. As a note of caution, it seems important to stress that the square shape should not constitute a case particularly subject to loads directly induced by acceleration. This allowed a full separation between the effects induced by the (insignificant) inertial forces and by the variation of the load coefficients due to the acceleration. On the other hand, elongated bodies are more likely to experience a combined effect of the two factors, possibly leading to different conclusions about the effects induced by thunderstorm outflows on structures. Results are likely to be strongly dependent on the wind incidence as well. To aid covering a meaningful set of shapes and cases, in order to cover the cases investigated in Part II, CFD numerical simulations may be employed to support the choice and the design of wind tunnel testing cases. Indeed, the simulations might provide precious information about the effects of the acceleration on the velocity and vorticity fields around the body and a deep knowledge of the wake and its features is invaluable for the development of adequate procedures for the prediction of the aerodynamic loading. In particular, the simulations may well be of great support to investigate the effects induced by the changle of the angle of attack of the wind direction on the bluff-body aerodynamics. To investigate this phenomenon in a wind tunnel, albeit able to reproduce unsteady flows, appears challenging. Another aspect worth of consideration might be the influence of the acceleration on the separation point for structures sensitive to Reynolds effects (e.g., circular cylinders).

Taking also into consideration the possible change of the planet climatology, this topic is of fundamental importance as regards structural safety and sustainability (Solari, 2020).