SPEECH QUALITY ANALYSIS FOR TWO-WAYS RADIO SUBJECTED TO WIND INDUCED NOISE

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SPEECH QUALITY ANALYSIS FOR TWO-WAY RADIO SUBJECTED TO WIND INDUCED NOISE

by

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for the degree of

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DECLARATION

I hereby declare that I have conducted, completed the research work and written the dissertation entitled "Speech Quality Analysis For Two-Way Radio Subjected to Wind Induced Noise". I also declare that it has not been previously submitted for the award of any degree or diploma or other similar title for any other examining body or University.

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ABSTRAK

Angin yang menghasilkan bunyi bising terjadi daripada angin yang bertiup melalui radio dua hala yang boleh mengurangkan keberkesanan komunikasi. Terdapat tiga objektif dalam kajian ini antaranya kesan sudut kedudukan radio terhadap angin yang bertiup, analisis kualiti bunyi untuk isyarat percakapan di bawah tiupan angin yang berbeza dan kepintaran ucapan yang diterima berdasarkan tingkatan hanbang yang berlainan. Ukuran untuk kualiti bunyi untuk isayrat kemasukan dijalankan didalam ruangan kedap udara dengan menggunakan LMS ukuran sistem. Kesan untuk sudut radio terhadap udara yang bergerak dikaji dengan menggunakan sepasang radio dimana satu diletakkan didalam terowong angin dan diletakkan di dalam ruanagn anechoic untuk mengasingkan daripada bunyi bising luaran. Sudut orientasi untuk radio penghantar mempunyai tujuh kedudukan dalam lingkungan 0 sehingga 90 dengan 15 kenaikkan. Analisis kualiti bunyi untuk isyarat ucapan di bawah kelajuan angin dijalankan dengan meletakkan pembesar suara 30 cm jauh daripada penghantar untuk menyediakan isyarat ucapan kepada radio manakala kelajuan angin berlainan daripada 0 ke 10 m/s dengan 2 m/s kenaikkan. Kualiti bunyi bedasarkan psikoakoustik pembolehubah iaitu tingkatan tekanan bunyi, kekasaran, kekuatan, kebingitan dan kadar artikulasi. Kawalan hanbang digunakan untuk membunag kebisingan latar dan angin daripada isyarat yang diterima. Ianya dikawal pada 0% ke 10% dengan kenaikkan 2% pada puncak yang tertinggi daripada isyarat yang diterima. Keputusan menunjukkan sudut yang menghasilkan kekuatan bunyi angin

yang bising meningkat dan kekasaran menurun dengan kelauan angin. Tingkatan ketajaman menunjukkan ketidakstabilan sepanajng masa ukuran. Kadar artikulasi menurun dengan halalaju angin. Kombinasi psikoakoustik pembolehubah menghasilka tingkatan kebingitan yang mana meningkat bersama halalaju angin yang meningkat. Kawalan hanbang diukur dalam tekanan tingkatan bunyi dan kadar artikulasi. Kedua-dua ukuran menunjukkan pembangunan yang baik dengan tingkatan kawalan. Kesimpulannya, sudut orientasi untuk radio terhadap angin yang bertiup dan halalaju angin sangat tinggi di pengaruhi kepada kualiti bunyi untuk isyarat yang diterima. Kawalan hanbang adalah satu cara untuk mengurang laju angin daripada tinggi kepada rendah.

SPEECH QUALITY ANALYSIS FOR TWO-WAYS RADIO SUBJECTED TO WIND INDUCED NOISE

ABSTRACT

Wind induced noise generated from winds flow over two-way radio can reduce communication effectiveness. There are three objectives in this study which are effect of the radio's angle orientation toward air flow, sound quality analysis of speech signal under different wind speed and Intelligibility of the received speech signal at different threshold hearing level. Measurement of sound quality for input signal was carried out inside an anechoic chamber by using LMS measurement system. Effect of the radio's angle orientation toward air flow was studied by used a pair of radios where a unit was placed inside a wind tunnel and the other was placed inside the anechoic chamber in order to isolate it from external noise. Angle orientation of the transmitter radio was varying for seven positions ranges from 0° to 90° with 15° increment. Sound quality analysis of speech signal under different wind speed was carried out by located a speaker at a 30cm away from the transmitter to provide an speech signal input to the radio while the wind speed varied from 0 to 10 m/s with 2 m/s increment. Sound quality base on psychoacoustics parameters of sound pressure level, roughness, sharpness, loudness, annoyance and articulation index. Threshold controller was used to attenuate the background and winds induce noise from the received signal. It was controlled at 0 to 10% with 2& increment toward highest peak of the received signal. The results show the angle lead to worst wind noise effect was 90° toward leading edge. The results show that the loudness of the wind noise increase and the roughness decreases with the wind speed. The sharpness level is fluctuated along the measurement period. The articulation index

