Wall pressure fluctuations (WPF) beneath a turbulent boundary layer (TBL), have been studied for decades for the impact they have on the on-board comfort and on the correct operation of sensors in naval, aerospace, and automotive engineering. The numerical resolution of this fluid-structure interaction problem is computationally demanding even for flat panels, at model scale size and ideal flow conditions for which scaling and similitude laws exist and analytical models can be used for the representation of the single point spectrum and of the cross spectral density of WPF.

For complex geometry and/or flow conditions, direct numerical simulations (DNS) of the Navier–Stokes equations should be used to calculate the WPF field but the actual capabilities of DNS are generally limited, for external wall bounded flow, to problems in which the local Reynolds number, based on the momentum thickness, is in the order of 6600. Some attempts to reduce the computational time using LES have been recently done obtaining satisfactory results at least at low frequency. Concerning, the numerical solution of the structural equations, it is well known that, when the structural wavelengths are small compared to the typical dimension of the problem (i.e. for high frequencies) the number of degrees of freedom, necessary to calculate accurately the structural response, increases very quickly. In this frame, energy methods such as the Statistical Energy Analysis can be invoked at high excitation frequencies. However, the definition of the input power, for a model of the pressure cross spectral density not using the separation of variables, can be very complicated and time consuming. Some issues about the development of a robust numerical solution are discussed in [1].

Several research groups have addressed the problem of reducing the computational time proposing efficient numerical algorithms, suitable approximations for WPF load representation as well as the identification of scaling laws for the structural response able to determine a unique representation independent of the particular flow conditions or structural properties. In ref. [2], a dimensional analysis is used to recover the dimensionless parameters for the definition of the scaling laws for the required axes: the excitation frequency and the power spectral density of the response. This work represents the first attempt to carry out the structural response, under a TBL excitation, using scaling laws. An alternative approach can consist in measuring the structural response of plates under a TBL excitation in a wind-tunnel facility. Specifically, these measurements are mandatory if the structures are complex and they cannot be easily modeled by the available numerical tools. Unfortunately, these experimental
works need the proper wind-tunnel facility (i.e. the proper aerodynamic conditions: flow speed, boundary layer thickness, etc.) and the proper test-article sizes and structural details. The availability of these optimal experimental conditions is only occasionally guaranteed. In the same time, the concept of structural similitude provides a powerful tool for engineers and scientists to predict the behavior of a structure using an appropriate scaled model. In particular, this approach is addressed in [3] but it is based on a homothetic transformation of the plate domain and it does not discuss the role of the flow speed and the reduced frequency in this fluid-structure interaction problem.

This work is a first attempt to address numerical and experimental structural response calculations on scaled domains, dealing with the necessary scaling of the flow speed so as to respect the key similitude parameters. The first phase of the work is based on the analytical development of the exact similitude laws using the case of a thin, flat and homogenous plate with simply supported edges and a Corcos model for describing the TBL load. The capabilities of this analytical framework are shown in Figure 1, in which are scaled two plates with different dimensions and, consequently, different flow speeds.

![Figure 1: Left) Unscaled results; Right) Scaled results](image)

Experimental data, that aim at validating the analytical similitude laws, are discussed and the main challenges to be undertaken in order to apply the similitude framework in the context of a TBL excitation are finally summarized.

References

