Journal of Fluids and Structures 78 (2018) 263–276

Contents lists available at ScienceDirect

Journal of Fluids and Structures

journal homepage: www.elsevier.com/locate/jfs

Flow noise in planar sonar applications

Christian Henke

ATLAS ELEKTRONIK GmbH, Sebaldsbruecker Heerstrasse 235, D-28309 Bremen, Germany

ARTICLE INFO

Article history:
Received 11 July 2017
Received in revised form 8 January 2018
Accepted 10 January 2018
Available online 4 February 2018

Keywords:
Sonar
Flow noise
Wall pressure fluctuation
Bending waves
Biorthogonal expansion method

ABSTRACT

In this paper an investigation of flow noise in sonar applications is presented. Based on a careful identification of the dominant coupling effects, the acoustic noise at the sensor position resulting from the turbulent wall pressure fluctuations is modelled with a system of hydrodynamic, bending and acoustic waves. We describe for the first time an analytical solution of the problem which is based on a biorthogonal system which can be solved in the spectral domain without the usual simplifying assumptions. Finally, it is demonstrated that the analytical solution describes the flow noise generation and propagation mechanisms of the considered sea trials.

1. Introduction

Most vehicle mounted hydrophones used in passive sonar sensors are mounted inside stiff sonar windows in order to protect the sensors and to reduce the hydrodynamical drag/vibrations of the sensors. On the one hand, when the vessel is in motion, the structure is excited by turbulent flow, and on the other hand, the generated turbulence causes additional noise. Thus, the acoustic waves of these contributions propagate to the position of the hydrophone and disturb the incoming signal. The aim of the paper is an investigation of flow noise generation and transport mechanisms with respect to different materials and geometries. The knowledge of these mechanisms could be used to maximise the signal to noise ratio. The mathematical modelling and a combined numerical/analytical solution of passive sonar acoustics will be validated against experiments. To consider real life underwater scenarios, the experiments involve sea trials with a test towed body, which realises a typical broadband sonar environment. On the starboard side, the hull of the test towed body includes a linear elastic plate, which is in front of the measurement system. This system consists of a line array having equally spaced hydrophones inside a water-filled measurement box, which is designed to protect the sensors from background noise. Furthermore, the box is mounted in such a way that it is decoupled from the body frame. In this way noise from the environmental conditions could be minimised. The flow noise generation and transport mechanisms of the sonar configuration under consideration are investigated by a wavenumber–frequency analysis. To reduce the dynamic range of the signal a prewhitening filter was applied to the measurement data. The filter considered the sea state, the sensor electronics and the receiving sensitivity of the hydrophones. Since the position dependent receiving sensitivity of the hydrophones is not included, position or wavenumber dependent measurement results should only be interpreted qualitatively. Figs. 1 and 2 show the unpublished results of a sea trial experiment which has been described in Abshagen et al. (2016). In contrast to the polyurethane/fibre-reinforced plastic sandwich plate of Abshagen et al. (2016), the experimental results of this work refer to a steel plate in front of the hydrophones.

In literature there are many investigations of sound radiated by boundary layer driven structures (see for an overview, e.g. Crighton et al., 1992; Howe, 1998; Ciappi et al., 2015). The coupling between the boundary layer pressure fluctuation

E-mail address: christian.henke@atlas-elektronik.com.

