Experimental and Theoretical Study of Air Flow with Obstruction Through Test Section of Wind Tunnel

Hayder Kraidy Rashid **Ali Hamza Kadhim Al-Shibany**
Mechanical Engineering Dep.- University of Babylon
haiderkraidi@yahoo.com. eng.ali_hamza_kadhim@yahoo.com.

Abstract:

This paper estimates the sound and flow 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. This behavior can be carried out by discovering the relation between sound excitation and fluid flow parameters like Reynolds number, Strouhal number and frequencies of turbulent fluid flow. 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 velocities2.5, 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 a 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. Sound measurements have been taken in an anechoic room at Babylon University. ANSYS program software is used to simulate all experimental results.The experimental and theoretical data that were presented in this paper will give further insight into the underlying sound generation mechanism.In the presented work, the linkage between sound generation and CFD results using thepresented work results and ANSYS simulation results was done.The results discuss the effects of fluid flow parameters such as Reynolds and Strouhal numbers on the sound generation, propagation features and vice-versa. The results are compared with other researchers which give good agreements.

Keywords: Turbulentair flow, acoustic excitation, cylinder, ANSYS.

الخلاصة

يوضح هذا البحث التدفق والصوت المتولد نتيجة تدفق الهواء المضطرب داخل القناة من معرفة متوسط كميات التدفق (متوسط السرعة ومتوسط الضغط الصوتي). يمكن استخدام الإثارة الصوتية الناتجة من تدفق المائع خلال القناة للتنبؤ بسلوك المائع. يمكن اعتماد هذا السلوك لاكتشاف العلاقة بين الاثارة الصوتية وخواص تدفق المائع مثل رقم رينولدز، عدد ستروهل وترددات تدفق المائع المضطرب. مع ذلك، فان استقرار محتوى تدفق المائع يمكن أن يؤخذ في الاعتبار في وقت واحد مع تأثير تدفق المائع المضطرب على نمو وتولد الصوت. النظام التجريبي المستخدم في هذا العمل هو تدفق الهواء خلال قناة النفق الهوائي دون الصوتي. تم حساب مستويات الضغط الصوتي خلال مقطع اختبار من النفق الهوائي دون الصوتي لثلاثة سرع مختلفة للهواء 2.5و 7.3و12.5 متر لكل ثانية. لا يمكن استخدام تولد واثارة الصوت من نفق الهواء خلال مقطع اختبار من نفق هوائي بدون اعاقة لمعرفة سلوك المائع. تم وضع اسطوانة مغموسة لمعرفة خصائص تدفق المائع وتوليد مصدر جديد للصوت. وهذه القضية هي ذات صلة بمجموعة واسعة من التطبيقات الهندسية بما في ذلك معدات هبوط الطائرات،مناسيخ السكك الحديدية ومرايا السيارات الجانبية. اتخذت قياسات سليمة في غرفة كاتمة للصدى في جامعة بابل. يمكن استخدام برنامج الأنسيز لمحاكاة كل النتائج التجريبية. النتائج المستحصلة من هذا البحث تعطي نظرة واسعة لالية نمو وتولد الصوت. في هذا العمل تم الربط بين خواص الصوت ونتائج ديناميك السوائل الحسابية باستخدام نتائج الجانب النظري ومحاكاة الأنسيز.ناقشت النتائج تأثير العديد من متغيرات المائع مثل عدد رينولدز وستروهل على نمو وتولد الصوت والعكس صحيح. أخيراً، تمت مقارنة النتائج مع الباحثين الاخرين والحصول على توافقات جيدة.

الكلمات المفتاحية: المضطرب تدفق الهواء، الإثارة الصوتية، اسطوانة،ANSYS

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

1. Introduction:

The present investigation isan experimentally and theoretically attempt to better understand the relation between the acoustic excitation and fluid behavior. 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. The sound generated by anunsteady viscous flow across a circular cylinder is representative of several bluff body flows found in engineering applications (e.g., automobile antenna noise, aircraft landing gear noise, etc.). The aim of this research is to find the relation between the acoustic generation and turbulent fluid properties.

This turbulent flow induced using circular cylinder plays as flow obstruction**(Hourigan *et. al.*, 1990)**.

(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 are used to predict a separated flow and to calculate the resonant sound field.As a result the peak sound pressure levelsobserved 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.

