CFD calculations to improve buffeting analysis of bluff bodies

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1 INTRODUCTION

The aim of this study is to demonstrate that available calculation procedures can be used to improve buffeting analysis of bluff bodies. The present research focus on two-dimensional aerodynamic functions, commonly used to improve two-dimensional formulations for wind forces on elongated bodies, such as bridge decks. CFD calculations of Küssner-type indicial functions are presented and limitations of the existing quasi-static formulation are pointed out.

2 BACKGROUND THEORY

Scanlan [1, 2] recalled that "buffeting forces acting on elongated bodies like long-span bridges have been described by theories and analytical formats strongly influenced by analogous expressions found in two-dimensionnal airfoil theory". Therefore, current theories for prediction of incident turbulent exitations are based upon a quasi-static formulation which relates the buffeting forces to the incoming wind velocity components. In this format the lift is given by

$$L_b(s) = \tfrac{1}{2}\rho U^2 C \quad [2C_l(\alpha_0)\frac{u_x(s)}{U} + C_l'(\alpha_0)\frac{u_z(s)}{U}] \tag{1}$$

Where s is a dimensionless time, $C_l(\alpha_0)$ and $C_l'(\alpha_0)$ are the steady lift coefficient and lift slope, C is the structure chord length, ρ is air density and U is cross flow velocity. Indicial functions have been used to improve this formulation. Following, as a guide method, the thin airfoil theory, the lift may be written in the frequency domain as

$$\hat{L}_b(k) = \tfrac{1}{2}\rho U^2 C \quad [2C_l(\alpha_0)\frac{\hat{u}_x(k)}{U}\hat{\Phi}'_{l_x} + C_l'(\alpha_0)\frac{\hat{u}_z(k)}{U}\hat{\Psi}'_{l_z}] \tag{2}$$

Where $\hat{L}_b(k)$ is the Fourier transform of $L_b(s)$, k is a reduced frequency, $\Phi_{l_x}(k)$ and $\Psi_{l_z}(k)$ are Wagner-type and Küssner-type indicial functions. The spectral form of (2) is

$$S_{L_b}(k) = \tfrac{1}{4}\rho^2 U^4 C^2 \quad [4C_l^2(\alpha_0)\frac{S_{u_x}}{U^2}\chi^2_{l_x} + C_l'^2(\alpha_0)\frac{S_{u_z}}{U^2}\chi^2_{l_z}] \tag{3}$$

This expression represents a simplification of the complete equation, since the cross power spectral densities of wind turbulence components $S_{u_x u_z}$ and $S_{u_z u_x}$ have been assumed to be negligible (this is a commonly used assumption). In these formulations, $\chi^2_{l_x}(k)$ and $\chi^2_{l_z}(k)$ are so-called "aerodynamic admittance" related to the indicial functions

$$\chi^2_{l_x} = \hat{\Phi}'_{l_x}(k)\hat{\Phi}'^*_{l_x}(k) \qquad \chi^2_{l_z} = \hat{\Psi}'_{l_z}(k)\hat{\Psi}'^*_{l_z}(k)$$

These equations quantitatively define $\chi^2_{l_i}(k) \quad (i = x,z)$ as frequency-based transfer functions, relating the spectrum of incident gusting velocities to that of associated lift. In the past, the Sears function was use as admittance but many authors have shown that this assumption was not appropriate, even for streamlined bridge deck sections. Moreover, in the context of bluff bodies, turbulence is induced by the structure itself (signature turbulence) and aifoil-type theories are unable to depict wind actions. In this case a CFD acquisition of indicial and/or admittance functions could be a step toward predicting the cross-wind excitation induced by the incident wind.

