LITERATURE REVIEW ON WIND INDUCED SOUND ON BUILDINGS

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Aeroacoustics is a scientific field that has been for many years explored in different kinds of engineering, in automotive and aerospace industry, in duct design or jets and turbine construction and other fields in which sound is generated by turbulent fluid motion, aerodynamic forces and periodical varying airflow. Nowadays, due to new types of building constructions and elements (e.g. different shading elements) installed on high-rise buildings (causing high windspeeds on the building facade) questions related to aeroacosutics are becoming more and more actual. Noise caused by wind flow around buildings having specific shapes and structures can lead to annoying sound levels and sound spectra of different kinds, ranging from tonal sounds tonal with pulsating components to broadband noises and contribute so to overall acoustic discomfort indoors and outdoors. In relation to architecture and building design, only little information can be found in literature on wind induced noise on building. This article gives a literature overview of wind-induced noise on building facades.

1. INTRODUCTION

Research on aeroacoustics has been most probably boosted by the well known wave equation of aeroacoustics formulated by Lighthill [21]. His theory has given a basis in solving different types of acoustic problems caused by wind in many various industrial areas, such as jet-engine construction, aircraft and automotive industry [1], [2], [16] [25], [31].

Nowadays, several ways on determinations of wind effect on elements or constructions exist. The most popular are numerical simulations based on empirical or semi-empirical approaches, different computational numerical simulations or measurements performed on real scale or scale by means of specialized laboratory that consist of wind tunnel coupled with anechoic chamber, or measurements in situ. Numerical solutions of acoustic wind actions are also based on Lighthills theory [21],[22]. The increased power of computer processors and amount of RAM memory enabled the computational fluid dynamics (CFD) to develop in very powerful prediction tool. CFD simulations have replaced the predictions of flow parameters of semi-empirical models by computed values. The combination of these two methods have been developed in computational aeroacoustics (CAA).

Overview of flow-induced vibrations and design recommendations for prismatic bodies and grids of prisms was published by Naudascher and Wang. [25] A literature review of algorithms in computational aeroacoustics has been sumarized in the article of Tam [30], where he has presented an extensive overview of calculation approaches in aeroacoustics and has opened discussion about CFD method usage in aeroacoustics prediction models. Lele [20] provided summary of artifacts inherent in numerical simulations influenced by various boundary conditions. He pointed out that, that progress has been made in solving nonlinear problems of the sound generation. Recent advances in aeroacoustics in computational fluid dynamics were investigated by Glegg [11]. A complementary review paper was written by Bailly and Bogey [3]. They have published a brief review of CFD, CAA and hybrid algorithms in jet noise calculations. Kurbatskiia and Mankbadi [19] have summarized knowledge in different CAA algorithms, such as finite difference method (FDM), Adams-Bashforth and Runge-Kutta (RK) method and similar. The theory of vortex rings was examined in an extensive study of Kambe [16], where theoretical predictions and observations and described vortex colisions and interactions were compared. Adachi et al. [1] performed an acoustic simulation study where wave equations with fluctuating pressure on the wing surface as a noise source were solved. A case study in which numerical simulation of near-field (large eddy simulation - LES) and far-field (Ffowcs Williams and Hawings - FWH) propagation of sound waves was presented by Yang et al. [31].

2. PRINCIPLE OF AEROACOUSTIC NOISE

Acoustics is a multidisciplinary scientific field that together with other specialisations forms subdisciplines like: physical acoustic, building and room acoustic, electro acoustic, musical acoustics, physiological acoustics, psycho acoustics etc. [8]. Aeroacoustics is one of them. In general acoustics, two types of acoustic source mechanisms are known. (1) Air borne sound source and (2) structure borne sound source. For instance, once a piston is moving up and down, it will cause pressure changes and radiate sound into the environment. The resonant vibration of a plate due to impact force, will also radiate sound. When dealing with air borne sound sources, the source mechanism is located in the air itself. Good example of such a source is mast in a windy harbor, which is generates sound due to wind flow across a pipe. In this case, the mast does not need to vibrate to generate sound. The air borne sound mechanism has its origin in the unsteady oscillations of the air in the otherwise steady-state flow. Such phenomena belong to science of aeroacoustics. The unsteady oscillations of the air are here often caused due to obstacles, such as sharp edges of a rigid structure, in the flow, causing turbulences or vortices. These turbulences or vortices generate sound or noise.

