

3D LES modeling of the effects of small-scale turbulence on bluff bodies and bridge decks

Félix Nieto ^a, Antonio J. Álvarez ^b, Kenny C.S. Kwok ^c, Luca Patruno ^d,

^aCITEEC, University of A Coruña, A Coruña, Galicia, Spain, felix.nieto@udc.es

^bCITEEC, University of A Coruña, A Coruña, Galicia, Spain, Antonio.jose.alvarez@udc.es

^cThe University of Sydney, Sydney, New South Wales, Australia, kenny.kwok@sydney.edu

^dUniversit of Bologna, Bologna, Emilia-Romagna, Italy, luca.patruno@unibo.it

SUMMARY

The effect of small-scale turbulence in the aerodynamic response of bluff bodies and bridge decks is studied by means of 3D LES simulations. The numerical model comprises an upstream rod to generate a turbulent wake mimicking the experimental approach proposed in Gartshore (1973). The turbulence intensity in the wake of the rod is compared with experimental data. The results obtained for a 3:2 rectangular prism show good agreement with the available experimental data. Additional results of the effects of small-scale turbulence on a long span bridge deck will be presented at the conference.

Keywords: small-scale turbulence, smooth flow, 3:2 rectangular prism, rod, bridge deck, Stonecutters.

1. INTRODUCTION

In wind engineering, turbulence is still one of the key topics featuring important uncertainties and gaps in our understanding of how it is affecting the aerodynamic and aeroelastic responses of structures. Furthermore, the impact of the scale of turbulence is a topic generally overlooked which still requires substantial research (Mannini et al., 2018).

In wind tunnel testing, uniform turbulent flow, that is without intending to simulate the atmospheric boundary layer, is usually generated by placing a grid upstream of the model. Typical length scales are roughly of the same order of magnitude as the characteristic dimension of the sectional model under study, or larger. Gartshore (1973) was the first to propose a method for generating small-scale free stream turbulence in the wind tunnel by placing a thin rod upstream of the studied body.

In CFD, models addressing turbulence effects typically rely on the 3D LES approach, where most of the turbulent scales are fully resolved, while only the smaller scales, below the grid resolution, are modeled. In this respect, a reference value for resolved LES simulations is having more than the 80% of turbulent energy content fully resolved. This is the so-called Pope's criterium (Pope, 2004).

One aspect that has required substantial effort has been the development of methodologies for the reliable generation of turbulent incoming flow (Patruno and de Miranda, 2020). Nowadays the Synthetic Turbulence Method may be considered as the accepted standard for modeling incoming turbulent flow; however, it would require a mesh of extremely high density to enable small-scale turbulent structures travel from the inlet to the targeted bluff body or bridge deck. Because of this, in this work the small-scale turbulent flow is generated by computationally implementing a thin rod upstream of the studied body, replicating the approach proposed for wind tunnels tests in

Gartshore (1973). In this manner the high-density mesh is only required in the wake of the rod, in the space between the rod and the stagnation point on the body under consideration.

2. MODELING SMALL-SCALE TURBULENCE IN THE WAKE OF THE ROD

The reliability of the proposed approach hinges on the ability of the CFD model to properly reproduce the turbulence intensity and length scale in the wake of the rod. This is of utmost importance as the turbulence intensity depends on the distance from the rod. To this end, a 3D LES model of the isolated rod has been developed. A conformal mesh comprising hexahedral elements has been selected after the pertinent verification studies, featuring 1024 elements in the spanwise direction for circular cylinder of aspect ratio 48:1. In figure 1, the turbulence intensity distribution along the mid-span wake centerline of the rod is provided along with the experimental values for validation.

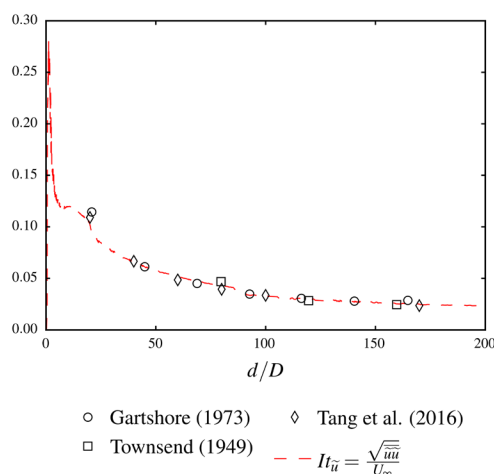


Figure 1: Turbulence intensity profile along the mid-span wake centerline of the rod.