(Mu and Maralinga,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 disturbances 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 flowsto 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 resultscompared 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.

(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.

(Ozyoruk and Long,2000)included sheared mean flow effectson 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. The solutionsshowed that were not attainable previously with uniform flows at high Mach numbers can now be obtained with the help of the no-slip conditions of sheared background flows at the wall.

(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 model is 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.

(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. Experimental work:

1.1. 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 toprevent 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 joins 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 that made from wood. Each sponge has base dimension (16 cm x 16 cm) and height 50 cm. The schematic of ceiling, floor and all sides for anechoic chamber with and without cylinderis shown in figure (2) respectively**(Hayder Kraidy Rashid, 2009)**.

Fig.1: The anechoic chamber photograph for wind tunnel without cylinder.

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

2. 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 are 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)**.

Table (1), Properties of sound level meter (Hayder Kraidy Rashid, 2009).

.

Display	**52mmx32mm LCD, 5digits with annunciator.**
Function	**(A&C frequency weighting), Time weighting (fast, slow), Hold, Memory (Max. &Min.) Max. Hold, AC output, RS232 output.**
Measurement range	**30-130 dB.**
Resolution	**0.1dB**
Frequency	**31.5 to 8,000 Hz**
Microphonetype	**Electric condenser microphone**
Microphone size	**Out size 12.7mm DIA. (0.5 inch)**
Calibrate	**B&k (Bruel &Kjaer), Multifunction acoustic calibrator 4226.**
Output	***AC output: AC 0.5 V r.m.s. corresponding to each range step. Output impedance –600 ohm.**

Fig.3:Photograph of sound level meter

Table (2),the physical properties of the air. (Frank M. Whit, ASME, 1991).

Fluid	Density - ρ - *(kg/m^3)*	Kinematic viscosity - ν - *x 10^{-6}(m^2/s)*	*Speed of sound (m/s)*
Air	1.20227	15.1751	343.28

3. Frequency:

The frequency for test section of wind tunnel without a cylinder (D_i=2.8 cm) is calculated from the following equation (Nortonet.al,2003):

$$f = \frac{U}{L} \quad (1)$$

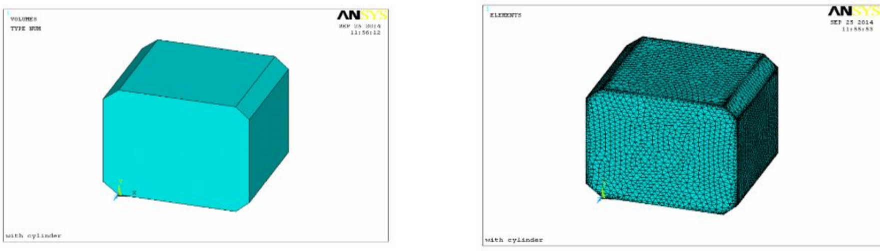
The vortex shedding frequency (STROUHAL NUMBER) in presence of cylinder can be obtained from the following equation(Jiawei Liu, 2012):

$$St = \frac{fD}{U} 0.198\left(1 - \frac{19.7}{Re}\right) \quad (2)$$

4. Building a Mesh:

One of the cumbersome and time consuming part of the CFD is the mesh generation. Although very simple flows, mesh generation is easy.It becomes very complex when the problem has many cavities and passages. Mesh generation is basically the discretization of the computational domain. The mesh in finite difference methods consists of a set of points which are

called nodes. The finite volume methods consider points that form a set of volumes which are called cells. The finite element methods use sub-volumes called elements which have nodes where the variables are defined. Values of the dependent variables such as velocity, pressure, etc. will be described for each element**(Huilin Xing *et. al*., 2000).**



a. b.