also decreases with the wind speed. Combinations of psychoacoustics parameters are performing annoyance level which was increasing as the wind speed increase. The threshold controller's performance was measured in sound pressure level and articulation index. Both of measurements show good development with the controller level. Conclusion, angle orientation of radio toward wind flow and the speed of wind are highly influent to sound quality of received signal. Threshold controller is one of the ways to reduce wind speed especially for low wind speed.

LIST OF SYMBOLS

D	Wire diameter (m)
F	Frequency component (Hz)
H	Height of radio (m)
L	Length of radio (m)
PA	Psychoacoustics Annoyance (PA)
S	Sharpness (acum)
SNR	Signal-to-noise ratio (%)
SPL	Sound Pressure Level (Pa)
T_D	Daytime temperature (°C)
T_N	Night temperature (°C)
U	Velocity (m/s)
W	Width of radio (m)
Z_i	Mixing layer (m)
v	Kinematic viscosity (m^2/s)
f	Frequency (Hz)
p	Phase lag (°)
T_{LOOP}	Time of feedback-loop (s)
T_1	Time period (s)
T_2	Time period (s)
ρ	Density (kg/m^3)
t	Time (s)
α_A	Angle of trash (°)
c_0	Speed of sound in air (m/s)
x_i	Distance in x-component (m)
x_j	Distance in y-component (m)

LIST OFABBREVIATIONS

AI	Articulation Index
FFT	Fast Fourier Transform
HL	Hearing Level
ISO	International Organization for Standardization
MMD	Malaysia Meteorological Department
N	Stage number
NI	National Instrument
PBL	Planetary boundary layer
PTT	Push-to-talk
SQ	Sound quality
St	Strouhal number
TIA	Telecommunications Industries Association
VHF	Very High Frequency
WAV	Waveform Audio File Format

CHAPTER 1

INTRODUCTION

1.1 Overview

In common use, the word noise means any unwanted sound. In physics world, noise is unwanted signals that randomly add to original signal, which is related to generalization of the acoustic noise ("static"), heard when listening to a weak radio transmission with significant electrical noise. Usually noise is generated by unstable of the wave like sound wave and electrical signal wave. Frequencies of noise depend on the source of sound. Generally, noise effect is interpreted by perception of human, which is closely related to the range of human hearing from 20Hz to 20 kHz. In acoustics study, range of noise is not limited only to the audible range of human. The range of acoustic frequencies of several sources is shown in Figure 1.1.

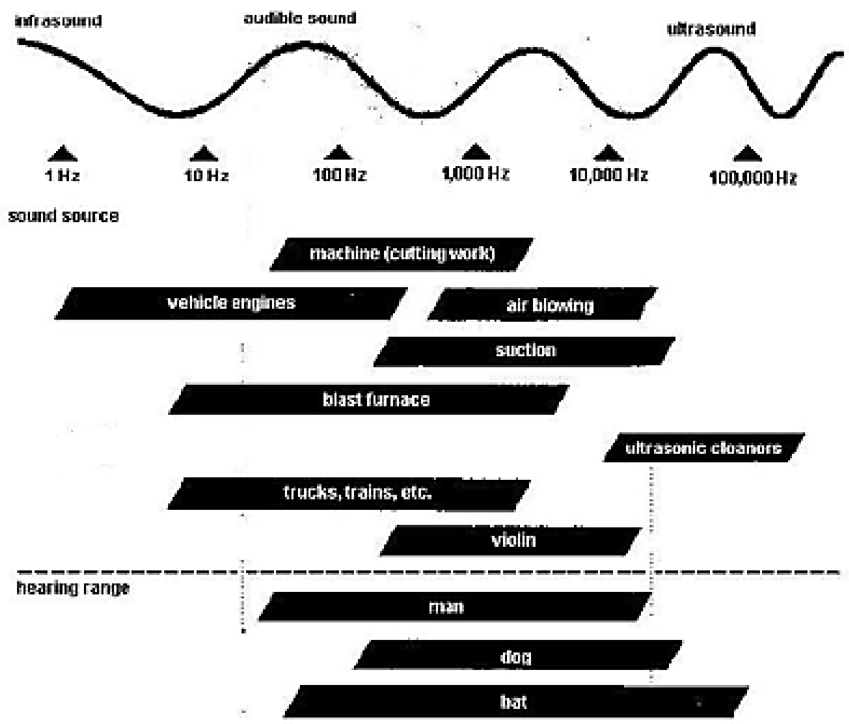

Figure 1.1: Audible frequency range and hearing range of various sources (Zwicker 2007)