In table 1, the nine components of the turbulent length scale matrix are provided for different points along the mid-span wake center line downstream of the rod. It can be noted that the turbulent length scale tends to increase with the distance from the rod. Furthermore, it is remarked the ability of the numerical models to provide the values for all the components of the turbulent length scale at each point, which is remarkably challenging in experimental testing.

Table 1: Turbulent length scales depending on the distance downwind the rod.

x/D	L_{ux}/D	L_{vx}/D	L_{wx}/D	L_{uy}/D	L_{vy}/D	L_{wy}/D	L_{uz}/D	L_{vz}/D	L_{wz}/D
1	0.51	0.28	0.51	0.46	0.70	0.23	0.11	1.40	0.21
5	0.70	0.66	0.42	0.47	1.51	0.46	0.50	6.74	0.36
12.5	1.68	0.67	0.58	0.55	1.35	0.34	0.85	2.95	0.56
25	1.59	0.68	0.89	0.49	1.48	0.40	0.65	1.03	0.73
50	1.96	1.06	1.34	0.83	1.64	0.63	0.75	0.78	1.14
100	2.74	1.63	1.97	1.20	2.13	0.84	0.76	0.95	1.48
200	4.14	2.50	3.03	1.42	3.53	1.27	1.32	1.65	2.00

The isolated rod 3D LES model has enabled the identification of the characteristics of the mesh that permits an accurate simulation of the turbulent wake. Consequently, those mesh characteristics are retained in the subsequent simulations where a 3:2 rectangular prism and the twin-box

Stonecutters bridge deck are considered to analyze the effects caused by the small-scale turbulent flow in their aerodynamic responses.

3. 3:2 RECTANGULAR PRISM CASE

The ratio 3:2 rectangular prism is a bluff body geometry that has been studied experimentally in recent times due to its proneness to galloping excitation, VIV galloping interference (Mannini et al, 2018) and also Reynolds number dependency of the drag coefficient and non-stationary and non-Gaussian distributions of aerodynamic forces (Nguyen et al. 2022). Here, we analyse the aerodynamic response of the 3:2 prism under smooth flow and small-scale turbulent flow with different turbulence intensities at different angles of attack.

A verification study for the rectangular prisms in smooth flow has been conducted. For the cases including the rod, the mesh characteristics are based on the previous verification studies conducted for both the isolated rod and the isolated 3:2 prism. The 5% turbulence intensity case corresponds to a distance between the rod and the windward face of the prism of $d=60D$, being D the diameter of the rod, which is $D=H/12$, being H the height of the prism. Similarly, the 9% turbulence intensity case corresponds to a distance between the rod and the prism of $18D$. In figure 2, a snapshot of the Q-criterion (regions where the vorticity magnitude is higher than the strain rate) iso-surfaces coloured by velocity magnitude is provided for the small-scale 9% turbulence intensity case.