Fig.4:Geometric model of the test section

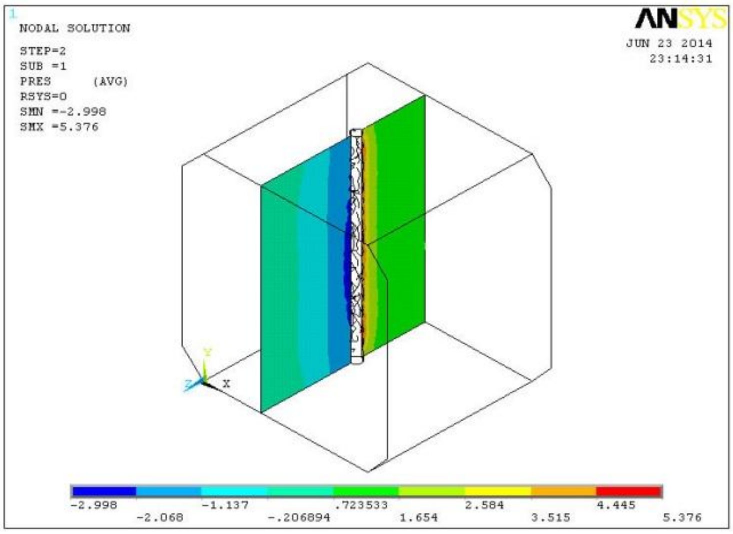
(a. without cylinder b. with cylinder with free meshing).

5- Results and Discussion:

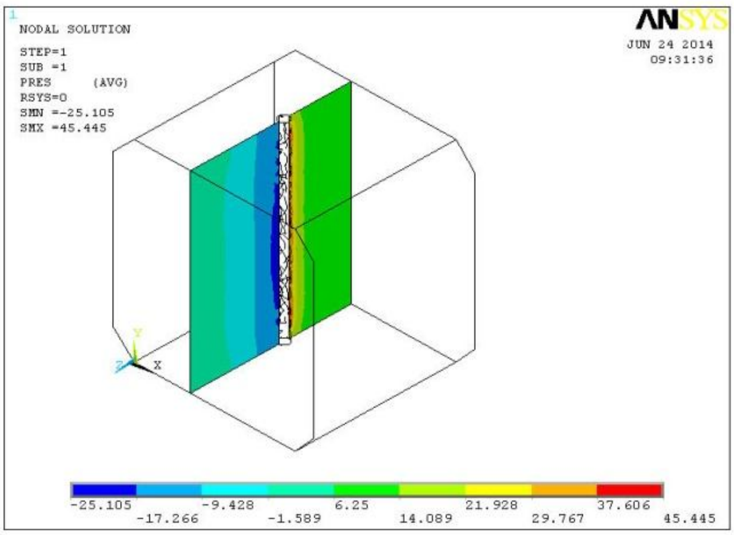
The theoretical and experimental work results are illustrated in sections A and B respectively.