In nature, there are numerous sources of noise for example wind flow. Naturally, wind flows without any disturbance do not produce any noise. Noise is generated when wind flow interacts with disturbance and the phenomenon is called as wind induced noise. Wind induced noise is a major problem in designing a product especially for product which has high exposure to wind flow. One of the products is the two-way radio.

A two-way radio is a radio that can both transmit and receive (a transceiver) speech signal, unlike a broadcasts receiver which only receives content. A two-way radio (transceiver) allows the operator to have a conversation with other similar radio operating on the same radio frequency (channel). Two-way radios are available in mobile, stationary base and handheld portable configurations. Handheld radios are often called walkie-talkies or handie-talkies.

One of the problems face during the operation of two-way radio is the noise (sound). Noise is generated from environmental sources like wind. Wind flow around the two-way radio causes wind induced effect and finally contribute noise to the system. The noise can be clearly identified through the situation when two-way radio is used at a windy condition for example at the seaside (Cato & Tavener 2009).The receiver is receiving sound signals from transmitter with high level of noise. The noise level increases when wind flow frequency increase. The analogy of the phenomenon is like blowing air at the mouth of a bottle.

Aerodynamic noise is a result of unsteady wind flow and the interaction of the unsteady wind flow with the associated walkie-talkie's structure. The unwanted wind flow and structure interaction may cause serious problems with noise. The interaction is proved by study of Kook and Mongeauin of wind induced noise due to wind flow (Kook & Mongeau 2002).

The unsteady wind flow and structure interaction effect cause radio's microphone to capture and convert the fluctuated pressure signal into sound signal before being sent to the receiver radio. The receiver radio receives the signal in the form of noise. The phenomenon can be illustrated by Figure 1.2. The figure shows the cross section of walkie-talkie on the region where the microphone is situated. From the figure, this problem can be divided into four different stages of engineering problem; It starts with wind flow pass through radio's body, which related to fluid dynamic concept. The second stage is vibration of air through microphone port produce noise. The next stage is vibration effect of air in the cavity. The last stage is vibration of membrane.

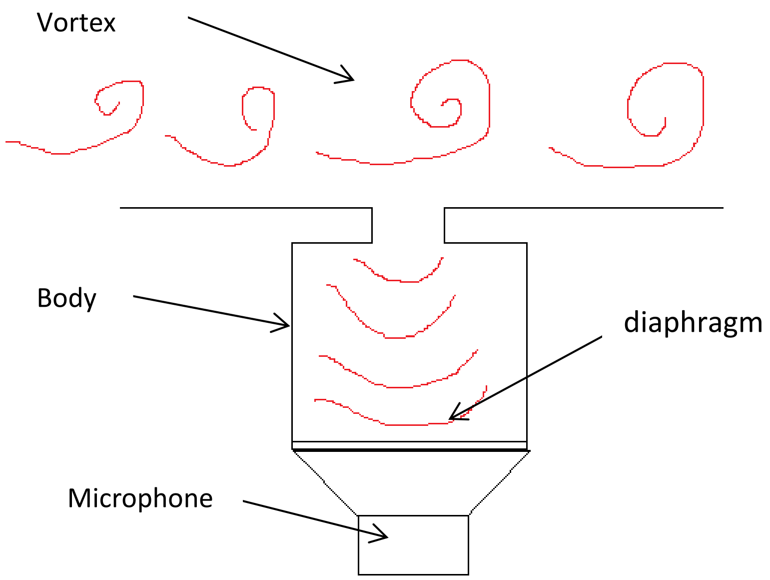

Figure 1.2 Cross section of walkie-talkie's microphone port

Wind noise affects the quality of transmitted signal. In this work, wind noise effect on the sound quality of the transmitted signal is analyzed using objective method. Sound quality is evaluated based on psychoacoustics parameters, which are roughness, sharpness and loudness. Intelligibility of received speech signal is measured by using articulation index parameter.

