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Applied Acoustics 67 (2006) 201–229
applied acoustics
www.elsevier.com/locate/apacoust

Acoustic characterization and prediction for fan-duct-plenum-room integrations

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Received 12 January 2005; received in revised form 12 May 2005; accepted 13 June 2005
Available online 25 August 2005

Abstract

This paper investigates mutual influence of duct and room acoustics in the whole fan-duct-plenum-room integrations. Applying the parametric design language of finite element software ANSYS (APDL), dimensional and positional influence on system acoustics has been studied. Models with different room dimensions, duct lengths, duct cross-sections, duct locations, duct discharges and duct elbow were constructed, and their characteristics were compared qualitatively. Results show that small rooms, short ducts, large duct cross-sections and bell mouth duct discharges help to increase room sound pressure levels (SPLs); SPLs in ducts and plenums are sensitive to duct dimensions and duct discharge types but insensitive to duct locations and room dimensions; duct elbows have relatively indistinct acoustic influence in each component. Based on the calculation results, a semi-experimental method was proposed for simply and approximately evaluating indoor acoustic spectra of fan-duct-plenum-room integrations, then an example was used to demonstrate the prediction process. Finally, by adopting several ideal models, sound field constitutions, duct and room wall admittances and duct end reflection were explored quantitatively. This study may give a detailed understanding of fan-duct-plenum-room acoustics for researchers, also it might provide a new, simple and approximate prediction method for professionals to evaluate and improve fan-ducted acoustics.

Keywords: Fan noise; Room noise; Sound pressure level; Absorption coefficient; End reflection

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doi:10.1016/j.apacoust.2005.06.006

1. Introduction

Fans are widely used in industry. Being rotary machinery, fans produce serious aerodynamic noise. There are many structures of fan installation and each structure has its own acoustic features. Ventilating blowers, dehumidifiers and central air conditioner terminals often adopt the fan-ducted structure that a fan in a plenum propels air into a room through a short duct. Since most of above facilities are for domestic and commercial use, the fan-ducted noise in this structure is one of the most critical problems to depress indoor environmental comfortability. Researching sound propagation in this structure has become an urgent task especially for ventilating and air conditioning industry.

There are many literatures concerning with acoustics of this structure. As for fan-ducted acoustics, the fundamentals that govern aerodynamic acoustics have been proposed for more than four decades. However, analytical solutions were hard to work out, so researchers turned to other substitution methods [1]. Cremer [2] suggested describing an in-duct fan as an acoustic two-port source in 1971, then Abom and Boden [3] in 1995 simplified the two-port source determination process. Eversman [4] in 1998 developed a finite element code for aft fan duct acoustic prediction in a turbofan engine, and Dunn and Tweed [5] in 1999 adopted a boundary integral equation to predict ducted fan engine noise. Nevertheless their work could only be adopted to some limited domains, the characterization and prediction of fan-ducted acoustics are still challenges to researchers today for its complicated principles and numerous influential factors. Room acoustics is also a hotspot, in 1985 Schultz [6] proposed an empirical prediction of the SPL in dwellings and offices as a function of source power level, room dimensions, sound frequency and the distance from the sound source, Franco [7] in 1999 suggested an improved statistical model considering the non-uniform reverberating energy density distribution for evaluating sound field in closed space. Pan [8], Dance [9] and Roman [10] also reported their recent work on acoustic propagation, modeling and prediction indoors.

However, in most of the published researches, room noise, duct noise and fan excited noise are studied independently; in some other studies only some particular integrations of above components are discussed. Little attention has been focused on the mutual influence of duct and room acoustics in general fan-duct-plenum-room integrations. Moreover, for the aspect of fan-ducted acoustic prediction, conventional methods requires much knowledge on fans' aerodynamic properties rather than sound propagation in the whole system, which is in fact less important or even impossible for many professionals and engineers. Also very little predicting work has been done based on indoor sound spectra.

In this study, with the aid of finite element software ANSYS, a qualitative investigation was undertaken to study the influence of dimensional and positional parameters on acoustic behavior of fan-duct-plenum-room integrations. Based on the investigation, a semi-experimental method was proposed for indoor acoustic spectra prediction of fan-ducted rooms. This study aims at presenting acoustic regulations of fan-duct-plenum-room integrations and providing a simple, approximate and