A. Theoretical Results:

a) v$_a$=2.5 m/s



b) v_a= 7.3 m/s



c) v_a=12.5

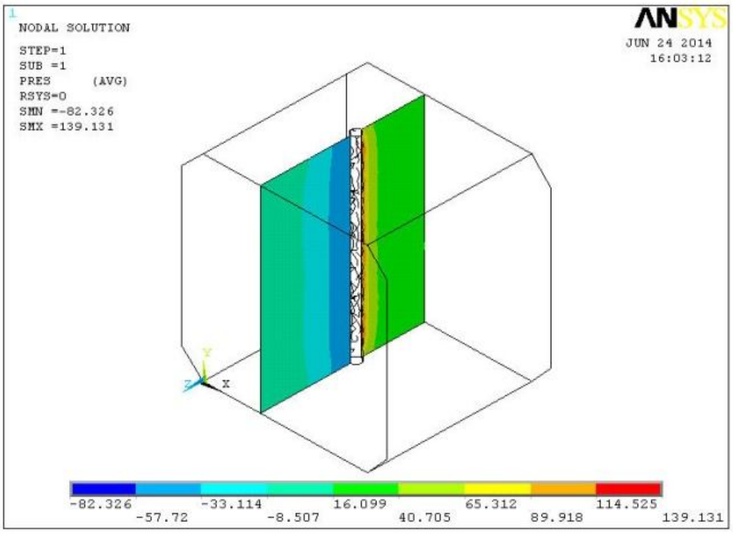
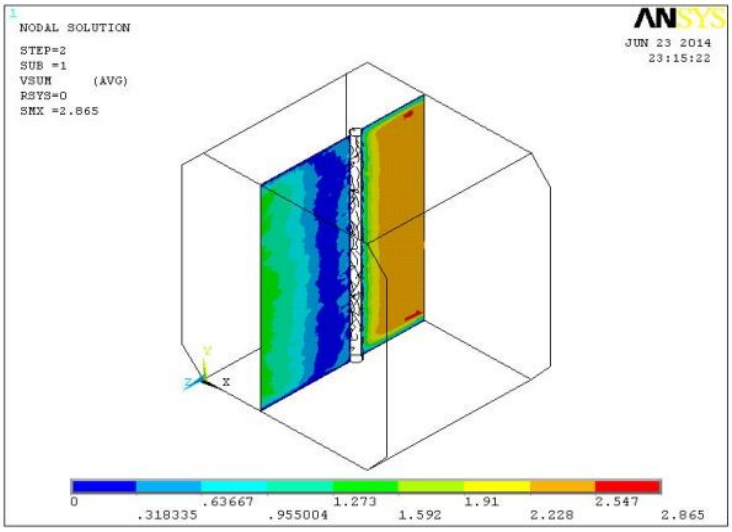
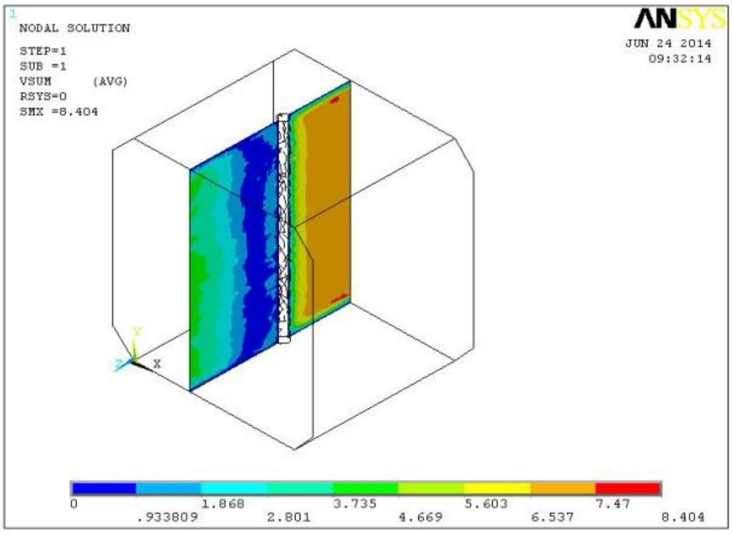


Fig.5: Contour section of air flow pressure(Pa) through test section with cylinder(a, b and c).

a) v_a=2.5 m/s



b) v_a=7.3 m/s



c) v_a=12.5 m/s

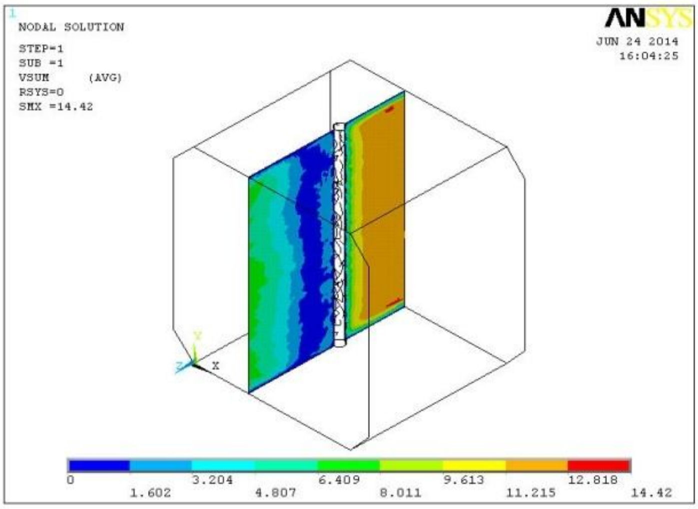
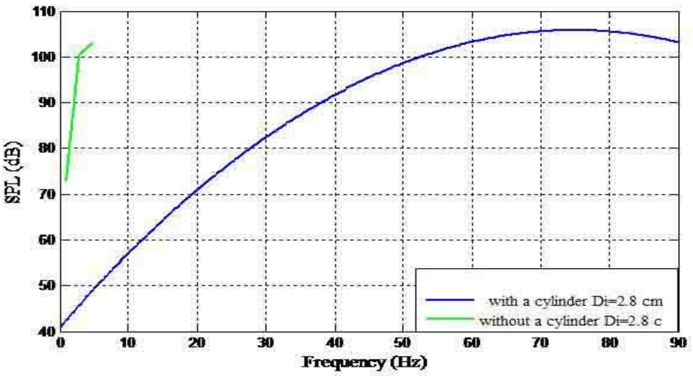


Fig.6: Contour section ofair flow velocity (m/s) through test section with cylinder (a, b and c).