Industrial applications establish a few technics and to attenuate the wind noise which are classified into mechanical and electronic approach. Mechanical approach is classical technique in reduction of wind noise. Geometrical study is the main idea of the technique. Another wind noise reduction technique is electronic approach, specifically signal processing technics. Nowadays, the technics is preferable among industry due to low cost and highly adaptive situation.

1.2 Problem statement

Two ways radio is used in various conditions such as windy environment. Wind flow affects the quality of the received signal. In some worst situation, the received signal is fully not understand because wind noise level is higher than speech signal. The situation is very dangerous in critical time for example a rescue team in operation to save human life.

In general, the generated wind noise is influenced by the orientation of object toward the wind flow. The hypothesis is proven by many studies such as the research by Zhang et al. (2014). Flow simulation of trash rack under difference angle orientation show the generated of wind induced noise with different level. In this study, the two-ways radio under different angle orientations are used to study the hypothesis.

Movement of air over the radio's body generates a noise which is increasing as the wind speed is increase. The noise generated is affecting the transmitted signal. Level of wind noise is depending on the angle of radio's body toward the wind flow. The level of affected signal is measured based on sound quality analysis.

There are a few techniques to attenuate the wind induce noise. The wind induced noise can be listened although at low wind speed. Sound-to-noise ratio (SNR) of wind noise to speech signal transmitted is large especially at low wind speed.

Based on this reason, a study of an amplitude filter (threshold filter) is carried out by varying attenuation level of the filter.

1.3 Objectives

The main objectives of the study are:

1) To identify the angle orientation of transmitter radio that lead to the worst wind induces noise effect.
2) To determine the effect of the wind flow speed on quality of the received speech signal.
3) To study the effect of threshold hearing level to intelligibility of the received speech signal.

1.4 Scope

The research is focused on sound quality of speech signal under wind noise effect. An experiment is carried out in the wind tunnel with various wind speed. The range of wind flow is varied from 2 to 10m/s with 2 m/s increment. A transmitter radio is place in the wind tunnel and projected with speech recording signal. A receiver radio is placed in anechoic chamber in order to prevent disturbing background noise of the received signal. Sound quality analysis is based on roughness, sharpness, loudness and articulation index. Amplitude filter is only applicable to low wind noise 2 m/s and 4 m/s due to large SNR. The amplitude filter is varied between 2 to 10% with increment 2% to maximum peak of signal during speech period. The study is based on a model of two-ways radio but it can be extended to other model of two-ways radio.

1.5 Thesis outlines

This thesis is presented in five primary chapters commenced with the introduction and followed by the literature review, methodology, results and discussion, and conclusion. The first chapter introduces the overview of the study include the wind induce noise concept, sound quality analysis and wind noise reduction techniques.

Chapter two deals with wind induced noise generated over microphone port theory. Sound quality evaluation based on psychoacoustics method is reviewed. The review of speech intelligibility analysis by articulation index approach is also summarized. The wind noise reduction method is reviews at the end of this chapter.

In chapter three, the experimental procedure of wind tunnel is presented. Sound quality analysis method and filtering technics are described in more detail in this chapter. All the processes used to achieve the objectives of the study are listed down in chapter three.

Chapter four presents the outcomes of the experiments. Results from sound quality analysis, and filtering process are reported. In this chapter, the evaluation and discussion of the results are presented.

Lastly, the conclusion for the conducted study, recommendations for future works, and the contributions gained from the study are presented in Chapter five.

CHAPTER 2

LITERATURE REVIEW

2.0 Overview

The aim of this chapter is to provide a review on the effect of wind noise generate to sound quality of transmitted signal. The general review focusses on two-way radio and wind generated noise. Background of sound quality analysis study is presented in this chapter. There are various methods in sound quality analysis; one of them is psychoacoustics analysis which is used in this study. Roughness, sharpness and loudness are psychoacoustics parameter representing sound quality of received signal. Speech intelligibility of the signal is measured by using Articulation Index method. At the end of this chapter, historical of microphone wind noise reduction is discussed focusing on threshold controller.

2.1 Two-way radio

Two-way radios is a communication tool that allows two-ways communication that can transmit and receive (a transceiver), unlike a broadcast receiver which only receives content. A transceiver can operate with other transceiver that operates on a same frequency (channel) .Two-ways radio can be divided into several types such as mobile, stationary base and hand-portable configuration (Anon n.d.). Hand radios are often called walkie-talkie, handie-talkie, or simply hand-helds. Two-way radio usually operates with a half-duplex mode not like mobile phone which is operated with full-duplex mode. The half-duplex mode allows the operator to receive or transmit in a time while the full-duplex mode allows the operator to receive and transmit at the same time. Two-way radio is a friendly user device to the operator which only needs to simply press a button to active the transmitter mode and release the button to active the receiver mode.