3. WIND-INDUCED NOISE ON BUILDINGS

Wind flow around building can cause the effects mentioned above and although noise induced by air flow can lead to rather strong acoustic discomfort, aeroacoustics in architectural applications is an area that remained unnoticed for a long period of time. Nowadays, a number of papers or presentations on aeroacoustics problems caused by wind action on buildings is significantly growing. It is probably due to growing number of high-rise buildings that are fitted with periodic strcutures of shading elements on facade. Wind speeds close to building facade on upper floors are usually very high and might cause unwanted noise. Once a building is in the way of the airflow, the airflow on the windward side of the building is stopped, at the sides of the building is accelerated and on the leeward side of the building vortices are formed. As wind flows through and around different building elements, such as sunshades, fins, grids, balustrades, cables, canopies, voids, ventilation openings, etc., annoying “whistling” or “humming” noises can be generated, depending upon wind speed and wind direction. As mentioned above, these phenomena are especially important in cases of tall buildings. Two architectural cases (buildings) in which problems with aeroacoustic noise were reported (Het Strijkijzer with height of 130 m and De Hotoren with height of 110 m, are described by Ploemen et al. [28], Both cases are in the Netherlands, country with typical regular and almost continues wind flow. Reported and measured sounds contained tonal components, due to steel grids applied as an ornament or as a functional addition to the building facade. Another very famous case is the tallest building the Beetham tower (171 m) in Manchester (Great Britain). In this case, a glass plate placed on the roof of the tower, generated a tonal noise induced by high speed airflow. The Cityspire Center Tower (248 m) in New York City, started to have problems with loud whistling noise very soon after the completion. Here the noise was caused by the wind blowing through decorative dome at the top of the building. In the design of buildings it is therefore very important to take the shape and location of a building and building elements into account and to perform predictions of wind flow around buildings, in relation to the prevailing wind direction and wind speeds, that depend on the region in which object is build. Two types of assessment methods can be applied. The first one is a numerical approach, in which the architectural design is studied in a computer simulation and in which the aerodynamic information is predicted and potential noise sources are identiffied. The second one is an experimental approach, in which full-scale details or scaled buildings are tested in a wind tunnel.

One of the first research studies in this field has been reported by by Curle [7]. Berhault [4] performed study on wind noise on buildings and Suda and Yoshioka [29] conducted a full-scale measurements of wind-induced acoustic noises in medium-rise and high-rise residential buildings. He has also shown how wind effects the occupants discomfort. Gerhard and Grundmann [10] introduced an aeroacoustic wind tunnel in I.F.I. institute in Aachen (Germany), which was specially designed for measurements of wind induced noise on building parts and structures. Published case study investigated the aeroacoustic noise produced by facade section of the 125 m high-rise building of the business center Graft and Durgin [12]. Acoustic resonances where measured and identified in the opening of a resonating cavity. Moleney et al. [24] have summarized some knowledge related to problems with wind-induced noise around buildings and have listed few methods for the assessment. Granneman et al. [13] and Ploemen et al. [28] investigated a full-scale steel grids with different rectangular mesh sizes and wind conditions in a wind tunnel. Their study is probably one of the most complete relatively recent research works dedicated to air-flow noise on building cases. Feng [9] performed experiments with perforated plates in the specialized laboratory that consisted of an anechoic chamber and an adjacent reverberation chamber. Chéné et al. [15] have compared different measurement approaches, theirs advantages and limitations. A case study published by Ahmed et al. [2] have shown the importance of anechoic chamber for aeroacoustic measurements and have discussedthe impact of anechoic chamber (so called acoustic free field) on accuracy and signal to noise ratio during aeroacoustic measurements. Blinet et al. [6] tested aluminum bar networks with different diameters and spacing between them, as well as perforated plates with different characteristics in non-acoustics wind tunnel.

The most recent approaches used for predictions of aeroacoustic noise are numerical algorithms that combine the computational fluid dynamics (CFD) and computational aeroacoustic (CAA). Their use on practical example has been shown by Bies et al. [5], Oshima et al. [26] who investigated the sound created due to airflow over square-section balusters of a building. In this study, the numerical calculation using large eddy simulation (LES) was chosen. They were followed by Kitagawa et al. [18], Kim et al. [17], Liu [23] and many recent studies that are based on CFD analyses.

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