3 OUTLINE OF NUMERICAL PROCEDURE

The present research investigates only indicial lift responses of structures penetrating (or enveloped by) a sharp edged gust. To that, the wind flows across the respective sections have been computed using a finite-element flow solver, CASTEM 2000. The wind has been assumed as an incompressible turbulent flow governed, in the atmospheric boundary layer, by the Navier-Stokes equations. CASTEM solved the Reynolds Average Navier-Stokes (RANS) equations. Throughout this study the RNG $k-\varepsilon$ turbulence model has been used with a Reynolds number of 8.10^6 (a previous study has shown that this model was more adapted to unsteady flows, with organised vortices, than the standard $k-\varepsilon$ model). The variables were rendered nondimensional with regards to the section chord C and the inlet flow velocity U_0. The computational domains used were $4C$ long upstream from the leading edge of the section, $12C$ long dowstream of the section and $4C$ wide on each side of the section. The calculations have been carried out on a 154×92 grid. The flow with 0^o angle of attack has been first computed with Dirichlet conditions imposed at the inflow boundary (freestream conditions with a turbulence level of 2 %), stress free conditions automatically imposed on the other boundaries (inherently by the finite element formulation) and near wall model on the wall boundary. Next, the vertical velocity of the flow field upstream of the airfoil was changed to $\frac{u_{z_0}}{U_0} = 0,0875$ (5^o angle of attack). The indicial lift response was obtained by integrating the pressure along the boundary of the section as the gust convects with the freestream. The corresponding aerodynamic admittance were obtained, by a fourier transform relationship. The method has been tested for a NACA0012 airfoil and carried out for rectangular bluff section ($\frac{H}{C} = 0.12$) and for streamlined bridge deck (Normandie Bridge).

4 COMPUTED RESULTS

For the airfoil, after a critical period of time, the lift reachs its quasi-steady value. The aerodynamic functions obtained are in good agreement with the exact Küssner and Sears solution.

For the rectangular sections, the indicial responses are quite different from the previous one. A strong "overshoot" in lift occurs. An examination of the aerodynamic flowfields indicates that this overshoot is due to the flow separating from the leading edge. Notes that, as the lift approaches its quasi-static value, a periodic vortex shedding takes place. The form of the associated aerodynamic admittance is strongly dependent on the form of the indicial function.

For the bridge decks, the results are different from both airfoil and rectangular sections ones. A small overshoot occurs and the admittance is close to unity.

The limitations of the quasi-static formulation are identified. In the airfoil case, this formulation can be used with the Sears function as admittance. In the case of streamlined deck sections, where a small overshoot in the indicial response occurs, the value of the admittance can be expected to be close to unity. For bluff sections, with strong overshoot, the use of this formulation may not be appropriate. In this case, the signature turbulence contributes largely to the buffeting forces and has to be taken into account.

5 CONCLUSION

CFD results provide an alternative to experimental data for deriving aerodynamic functions useful in buffeting analysis. The form of the indicial and admittance functions is strongly dependent on the creation of separation bubbles and on the formation of vortices in the wake of the body. Therefore, the form of these functions provides a simple yet effective way to determine the limitations of the existing quasi-static formulation, commonly used in buffeting analysis.

References

[1] Scanlan R.H. "Problematics in formulation of wind-force models for bridges decks", Jnl. Engrg. Mech., Vol 119, No 7, 1993

[2] Scanlan R.H. "Liens méthodologiques entre l'aéroélasticité des corps allongés en génie civil et l'aéroélasticité des avions", Revue Française de Mécanique, No 1995-1, 1995