Two way radios are widely used for verbal communication in work site which is usually in the open environment. Rescue squad like fire fighter and policeman are the main user for this type of radio. In open environment condition, the user will face many obstacle like wind flow and background noise.

Two way communication devices are available for commercial as early 1907 which is two-way telegraphy. The device capable to send and received information across the Atlantic Ocean. In 1912, two ways communication is installed in commercial and military ships which are allow the ships communicated real-time with land(Anon n.d.).

In 1923, Senior Constable Frederick William of the Victorian Police in Australia is the inventor for the first truly mobile two ways radio (Haldane 1995). The radio is installed in patrol car which allows them to communicate with based station. Started with the design of mobile two-way radio by Constable Frederick, technology of the two ways is developing days by days. Powerful, compact and user friendly design are the main target among of developers. Nowadays, manufacturers like Motorola, Kenwood and ICOM are among of the famous two ways radio's manufacturers. Consumer friendly concept Push-to-talk (PTT) is introduced by the manufacturers which allow the radio is operating by only push a button.

The latest technology evented for two-ways radio communication is occupied with navigation technology. The technology allows both parties to know their locations. In the emergency situation, the radio is required for rescue squad in order to receive information from the helpline.

2.2 Wind induced noise

Wind is a natural phenomenon happening around the world. Wind is caused by spatial differences in atmospheric pressure. It is a once of common part of the meteorological cycle for daily life. Base on the study by Panofsky in 1985 (Panofsky 1985), the first layer of wind from the ground is called the “friction layer” or the “planetary boundary layer” (PBL). Normally, PBL is at level 1 to 2 km above the ground surface which is can be defined by the vertical exchange of momentum, heat, and moisture due to surface effects. Alternatively, PBL thickness can be identified by acoustic sounders in the 1 to 3 kHz range and is predicted by a wind speed at 10 m height linearly (Koracin D 1988).

Wind is closely related to atmospheric turbulence that can be classified into two types convective and mechanical. Convective turbulence happens due to thermal instability. It is the predominant mechanism of mixing in the troposphere, which commonly relate to clouds. Mechanical turbulence is generated based on the interaction of the wind over topography and ground-based objects.

Figure 2.1 shows a height of the wind profile is inversely to temperature (Walker & Hedlin 2009). During the day, solar heating warms the surface of ground. The lower PBL occurs at the height of z_i, which the temperature gradient changes inversely. The phenomena occur due to gravitationally unstable of the warmer air near the surface. Variety of scales producing wind occurs at the ground surface due to the both convective and mechanical turbulence. Smaller scale turbulence occurs at thickness h that can be define as mixing layer (surface layer), which is approximately equal to z_i during the day. During night, wind and turbulence are often less produce due to the air gravitationally stable near to the ground surface. However, small amount of mechanical turbulence still occurs in the surface layer lower than 100 m on clear nights with weak winds.

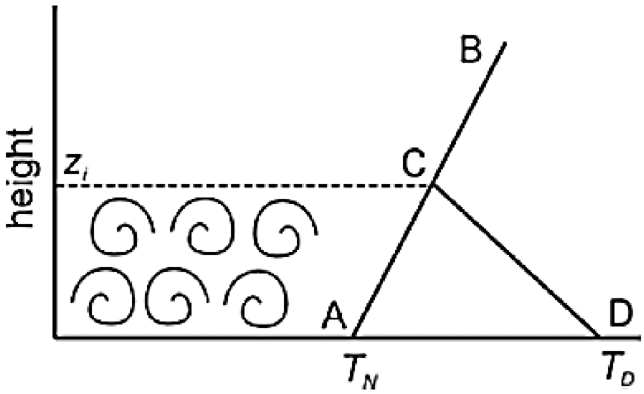

Figure 2.1: Temperature profiles during the night (AB; inversion) and day (BCD; inversion between CB). The temperature in the surface layer warms during the day, which is one mechanism for driving wind. T_N and T_D are the night time and daytime temperatures, respectively (Walker & Hedlin 2009).

During the day, convection pattern is influence by regional variations in solar heating. Figure 2.2 shows wind flow process on the day. Differences in solar heating at the surface leads to horizontal air temperature and pressure gradients, thus it can lead to a closed convection system. During night, there is no variation in surface heating or cooling that lead to convection and surface winds. During night, convection system is driven the specific heat capacity of the water. The water is releasing heat during night.