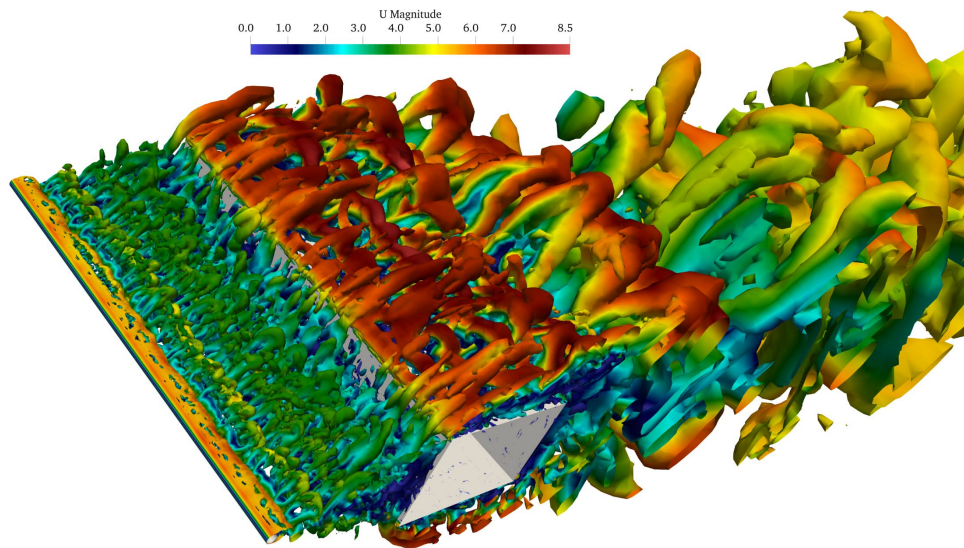


Figure 2: Snapshot of Q-criterion coloured by velocity magnitude for the rod-induced 9% turbulence intensity case.

In figure 3, a selection of results obtained for the mean and fluctuating force coefficients in smooth flow and rod-induced small-scale turbulent flow are provided along with experimental results for validation, when available. The numerical simulations are providing the trends in the values of the force coefficients related with both the angle of attack and the turbulence intensity level. It is to note that the experimental values for turbulent flow correspond to tests featuring grid-induced turbulent flow as there is not currently experimental data available for rod-induced turbulent flow for this geometry. Lower values obtained for the drag coefficient at 0° angle of attack for rod-induced turbulent flow cases are related with the weak sheltering effect caused by the rod.

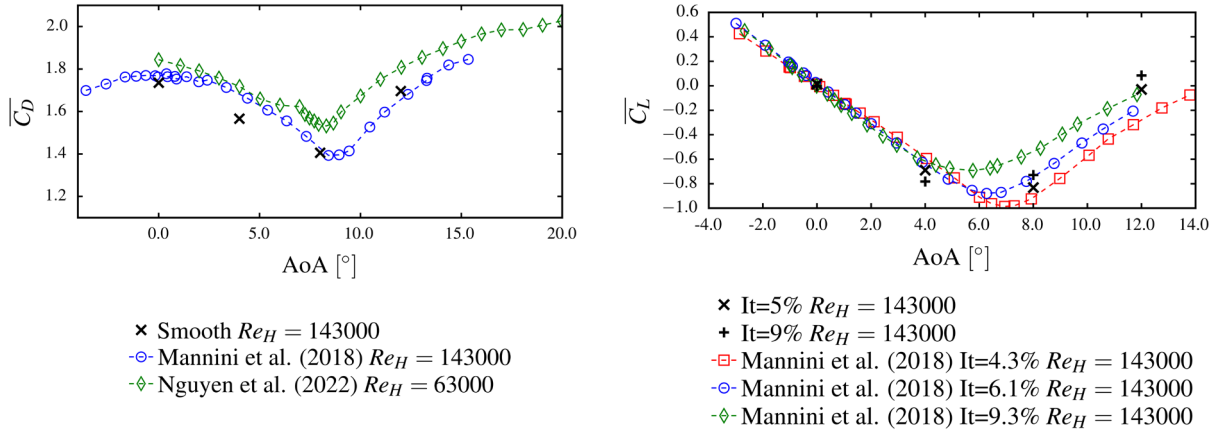


Figure 3: Mean drag coefficients in smooth and mean lift coefficients in turbulent flow.

4. TWIN-BOX DECK OF THE STONECUTTERS BRIDGE

In the conference, the results obtained for the Stonecutters Bridge under smooth flow and rod-induced small-scale turbulent flow will be also presented. The modeling approach is similar to the one reported in the previous section for the 3:2 rectangular prism.

5. CONCLUSIONS

In this work a CFD-based approach for the generation of small-scale turbulent flow is proposed based on the original implementation in wind tunnel testing in Gartshore (1973). The need for extensive verification and validation has been commented upon, especially to guarantee the accurate reproduction of the turbulent characteristics in the wake of the rod. The method has been successfully applied for a ratio 3:2 rectangular prism, providing a good comparison with the existing experimental data in the literature. The results obtained for the Stonecutters Bridge will be reported at the conference.

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