Toward the vibroacoustic response prediction of a curved panel under a turbulent boundary layer

Cédric Leblond[1], Quentin Rakotomalala[1], Jean-Charles Poirier[2], Myriam Slama[3], Jacques-André Astolfi[4], and Pierre Sagaut[5]

[1]CESMAN, Naval Group, Technocampus Océan, 44340 Bouguenais, France
cedric.leblond@naval-group.com, quentin.rakotomalala@polytechnique.edu
[2]Sirehna, Naval Group, Technocampus Océan, 44340 Bouguenais, France
jean-charles.poirier@sirehna.com
[3]LOMC UMR 6294, CNRS, Université Le Havre Normandie, 76058 Le Havre, France
myriam.slama@univ-lehavre.fr
[4]IRENav EA 3634, Ecole Navale, 29240 Brest, France
jacques-andre.astolfi@ecole-navale.fr
[5]M2P2, Aix Marseille Univ, CNRS, Centrale Marseille, 13451 Marseille, France
pierre.sagaut@univ-amu.fr

The numerical prediction of the vibroacoustic response of a submerged curved structure excited by a turbulent boundary layer remains a challenging scientific problem. One of the critical issue is the characterization of the turbulent loading. For instance the influence of the mean pressure gradient, induced by the curvature, on the fluctuating wall pressure spectrum is neither theoretically nor experimentally fully established. As for the subconvective range of the spectrum, its level remains a major source of uncertainty, with and without curvature, on the response of large submerged structures. An adverse mean pressure gradient can also induce a fluctuating loading with significant localized effects, for example a turbulent boundary layer detachment, which makes spectral formulations unsuitable.

Two complementary approaches are proposed in the present work in order to estimate the vibroacoustic response of curved structures to turbulent excitations. The first one, limited to attached turbulent boundary layers with weak spatial evolutions, is based on the classical formulation [1] for the vibroacoustic response $\phi_{uu}(\mathbf{x}, \omega)$ at point $\mathbf{x}$ and frequency ω:

$$\phi_{uu}(\mathbf{x};\omega) = \frac{1}{(2\pi)^2} \int_{-\infty}^{+\infty} \int_{-\infty}^{+\infty} \phi_{pp}(\mathbf{k};\omega) |\Gamma(\mathbf{x},\mathbf{k};\omega)|^2 d\mathbf{k}^2$$

with $\phi_{pp}(\mathbf{k};\omega)$ the wavevector-frequency turbulent wall pressure spectrum and $\Gamma(\mathbf{x},\mathbf{k};\omega)$ the space-varying Green function of the vibroacoustic problem defined in the wavevector-frequency domain. The new ingredients here are (i) an efficient numerical approach to compute $\Gamma(\mathbf{x},\mathbf{k};\omega)$ thanks to plane waves summation [2] and fluid-structure reduced basis [3], and (ii) an extension of the work [4] to compute the turbulent wall pressure spectrum $\phi_{pp}(\mathbf{k};\omega)$ from RANS simulations. More precisely, this extension is based on the Kriging-based elliptic extended anisotropic model [5] and enables to take into account, at first order, the impact of a mean pressure gradient on the wall pressure spectrum. This whole numerical method is validated by confrontation to experiments involving a vibrating panel subjected to a turbulent boundary layer, performed in the hydrodynamic tunnel of IRENav [2].

The second approach, more computationally involved, is based on the direct evaluation of the turbulent excitation through Large Eddy Simulations. It is therefore adapted to flows with strongly localized effects, including detached turbulent boundary layers. For illustration, the fluctuating wall-pressure on a NACA

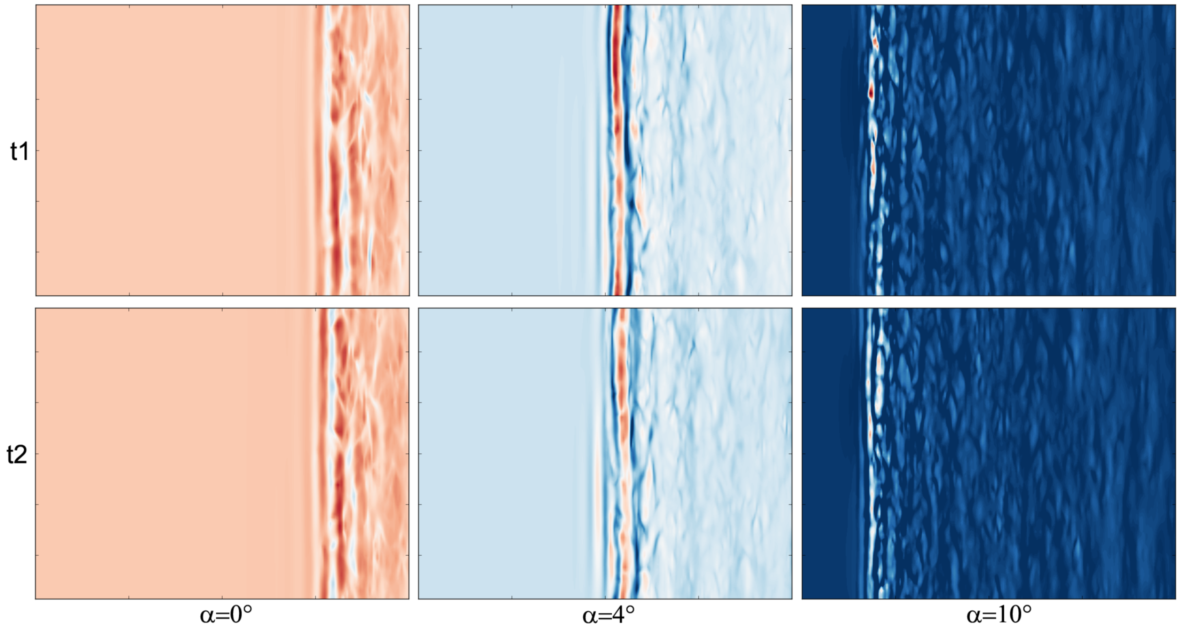

Figure 1: Fluctuating wall-pressure on the upper side of a NACA0018 profile at different times and angles of attacks for $Re = 160000$, obtained with Large Eddy Simulations.

profile is shown in figure 1 for different angles of attack and times. The challenging topic here is to find a compact representation of the fluctuating fluid loading, taking into account the variability of the flow parameters (for instance the Reynolds number and the angle of attack). In this regard, hierarchical tensor product decomposition methods and reduced order models techniques are investigated, for both the hydrodynamical part and the related vibroacoustic response. The strengths and weaknesses of each approach are discussed, as well as what needs to be done to deal with industrial applications of the naval defense.

References

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