https://doi.org/10.1016/j.jfluidstructs.2018.01.007
0889-9746/

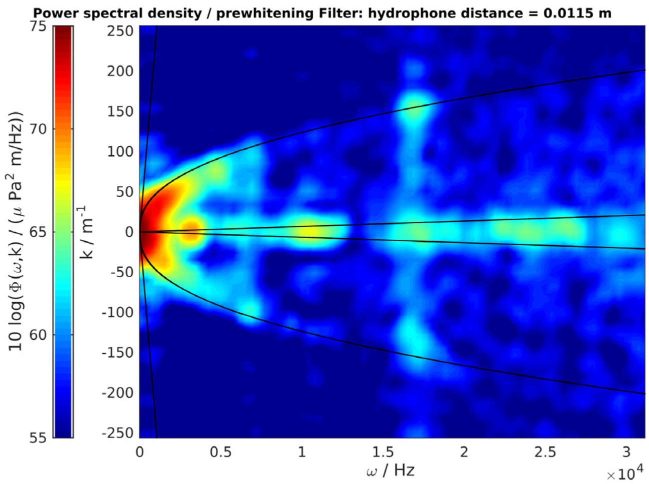

Fig. 1. Power spectral density of the acoustic pressure, sea trial: wavenumber–frequency plot for towing speed $u = 8$ kn and a hydrophone distance of 0.01 m. The straight lines show the relations $k = u^{-1}\omega$ and $k = c^{-1}\omega$, where k is the wavenumber, ω denotes the angular frequency and c is the speed of sound. The curved line represents the dispersion relation which is investigated in the following sections. The dominant noise at 17000 Hz is caused by the environmental conditions. The Figure is based on a time signal of 0.2 s and is divided into segments with an overlap of 50%, which are weighted with a Flat-Top window.

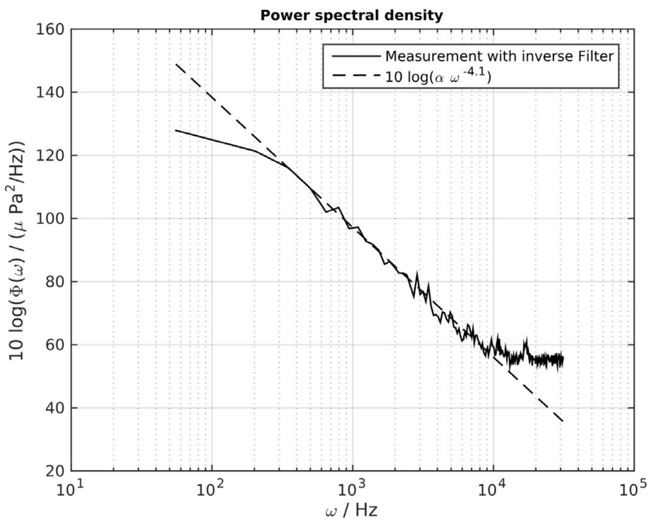

Fig. 2. Point pressure frequency spectrum $\Phi(\omega) = 1/N \sum_k^N \Phi(\omega, k)$ (sea trial experiment).

of a finite rectangular plate and the acoustic pressure fluctuation in an acoustic indefinite domain was investigated by Strawderman (1994) with a coupled eigenfunction expansion method. Because of the unknown inverse of the system matrix (cf. Strawderman, 1994, p. 5-46–5-47), this approach cannot be used for practical applications without simplifying assumptions on the fluid loading and the crosscoupled modal terms. Besides the above considered application, this problem is also a common task in aircraft cabin noise studies. For aircraft applications, Graham (1995, 1996a, b) proposed also a model for the acoustic response of a finite rectangular plate in an acoustic indefinite domain. These investigations were based on the empirical Efimtsov model (Efimtsov, 1982) for the forcing pressure and derive the wavenumber–frequency spectrum $\Phi(\omega, k)$ which is the Fourier transformation of the space correlation function of the wall pressure. However, in the averaging process of the Efimtsov model and comparable approaches like Corcos or Chase (see Howe, 1998, Chapter 3, for an overview), much of the relevant informations (e.g. phase relationships) are lost.

Since the above mentioned simplifications were also used by Graham, the approximation of the acoustic response was improved in Maury et al. (2002a, b) by using a different set of eigenmodes. To overcome the simplifying assumptions, Mazzoni solves in Mazzoni and Kristiansen (1998) and Mazzoni (2003) the underlying partial differential system by a finite difference discretisation. In Crighton et al. (1992, Chapter 17) an asymptotic analysis is performed, which causes the author to comment that the above problem is not already well understood: