Noise Power Prediction of Air Flow with Obstruction through Subsonic Wind Tunnel

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Abstract: ***This paper estimates noise power generated by a turbulent air flow in a duct from the knowledge of mean quantities (average velocity and sound pressure level). The sound excitation by fluid flow through duct can be used to predict fluid behavior. However, the fluid flow container stability has to be taken in account simultaneously with fluid flow effect on sound generation and propagation. The experimental system used in this work is air flow through subsonic wind tunnel duct. The sound pressure levels of air flows through test section of subsonic wind tunnel (at three air flow velocities 2.5, 7.3 and 12.5 m/s) respectively were carried out experimentally. The sound excitation or generation by air flow throughout the test section of subsonic wind tunnel without any obstruction can't be used to imagine the fluid behavior. To predict fluid flow properties, an infinite cylinder was immersed in order to obstruct the air flow and generate new source of sound. This case is relevant to a wide range of engineering applications including aircraft landing gear, rail pantographs and automotive side-mirrors. The results discuss the effect of Reynolds number on the sound generation, propagation features and vice-versa. The results are compared with other researchers which gives a good agreement.***

Keywords: Turbulent air flow, acoustic excitation, cylinder, noise power.

1. Introduction

The present investigation is an experimentally and theoretically attempt to better understand the relation between noise power and Reynolds number. Flows in ducts are both fundamental and very important because several types of ducts are used, for example, as basic machine elements, in a number of engineering fields. The fluid behavior depends on fluid properties and flow types. Therefore, several researchers have presented experimental and analytical reports about the flow behavior in ducts in order to contribute to apparatus design. However, in several cases, ducts have been used for turbulent flows. In addition, abrupt geometrical changes in cross-sections along the flow direction cause flow rapidly, resulting in the formation of large-scale vortices. The subsequent convection of vortices gives rise to significant flow unsteadiness and has an immediate effect on sound generation. However, in general, a turbulent flow involving separation is one of the most complicated and difficult flows to predict numerically. As such, several studies have examined separated flow propagation in both experimentally and theoretically.

(Hourigan et al , 1990) studied experimentally and numerically the generation of resonant sound by flow in a duct containing two sets of baffles and the “feedback” of the sound on the vortex shedding process. Likewise, the finite difference method and a discrete-vortex model used to predict a separated flow and to calculate the resonant sound field. As a result the peak sound pressure levels observed that it happens when large scale vortices formed in the shear layers separating from the upstream group of baffles, approach the downstream group of baffles at a particular phase of the induced resonant acoustic cycle. Furthermore, the secondary flow structures investigated numerically in turbulent flows through horizontal pipes with circular cross sections based on large eddy simulation and an Euler-Lagrange approach. An essentially longitudinal resonant acoustic mode can be excited in a duct by flow over two sets of baffles.

(Mu and Mahalingam, 1996) studied the interaction between an imposed monochromatic, time-dependent acoustic disturbance and a steady mean shear flow in a two-dimensional duct using DNS to verify and to understand the role of oblique waves generated through acoustic refraction when a monochromatic, acoustic velocity disturbance introduced at a fixed duct location is allowed to interact with a steady shear flow in a two-dimensional duct. The interaction of an acoustic wave disturbance with a shear flow provides a mechanism for transfer of energy between the mean and various modes of the acoustic flow. This problem is investigated via direct numerical simulation (DNS) of the interaction between an imposed acoustic velocity disturbance in an otherwise steady shear flow in a two-dimensional duct. Good agreement with analytical predictions of Wang and Kassoy is obtained.

(Longatte and Lafon, 2000) investigated acoustic field computations in complex flows to validate the wave operator associated with linearized Euler equations. Numerical tests deal with propagation in two-dimensional sheared ducted flows and refraction effects on propagation and oblique wave generation are included. The obtained results compared with other solutions deduced from analytical developments and direct numerical simulations. They showed good agreement with analytical theories and numerical solutions deduced from direct simulation. The LEE suitably describe mean shear effects on the acoustic intensity distribution in ducts. A validation of acoustic fields computed in confined configurations. This is a first step in the analysis of coupling occurring between flows and waves originating from embedded noise sources.

(Ju and Fung, 2001) explored the development of time domain impedance boundary condition (TDIBC) for prediction of aero-acoustics in wall bounded flows and the presence of a flow and its boundary layer over a wave-absorbing surface complicates the modeling and implementation of TDIBC. There are three different approaches considered here to account for the effects of wave refraction, absorption, reflection, and convection at a wave-absorbing wall. It is shown here that the effective plane-wave impedance provides a simple and satisfactory account of wave refraction in a shear flow for walls with high absorption. The implementation of convection-modified impedance as TDIBC leads to the amplification of numerically supported spurious waves at impedance discontinuity.

(Ozyoruk and Long, 2000) included sheared mean flow effects on sound propagation over acoustically treated walls. The modern application of the time-domain equivalent of the classical acoustic impedance condition, i.e., the particle displacement continuity equation to numerical simulations of a flow impedance tube in the time domain yielded reasonably good results with uniform mean flows.

(Eldredge and Dowling, 2003) reported the effectiveness of a cylindrical perforated liner reported with mean bias flow in its absorption of planer acoustic waves in a duct. The used liner which converts acoustic energy into flow energy through excitation of vorticity fluctuations at the rims of the liner apertures. Also, the developed a one dimensional model that embodies this absorption mechanism which utilizes a homogeneous liner compliance adapted from the Raleigh conductivity of a single aperture with mean flow. The evaluated the model compared with experimental results to get excellent agreement besides they noticed that such a system can absorb a large fraction of incoming energy which can prevent all of the energy produced by an upstream source in certain frequency ranges from reflecting back. Finally, the planer sound waves produced by an upstream source travel through the lined section subjecting each aperture to a harmonic pressure difference that causes the periodic shedding of vortices from the aperture rim.

(Hu et al , 2006) executed simulations at a series of Reynolds numbers up to Re_t=1440 which corresponds to $Re_t=6.92\times 10^4$ based on channel width and center line velocity. A single-point and two-point statistics for velocity, pressure and their derivatives have been collected, including velocity moments up to fourth order. The point spectrum of wall pressure collapses concluded obviously for $Re_t \geq 360$ under a mixed scaling for frequencies lower than the peak frequency of the frequency-weighted spectrum, and under viscous scaling for frequencies higher than the peak. Good agreement for similar Reynolds numbers and above the peak frequency, wall pressure spectra collapse under viscous scaling is showed.

2. Experimental Work:

Test Rig Equipment:
The Rig consists of the following main parts:

2.1.1. Anechoic Chamber

Anechoic ***(an – means 'no', echoic – echo)*** chamber is a room that has been prepared to minimize sound reflections from walls. The Anechoic room is used to prevent the undesirable noise for reaching a test place. To predict a good sound insulation, three parameters are taken into account:

1) The sound source and everything that join to it like sound degree and sound intensity.
2) The direction of propagation of sound wave.
3) The undesirable or extra sound effect.

For accurate results in experimental work on noise generation and noise propagation, an anechoic chamber was built to avoid any additional sound or noise from other sources. The anechoic chamber photograph is shown in figure (1). The triangular sponge was used to distribute on all sides, ceiling and floor of the room made from wood. Each sponge has base (16 cm x 16 cm) and height 50 cm . The schematic of ceiling, floor and all sides for anechoic chamber with and without cylinder is shown in figure (2) respectively **(Hayder Kraidy Rashid, 2009)**.
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Figure 1: The anechoic chamber photograph for wind tunnel without cylinder.

Figure 2: Photographic picture of the used test section for wind tunnel with cylinder.

Sound level meter

Sound pressure level is measurement of the sound strength on a logarithmic scale (base ten). It is used for measuring the sound pressure level. The unit of a "Bell" was first defined there. Because a "Bell" was a small value, sound level meters read in deci-Bells (dB) or more commonly spelled "decibels". The properties of sound level meter are presented in table (1) while the physical properties of the air is given in table (2) and photograph of SPL, where $p_{ref} = 2\times 10^{-5}$Pa for sound propagating in gases. The sound level meter is illustrated in figure (3) **(Hayder Kraidy Rashid, 2009)**.

Figure 3: Photograph of sound level meter

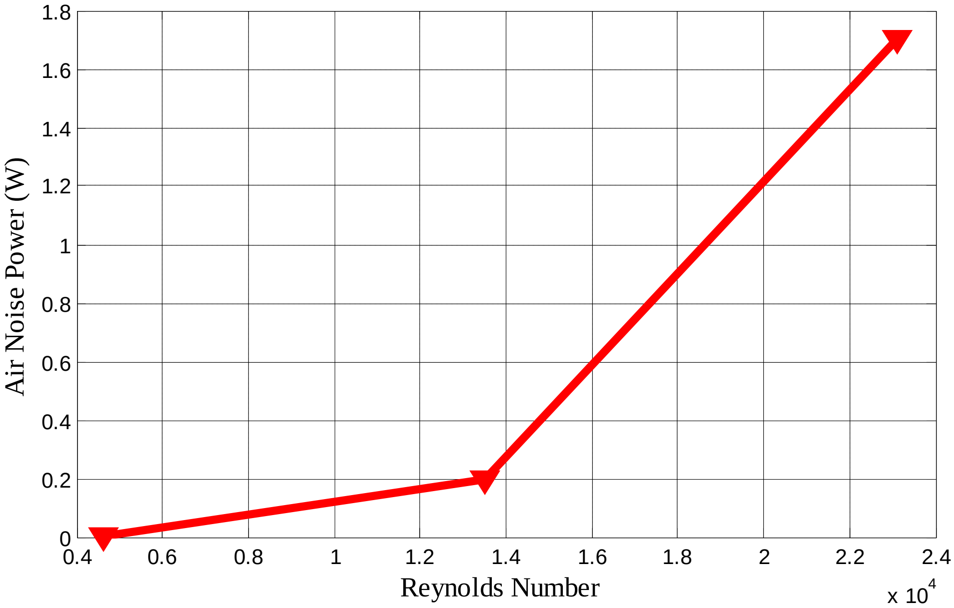
Table 2: The physical properties of the air

Fluid	Density - ρ - (kg/m³)	Kinematic viscosity - ν - x 10^{-6} (m²/s)	Speed of sound (m/s)
Air	1.20227	15.1751	343.28

3. Results and Discussion

Figure 4 represents the effect of increasing Reynolds number on air noise power. Air noise power increases due to increasing Reynolds number. The air noise power increases as a result of vorcies generation and increaing the frequency, i.e, the generation of turbulent flow. This leads to generation the vortices.

Fig. 4: Relation between noise power and Reynolds number for test section of wind tunnel



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Nomenclature

SYMBOL	DESCRIPTION	UNITS
D	Diameter of cylinder.	m
L	Length	m
LCD	Liquid crystal display	----
Re	Reynolds Number	----
SPL	Sound pressure level	dB
U	Air flow velocity.	m/s
St	Strouhal Number.	----
f	vortex shedding frequency.	Hz
ρ	density	Kg/m^3
DNS	Direct Numerical Simulation	----
TDIBC	time domain impedance boundary condition	----
LEE	Large Euler Equations	

Subscript

a= air