B. Experimental Results:

The experimental results compared with other researchers and hence the acceptable results were obtained.



Relation between sound pressure level and frequency.Fig.7:

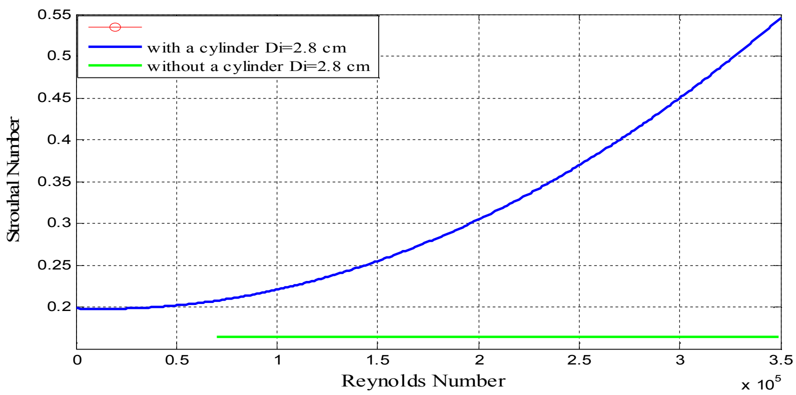
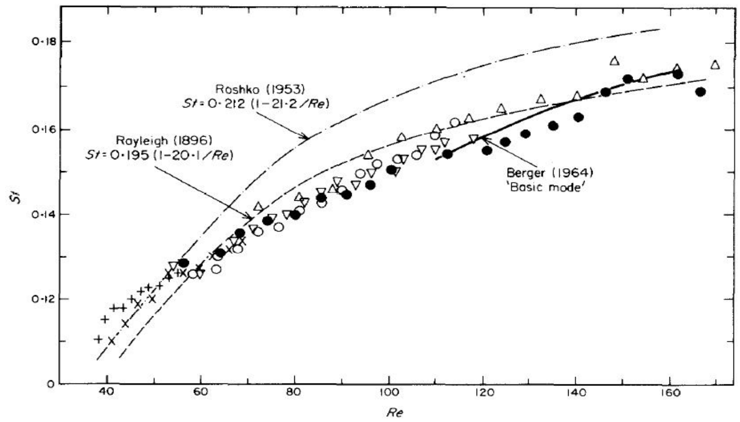


Fig.8: Relation between the strouhal number and Reynolds number.



Diameter (mm): +, 0.179; ×, 0.231; Δ, 0.286; ◯, 0.327; ●, 0.394; 0.499.—— Rayleigh (1896), St=0.195 (1-20.1/Re); —.—, Roshko (1953), St=0.212 (1-21.2/Re); ——, Berger (1964) "basic mode" St = 0.220 (l-33.6/Re).

Fig.(9): Re-plot of Strouhal's results for thin resonating brass wires, with the formulas of Lord Rayleigh, Roshko and Berger for comparison (Jiawei, 2012).

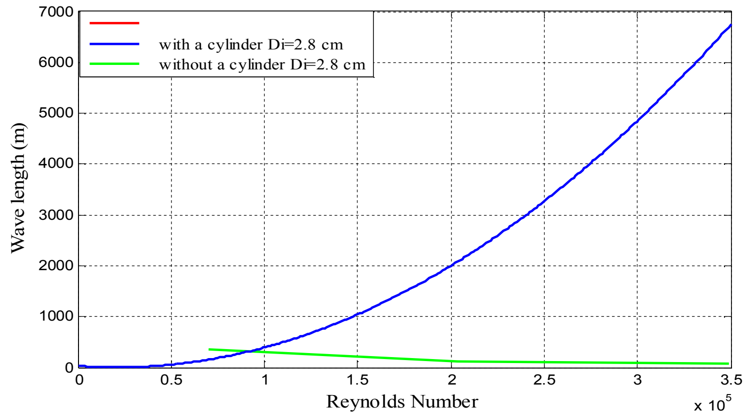


Fig. 10: Relation between the wavelength and Reynolds number.