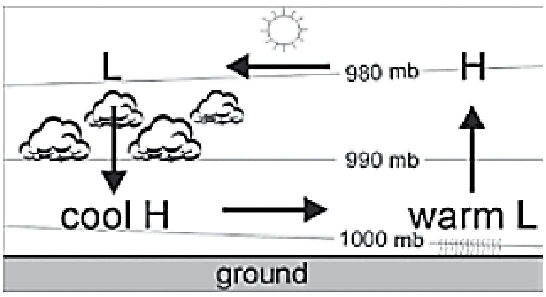

Figure 2.2: Wind cycle during the day (Walker & Hedlin 2009)

Successful of wind noise reduction is started with better understanding of the local wind patterns at study site (Pidwirny 2006). Wind is derived by differences in atmospheric pressure related to changes in temperature due to solar heating and surface radiation. A research by Malaysia Meteorological Department in 2010 ((MMD) n.d.) shows highest mean daily wind speed on the ground is 3.8 m/s recorded at Mersing, Johor. In this research, wind speed is categorized based on highest mean daily wind speed into three groups: low, moderate and high. Low wind speed is below 2 m/s, while moderate wind speed ranges from 2 m/s to 6 m/s. The higher wind speeds group for speed between 6 m/s and 10 m/s.

Flow of wind across through ground-based objects can result an audible tone due to aeroacoustics phenomena. For instance, the phenomenon like resonances, vortex shedding, Aeolian tones, cavity flows and flow induced vibration are contributed to the development of coupled “sounding board” effects. The complex interactions between the wind flow field and geometry of the ground-based objects are creating the tones (aeroacoustics noise). In some cases, the aeroacoustics noise can be audible at several hundred meters away from the source for large ground-based objects like building and windmill. Besides, small scale ground-based objects like microphone also face the same situation. The only difference between the large and small scale objects is the wind induce noise is audible near the source for small object compare to large object which audible for several hundred meters away.

Vortex shedding is one of the phenomena develop by the interaction between wind flow and ground-based objects. In fluid dynamic study, vortex shedding is defined as an oscillating flow develops when a fluid (air or water) flows past a bluff body at certain velocity which depends on the size and shape of the bluff body. Vortices can develop either at the back or side of the body (Anon n.d.). Alternative low pressure vortices on the downstream side of the object is developed when the fluid flow past the object and lead the object move toward the low pressure area.

Reynolds number is an important parameter influence an oscillatory pattern for some flow. Figure 2.3 shows formation of vortex behind a circular cylinder.

Figure 2.3: Vortex shedding on cylinder

Formation of vortex begins at near top of the cylinder surface. For the bottom site, vortex formation is little bits delay and develops away from the cylinder. Special for cylinder or tubular geometry object, the formation and shedding of vortices alternately from one side and then the other (Yokoi & Kamemoto 1994). The alternate formation and shedding of vortices develop unsteady aerodynamic that is important factor for engineering design. The unsteady aerodynamic is frequently develop as the velocity of the flow increases (Young et al. 2001).

Vortex shedding is producing a induce noise, which is audible sound. The aeroacoustics phenomena is proved in an experiment by Blevins (Diego 1984). The experiment results prove the vortex shedding is a dipole source of the generated sound. Figure 2.4 shows the experiment setup consist of copper wires of 0.18-8.5mm diameter and 49mm length stretched between radial arms from a rotating shaft.

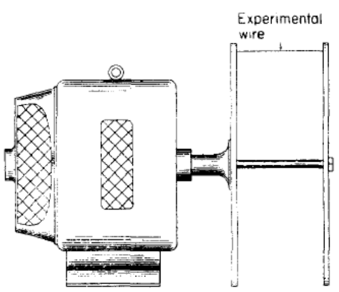

Figure 2.4 Motor-driven “whirler” of Relf (Diego 1984)

The theory proposed by Strouhal (1878) was inspired for the experiment, which audible tones generate at frequencies 600 Hz for low velocity and 3000 Hz for high velocity . Velocity U of air flow over the wire exceeded about 5 m/s (Reynolds number based on wire diameter D and kinematic viscosity v, UD/v > 300). The frequency of the tone is measured by control the shaft rotation speed until match to the pitch of reference string (sonometer). The relationship of frequency to velocity of air is approximately predicted by the eqution:

$$f = \frac{SU}{D} \qquad (2.1)$$

From the relation, S is a Strouhal number, which is vary depending on diameter of wire. Level of S between 0.156 for the smaller diameter wires and 0.205 for the larger diameter wires. Base on his study, the tones is generated by the friction of the wind against the wire, thus the tone is named as friction tones (Reibungstonen). Figure 2.5 shows the vortex formation of the experiment. Which are theoretical vortex street postulated by von Karman and vortex street behind a vibrating cylinder are shown in Figure 2.5(a) and (b) respectively (Diego 1984).

