Wave Finite Element schemes for Vibrations and Noise under Turbulent Boundary Layer excitation

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The flow-induced noise and vibrations of structures have received large attention over the last decades [1, 2]. Even though analytical and Finite Element(FE)-based numerical approaches have been developed to deal with specific problems, some limits still persist. For example, the computational effort can easily become cumbersome even for simple structural shapes or for increasing excitation frequency; the convective wavelengths, for most industrially-relevant cases, are largely smaller that flexural ones and, thus, the meshing requirements become more demanding. When the structural complexity increases, even small scale models might require a high number of elements increasing computational cost.

In the frameworks of FE and WFE based methods, this work proposes two numerical approaches to deal with the vibrations and noise induced by a Turbulent Boundary Layer (TBL) excitation on periodic structural systems.

Firstly, a 1D WFE (Wave Finite Element) scheme is developed to deal with random excitations of flat, curved and tapered finite structures: multi-layered and homogenised models are used [3, 4]. In this case a single substructure, as in Fig. 1a, is modelled using finite elements. At each frequency step, one-dimensional periodic links among nodes are applied to get the set of waves propagating along the periodicity direction; the method can be applied even for cyclic periodic systems. The set of waves is successively used to calculate the Green transfer functions between a set of target degrees of freedom and a subset representing the wetted (loaded) ones. Subsequently, using a transfer matrix approach, the flow-induced vibrations are calculated in a FE framework.

Secondly, a 2D WFE approach is developed in combination with a wavenumber-space load synthesis to simulate the sound transmission of infinite flat, curved and axisymmetric structures [5]: both homogenised and complex periodic models are analysed (Fig. 1b). In this case, finite-size effects are accounted using a baffled window equivalence for flat structures and a cylindrical analogy for curved panels.

The presented numerical approaches have been validated with analytical, numerical and experimental results for different test cases and under different load conditions. In particular, analytical responsec and classic FEM have been used as references to validate the flow-induced vibrations of plates and cylinders under turbulent boundary layer load; FE method has been used also to validate a tapered conical-cylindrical model under diffuse acoustic field excitation and the flow-induced noise computations under TBL.

From experimental point of view, the approach has been validated comparing results in terms of transmission loss evaluated on aircraft fuselage panels (composite honeycomb and doubly-ribbed curved panels) under diffuse acoustic field excitation.

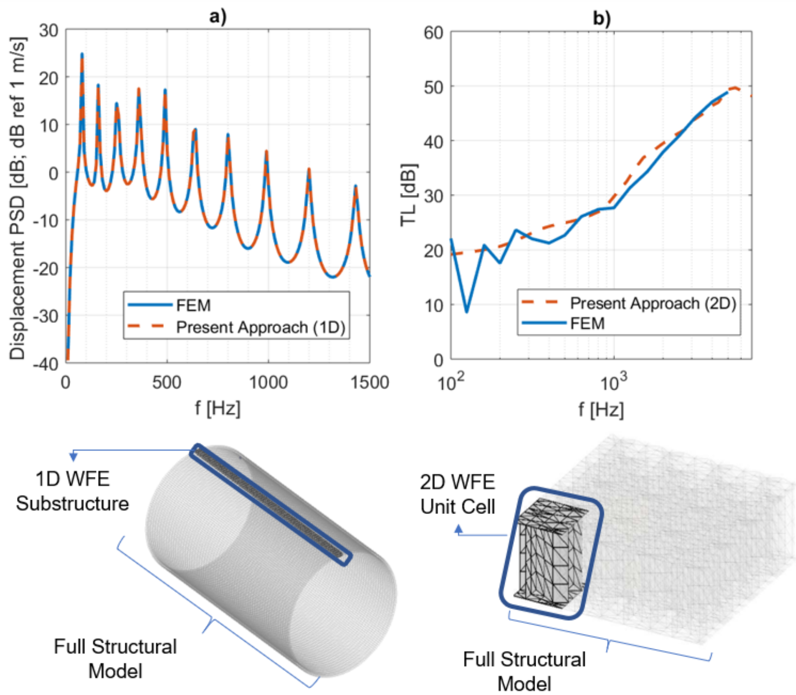

Figure 1: Two validations for the present WFE schemes with full FEM computations. TBL model: Corcos. a) 1D WFE method - Cylinder displacements PSD under an axial flow at 180 m/s; b) 2D WFE method - Sandwich plate with auxetic core loaded by TBL at 140 m/s.

Finally, the use of the presented methodologies for the vibroacoustic optimization of sandwich plates, is analysed and proposed through some case-studies. Standard periodic core designs are modified tailoring the bending and shear waves' propagation versus frequency against the acoustic and convective wavenumbers. The resulting sound transmission losses are computed using the numerical approaches developed in this work and validated with measurements under diffuse acoustic field, taken from 3D-printed models. Strong increases of sound transmission loss are observed for fixed mass of the plates.

References

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