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FLOW-INDUCED NOISE AND VIBRATION ON HIGH-SPEED VEHICLES

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1. INTRODUCTION

Whether we talk about environmental problems or interior acoustic comfort, the noise radiated by high-speed vehicles is an important issue. Regarding noise from trains, most of the effort has been directed towards wheel/rail interaction. Concerning airplanes interior noise, it is essentially annoyance caused by the propulsion system that has been studied. New techniques, now, allow manufacturers to reduce the effect of these source types. Meanwhile, the speed of vehicles increase, thanks to more powerful engines and lighter structures, therefore, aerodynamic excitations emerge as a new source type.

The Turbulent Boundary Layer (TBL) developing around high-speed vehicles is still subject to research. No model is able to represent in detail the complete random pressure field created. Induced vibrations and sound radiated into the cabin are even harder to estimate. This paper intends to present a short review of the models proposed for studying flow-induced noise and vibration, and in addition, some further work is discussed.

2. INFLUENCE OF FLOW CHARACTERISTICS

In this paper, the engineering applications of main interest are aircrafts, high-speed trains, and cars, i.e. "high-speed" vehicles moving in gaseous media. In general, the maximum response of a structure occurs at the so-called aerodynamic coincidence, i.e. when the convected turbulence velocity equals the bending wave propagation speed.

The convection speed, U_c, is typically considered as a constant fraction of the main flow speed. Phase velocities are usually represented as in figure 1, i.e. via a dispersion relationship. Aerodynamic coincidence can only occur at or below the so-called aerodynamic coincidence frequency ω^c_{aero}. Below this critical frequency the bending waves travel slower than does the convected turbulence.

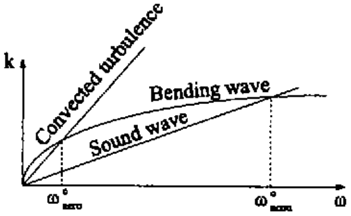

Figure 1. The coincidence frequencies. In the figure, k is the wave number, ω the angular frequency, and ω^c_{acou} the acoustic coincidence frequency.

In hydrodynamic applications, the fluid travels at lower speed and the first resonant frequency is usually larger than the aerodynamic coincidence frequency. In aerodynamic engineering applications the flow speed is typically of the same order as the flexural wave speed, resulting in a strong response.

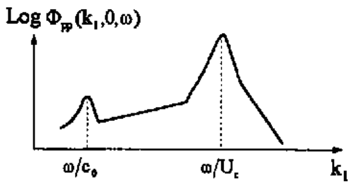

Figure 2. Wave number-frequency spectrum for TBL pressure. c_0 is the speed of sound and k_l is the wave number in the mean flow direction.

Research in wall pressure modelisation started 40 years ago and has been very active since, as it is reported in Bull's recent review [1]. Attention has been concentrated on the wave number-frequency spectrum Φ_{pp} describing the pressure fluctuations in a TBL (figure 2). It gives a good physical insight and allows direct response calculations.

The first model for Φ_{pp} was developed by Corcos [2] who considered only the excitation from the convective wave number range. This model is easy to use but overestimates the pressure spectrum in the low wave number zone. Due to the importance of this region in water applications other writers as Chase [3], Ffowcs Williams [4], and Smol'yakov [5], developed a finer modelisation. Nevertheless the Corcos approximation is accurate enough when estimating the structural response for aerodynamic applications and is still often used. For example, the TBL model chosen by Lesueur et al [6], is based on Corcos work [2].

3. TWO RELATIVELY UNKNOWN CONTRIBUTIONS

In current publications, sound from flow-induced vibrations mostly concerns interior noise problems and is not easily predicted [7]. Preferentially excited and highly responding modes are aerodynamically slow but also acoustically slow which gives them a low radiation efficiency. High frequency vibrations are more efficient radiators of acoustical energy.

The resulting radiated acoustic power receives consequently contributions from two different frequency ranges (see figure 3). In case the acoustic power is found to receive a significant contribution from high frequencies, a better modelisation of the low-wave number zone, than the one Corcos can provide, is necessary.

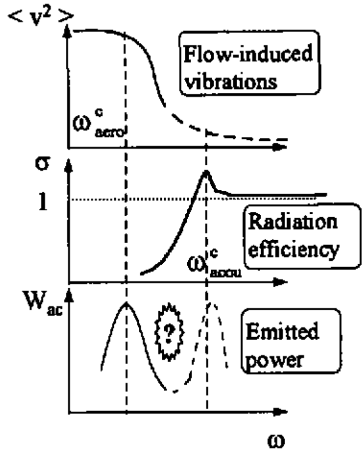

Figure 3. Schematic representation of the final emitted acoustic power (W_{ac}). Dashed lines indicate region of uncertain data due to inaccurate model of the TBL spectrum.

4. NUMERICAL AND EXPERIMENTAL ESTIMATIONS

Surprisingly enough, only a few works have been reported on noise radiation from turbulent boundary layer-induced vibrations:

i) Borisyuk [8] reports calculations of the radiated power from a flat elastic plate excited by a TBL using the models mentioned in section 2. He assumes that highly responding modes radiate so poorly that they should not be taken into account. The results show that the Corcos model lead to an overestimation of the acoustic power. This is not surprising as excitation from the convective peak is skipped in the calculations. Moreover, the results show a strong modal response that makes direct conclusions more difficult.

ii) Measurements of the radiated power from flow-induced vibrations require elaborate experimental facilities and few have been achieved. Davies [9] succeeded to measure the noise emission from an elastic panel mounted flush in the wall of a wind tunnel. The results show a high level below coincidence. But the panels are very thin and behave more like membranes rather than plates. Wilby [10] reported aircraft interior noise measurements. The results show that the boundary layer noise is predominant at mid and high frequencies.

5. FURTHER WORK

Numerical and experimental data are necessary to investigate the relative contribution from the two frequency ranges mentioned. In addition, when performing calculations and measurements, the modal response indicated earlier should be removed. As a matter of fact, the utilization of finite plates induces response filtering by modal-weighting and makes difficult any interpretation of the results. Also the study should be carried out on plates of interest for engineering applications (composite materials, periodically stiffened structures, etc...). The following work is suggested :

i) In order to get rid of the modal filtering effect, an "infinite plate" will be considered, corresponding to large structures where a large number of modes are excited in the frequency range of interest and no distinct modal response occurs. This "infinite plate" (figure 4) can be realized by considering a finite plate excited by a TBL and with reflection-free boundaries for bending waves.

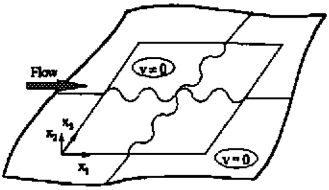

Figure 4. The "infinite plate" model suggested for further studies.

ii) The procedure that should be followed is first to estimate the total emitted power and to determine the main contributing frequency range. The influence of the flow speed should also be investigated. In a second step and according to the results obtained an adequate model should be chosen.

Studies suggested here are in progress and will be reported in later publications.

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