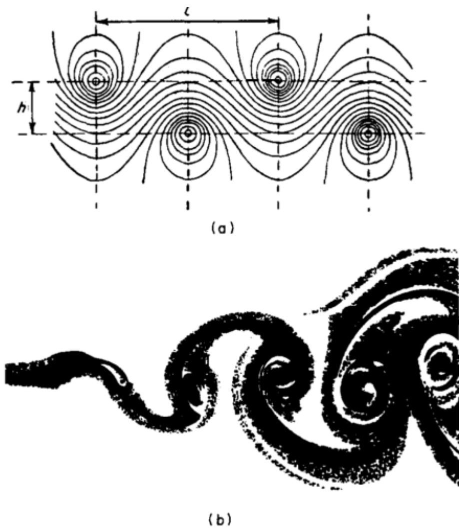

Figure 2.5 Comparison of (a) theoretical vortex street of von Karman (b) smoke visualized vortex street behind cylinder (Diego 1984)

In 1923, Richardson proposed the last set of early experiments without benefit of electronic instruments. His study was supporting theoretical evident by Strouhal which indicated the equation (1) held above a minimum Reynolds number. However, unlike Strouhal, he detected tone is generated when the vortex shedding vibrate the wire. So, he conclude the vibration induce sound is produced by the wire movement alone.

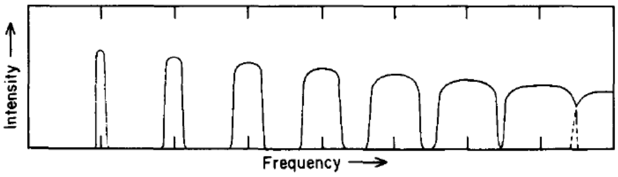

Figure 2.6 Sound intensity from a wire in air with increasing air velocity observed by Richardson (Diego 1984)

In the study of wind induced noise over cavity is pioneered by Wesley L. Nyborg in 1954 (Nyborg 1954). From his study, a theory of the self-maintained transverse oscillations is presented. The study is carried out by projecting a low-velocity jet to an obstacle. Interaction between the transverse forces act on each particle of the jet to the obstacle is generating edge tones. The transverse force is due to hydrodynamic origin of the obstacle. Summarize of his study with a theory for important properties of jet-edge systems and of the edge tones is derive from the equation.

$$f = \frac{N+p}{T_{LOOP}} = \frac{N+p}{T_1+T_2} \tag{2.2}$$

The equation is expressed an edge tone frequency f. N is presenting the stage number, while p prsent phase lag. The total time of feedback-loop is T_{LOOP}. T_1 and T_2 are the time period for the jet-disturbance is converted from the nozzle to the edge and acoustic sound propagates form the edge to the nozzle. The theory also has been discussed by other researchers in their studies (Powell 1953) and (Woolley, J. P., and Karamcheti 1974).

In 2002, Kook, H. and Mongeau, L. carried out a study on wind induced noise over wind flow (Kook & Mongeau 2002). The experiment is focusing on subsonic flows over Helmholtz resonators that cause pressure fluctuations inside the resonators. The feedback loop model is used to analyse self-sustained oscillation phenomenon where the flow excitation and the acoustic response of the resonator are approximately being model. The frequency and the relative amplitude of the cavity pressure fluctuations are predicted for a range of flow velocities. Figure 2.7 shows the predicted vorticity formation under different frequency flow. The experimental setup uses a rigid-walled cavity which is located at the middle of a low-speed wind tunnel as shown in Figure 2.8. The experimental finding agrees with the model prediction.

