AERODYNAMIC LOADING OF PERIODIC STRUCTURES

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ABSTRACT

The main aim of the present paper is to describe the issues and aspects related to the flow induced noise and vibrations, as well as the original features and the expected results of the ongoing research, mainly focused to a specific use of periodic structures for vibro-acoustic purposes. A literature review both on the flow excitation and on the induced response is reported. Some Early-stage research steps are then expressed to give a complete overview of the project.

Keywords: *Flow-induced vibrations, radiated noise, TBL excitation, periodic structures, wave-base expansion, stochastic methods in structural dynamics*

1 INTRODUCTION

Among the many noise and vibration sources, the aerodynamic load is surely one of the most relevant in engineering problems. This peculiar excitation source usually operates in a broadband frequency range, which widely increases the analysis issues when dealing with the forced response of a generic structure. It also concretizes in a spatially correlated stochastic load, as for the case of the Turbulent Boundary Layer (TBL) excitation, thus, deterministic approaches are not feasible and correlation functions are used instead.

Moreover, the need of investigating this peculiar field derives from its impact, in terms of radiated noise, on the acoustic comfort of transport means, such as airplanes. For example, the TBL, or the aerodynamic excitation in general, is the highest contributor to interior noise for an aircraft in cruise flight conditions. It affects even the structural dynamic behaviour of a submarine, despite its low speed. Launch vehicles, at lift-off or in flight ascent, are subject to a hard acoustic and aerodynamic environment, random by nature.

Depending on the frequency range of analysis different approaches are nowadays used, most of them limited by computational cost or invalidity outside specific operational borders.

On the other hand, increasing interest is tangible on periodic structures and their features, which enable, through the use of particular wave-bases, to easily compute the dispersion characteristics and the forced response of structures by analysing a single repetitive element. Many industrially relevant structures, even stiffened and curved, can, in fact, be considered as a periodic assemble of elementary cells.

Since these two fields seem to have been considered separately up to now, the ESR-2 doctorate has the target to bridge this gap enabling to efficiently evaluate the response of fluid-loaded periodic structures in a broadband operational field.

2 LITERATURE REVIEW

Over the past decades, many authors have investigated TBL both in terms of source characterization and application to dynamic and vibro-acoustic models, in order to simulate and calculate the radiated noise and the structural response. An overview, to set and clarify the problem background, is here reported. In any case the following assumptions will be given for granted:

1. TBL fully developed, stationary and homogeneous in space.
2. Weak coupling with the structural operator: pressure fields not influenced by structural vibrations.
3. Random processes are considered as ergodic.

2.1 TBL models

Even though many advances in computational fluid dynamics and in turbulence modelling, some semi-analytical models are still the most used. The Corcos model [1] and the Chase model [2] are among the references in this field. The first model, whose correlation function is here reported for clearness, describes the cross-spectra of the wall pressure fluctuations due to a TBL as a function of the sole distances between two different points, and as harmonically propagating only in the stream-wise direction. The coherence function is bi-dimensional and there is need to experimentally evaluate the stream/cross-wise correlation coefficients α .

$$X_{pp}(\xi_x, \xi_y, \omega) = S_p(\omega) \exp\left(-\alpha_x \left|\frac{\omega \xi_x}{U_c}\right|\right) \exp\left(-\alpha_y \left|\frac{\omega \xi_y}{U_c}\right|\right) \exp\left(\frac{i \omega \xi_x}{U_c}\right)$$

2.2 Structural Vibrations and Noise

The aerodynamic loading has the peculiarity of being a spatially correlated load. This increases the issues when evaluating the structural frequency response.

Taking into account the structural mode shapes, the power spectral density of the velocity of a structure, subject to random excitations, can be expressed using Green functions [3]. This leads to the need to evaluate the joint acceptance function (JAF), which is a costly integration of the product of the correlation function of the excitation and the structural steady modes. Ichchou et al. [4], for example, proposed an equivalent ROF excitation, with a wavenumber-space equivalence of the correlation function. This method allows an easier and cheaper evaluation of the JAF, in the medium-high frequency range, thus reducing the effort with respect to classic methodologies. On the other hand, the approach proposed by De Rosa et al. [5], making use of the modal aspects of the stochastic response, shows a simple and direct method to evaluate the vibratory field. Moreover, in [6], a methodology to reduce the computational cost of a full stochastic response is proposed. A pseudo deterministic modal excitation, based on the pseudo-excitation method (PEM), is simulated taking into account three different approximations, modulated for the three frequency ranges wherein the load matrix has different characteristics. Scaled models provided good accuracy in the medium high frequency range too, extending the applicability of a full model to higher frequencies [5].

Other methods proposed in literature make use of subsystem reductions, [7], to reduce the problem size in terms of degrees of freedom, nevertheless substituting the random load with deterministic point loads [8].

Different Approaches to couple a stochastic wall pressure field with deterministic vibro-acoustic models have been described by Matix et al., [9]. Among the techniques proposed the reciprocity method and the sampling of uncorrelated wall plane waves can be important inputs, even with deep modifications due to the limited applicability of these to very simple cases, in the framework of this EJD.

A SEA formulation using finite element and periodic structure theory has already been proposed by Cotoni et al., [11]. Even though its limited applicability to the cases of Born-von Karman boundaries, this gives a starting point of view for energy approaches to the problem.

2.3 Periodic Structure Theory

Examples of periodic structures can be found in every engineering field. If we think to a fuselage bay, a piezoelectric patch, honeycomb sandwich panels or a train rail we can always imagine the same structure as composed of periodic elementary cells assembled together. In this case the Bloch-Floquet theorem can be applied in order to relate the dynamic properties of the whole structure, as forces and displacements, to the ones of a single substructure, and the ones of a substructure to the ones of one single side or node [10]. A Bloch wave has the here reported form, with β a phase constant and u_r a spatially periodic function.

$$\{\psi_r\} = e^{-i\beta r}\{u_r\}$$

The field on one point can be related to the field in any other point by a magnitude variation and phase shift. The entire problem of the forced response can be reformulated in a different base, which is the wave-base. A transformation is performed between the physical domain, where the system's behavior is described in terms of forces and displacement fields, and the wave domain, where the behavior is described in terms of waves travelling in the positive and negative directions, each with a specific amplitude depending on the excitation, boundary conditions and structure properties and geometries.

Directly excited and reflected wave amplitudes can be then computed using this wave-base and evaluated in the reference position to get the structural response.

3 FURTHER STEPS AND EXPECTED RESULTS

As said a broadband strategy to deal with the flow-induced vibrations is expected as final result. The main and most directly tangible issues that arise are to be addressed to the different work-bases of the PST and classic TBL vibro-acoustic models, in which a full description of the discretized structure is mandatory.

On the early stage phases, an analysis on where addressing the focus and efforts is needed. Both the load spectra and structural operator are characterized by peculiar features. Understanding on which aspect to operate is a key step for further developments.

A decomposition of the load cross-spectra might be a feasible approximation to make a first reduction of the size of the problem. Mathematical tools are already present for this purpose.

Deeper reduction can be achieved when and if the spatial description needed for the excitation can be related to the wave-base of the periodic structure. This latter achievement might be a breakthrough since we can make use of the developments on the deterministic response of any periodic structure, which can be calculated at very low computational cost within the wave-base expansion. About this, the present authors have already investigated and validated a WFE/FE approach, applied in the case of curved and stiffened structures, to get the structural frequency response for any point load.

The present authors are actually testing and validating a wave-based technique to get the stochastic response of a periodic structure.

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