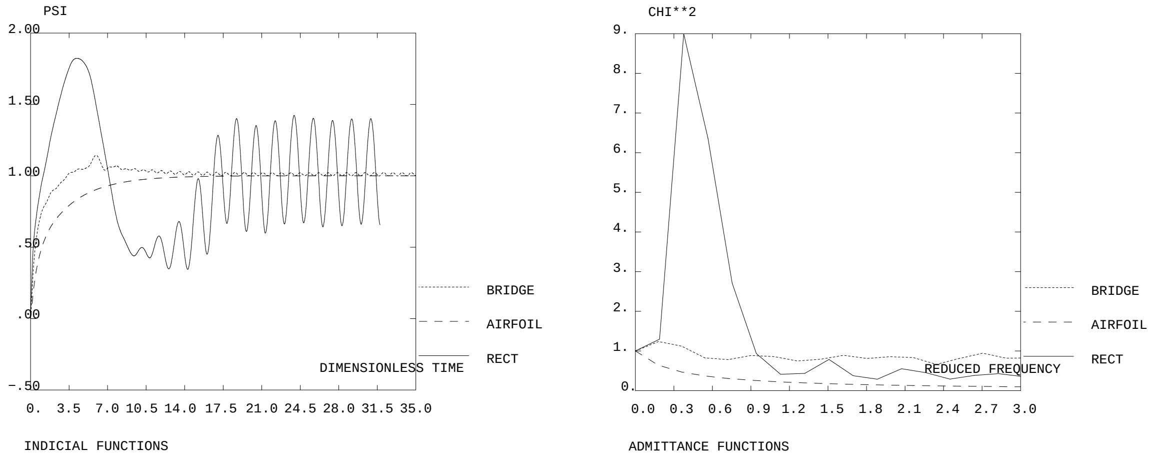

Figure 1: Aerodynamic functions

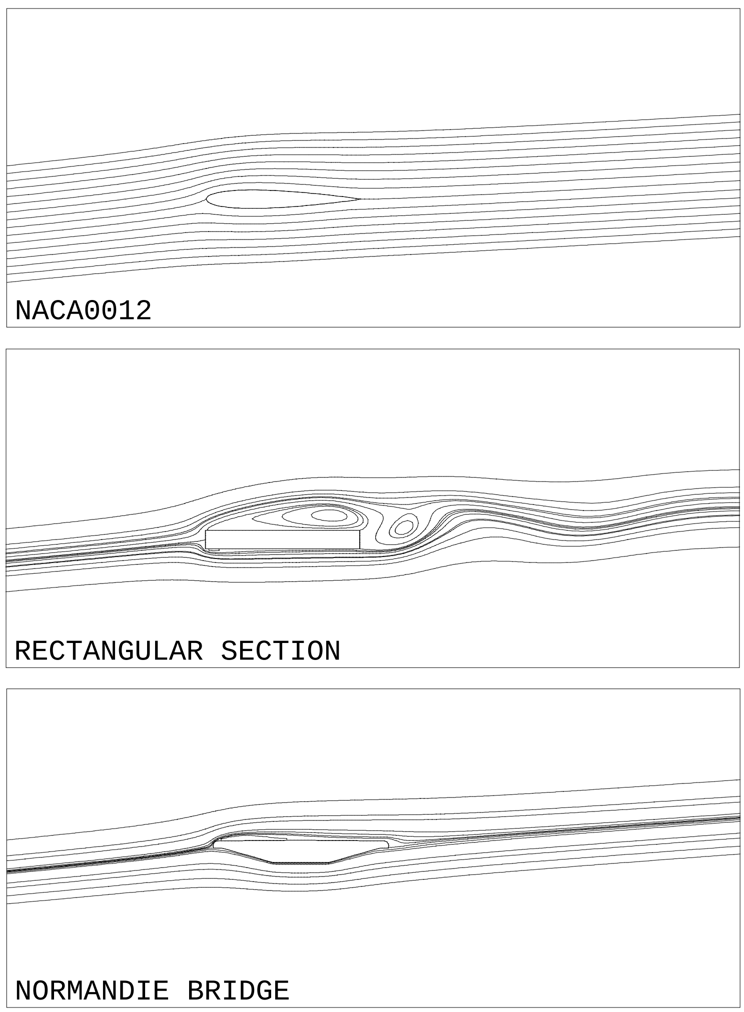

Figure 2: Aerodynamic flowfields