Fig.5 representscontour section of air flow pressure through test section with cylinder for three velocities. The air pressure variation increases as a result of changing the air velocity and presence of obstruction which disturbs the flow at or near the cylinder.

Fig.6 represents contour section of air flow velocity through test section with cylinder for three velocities.As velocity increases, the velocity distribution inside test section of wind tunnel generally increases because of increasing the air dynamic pressure.

Fig.7 represents the effect of changing the air frequency with and without cylinder (D_i=2.8 cm) on the experimentally generated sound pressure level. At frequency equals to 90 Hz, the generated sound pressure level is maximum with cylinder.This will be clear in case of presence the obstruction.Acoustic pressure increases with increasing frequency because of the sudden change in the flow type and as a result generated swirling different frequencies.

Fig.8 represents the effect of increasing Reynolds number on strouhal number (equation 2).Strouhal number increases due to increasing Reynolds number and frequency. The frequency increases as a result of vorcies generation.

Fig.9 illustrates Re-plot of Strouhal's results for thin resonating brass wires, with the formulas of Lord Rayleigh, Roshko and Berger for comparison. Fig.8 has similar behavior as fig.9, i.e, the acceptable results were obtained.

Fig. 10 represents relation between the wavelength and Reynolds number.The wavelength increases with increasing Reynolds number because of increasing the frequency.

6.Conclusions

The conclusions can be summarized in the following points:

1. The sound pressure level increases as a result of increasing the air frequency especially with cylinder which represents the obstruction to air flow inside a test section.
2. The disturbed flow increases the ability to find the relation between the sound properties and fluid flow behavior around the cylinder.
3. The oneset turbulent flow gives a sufficient imagination about the flow behavior.
4. The generated sound pressure level with cylinder increases due to increasing Reynolds number.
5. The increase of Reynolds number in the test section of wind tunnel with cylinder for different flow rates increased strouhal number.

References

Elisabeth Longatte and Philippe Lafon, 2000,"Computation of acoustic propagation in two-dimensional sheared ducted flows", AIAA Journal, vol. 38, No. 3, pp.389-394, March.

Frank, M. 1991,White,"Fluid Mechanics", ASME.

Hayder Kraidy Rashid, 2009,"Study of flow induced Noise in rectangular test sections with an obstruction",University of Technology.

Huilin Xing,Wenhui Yu and Ji Zhang, 2009,"3D Mesh generation in geocomputing", The University of Queensland, Earth Systems Science Computational, Centre, St.Lucia, Brisbane,QLD 4072,Australia, Dalian University of Technology, Dalian, China.

Hongbin Ju, and Fung, K. Y.2001,"Time-domain impedance boundary conditions with mean flow effects",AIAA Journal,vol.39, No. 9, pp.1683-1690, September.

Jeff, D. Eldredge and Ann. p. Dowling, 2003," The absorption of axial acoustic waves by a perforated liner with bias flow", J. Fluid Mech. ,PP. 307–335,vol. 485.

Jiawei Liu, 2012,"Simulation of Whistle Noise Using Computational Fluid Dynamics and Acoustic Finite Element Simulation", Master Thesis, Lexington, University of Kentucky .

Jiawei Liu, 2012,"Simulation of whistle noise using computational fluid dynamics and acoustic finite element simulation", Master Thesis, Lexington, University of Kentucky.

Norton, M.P. and Karczub, D.G., 2003 ,"Fundamentals of noise and vibration analysis for engineers", Cambridge University press, Second Edition .

Siming Muand Shankar Mahalingam, 1996, "Direct numerical simulation of acoustic/shear flow interactions in two-dimensional ducts", University of Colorado, AIAA JOURNAL, vol. 34, No. 2, pp.237-243, February.

Yusuf Ozyoruk and Lyle N. Long, 2000,"Time-domain calculation of sound propagation in lined ducts with sheared flows", AIAA Journal, vol. 38, No. 5, pp.307-335, May.

Zainab Kareem Gheben, 2013,"Experimental and Numerical analysis for gas liquid slug flow in horizontal Pipe", University of Babylon.

Hu, Z.W., Morfey,C. L., and Sandham, N. D., 2006,"Wall pressure and shear stress spectra from direct numerical simulations of channel flow up to Re= 1440",University of Southampton, Southampton, AIAA Journal, pp.1-10, 13 February.