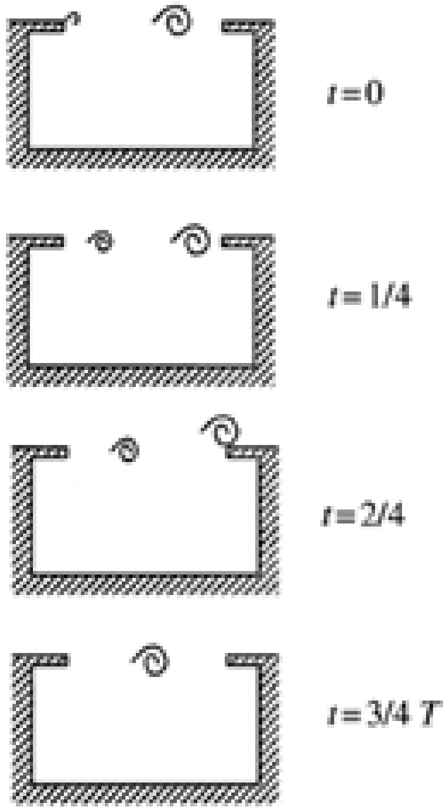

Figure 2.7. A diagram of circulation strength fluctuation (Kook & Mongeau 2002).

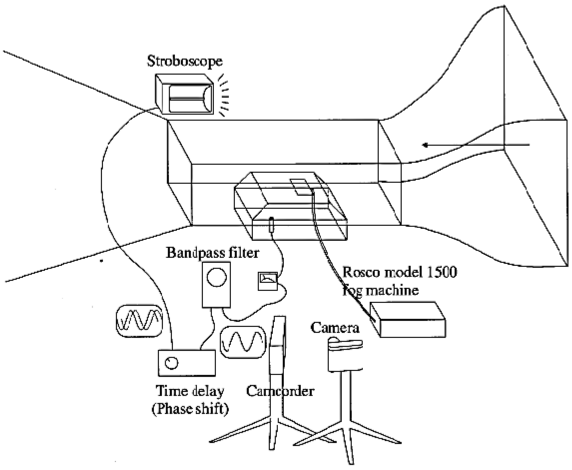

Figure 2.8. Experimental setup for flow visualization

In 2013, Zhang and colleagues are carried out simulation study of low-induced noise caused by different angles of the trash rack (Zhang et al. 2014). The simulation analysis is carried out with three steps. It starts with identical of flow field information like velocity and pressure follow by interpolation between the CFD mesh and the acoustic mesh and finally end up with the simulation by ACTRAN software that run using the Lighthill's acoustic analogy theory. Lighthill’s acoustic analogy theory is an extended derivation of N–S equation. The non-linearity of the flow and acoustics effect of flow make the equation hard to solve. The acoustics affect is classified into two types, which are the near field also known as the source area and the far field aka the radiation area. The Lighthill’s acoustic analogy theory equation is used in this simulation:

$$\frac{\partial^2 \rho'}{\partial t^2} - c_0^2 \nabla^2 \rho' = \frac{\partial T'_{ij}}{\partial x_i \partial x_j} \tag{2.3}$$

Various angle of trash rack is simulated, which the angles are of -30°, -45°, -60°, 30°, 45° and 60° according to the type of trash rack as shown in Figure 2.9.

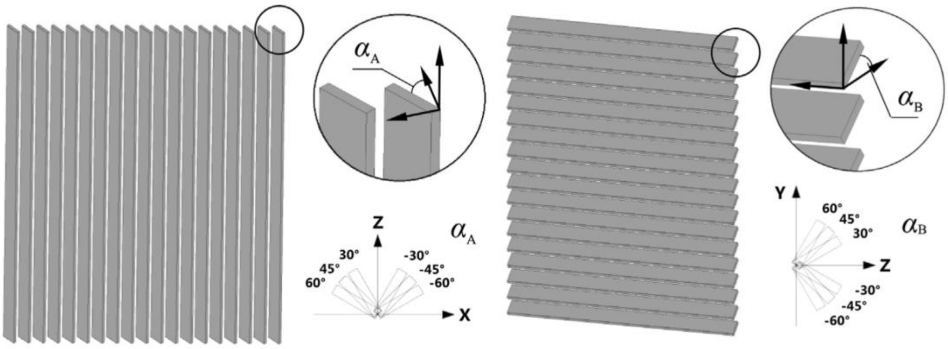

Figure 2.9: Trash rack model with different angles(Zhang et al. 2014)

Figure 2.10 shows the result of simulation which is illustrated by the vorticity contour of the trash rack with different angles. From the figure, the vorticity near the trash rack is concentrated at the trash rack. The acoustic results showed that SPL of α_A -30°, -45°and -60° produced higher noise level compared to α_A of 30°, 45° and 60° with the value of 50 dB compare to 30 dB respectively. From the research, wind induced noise is highly dependent on the angle of the object.

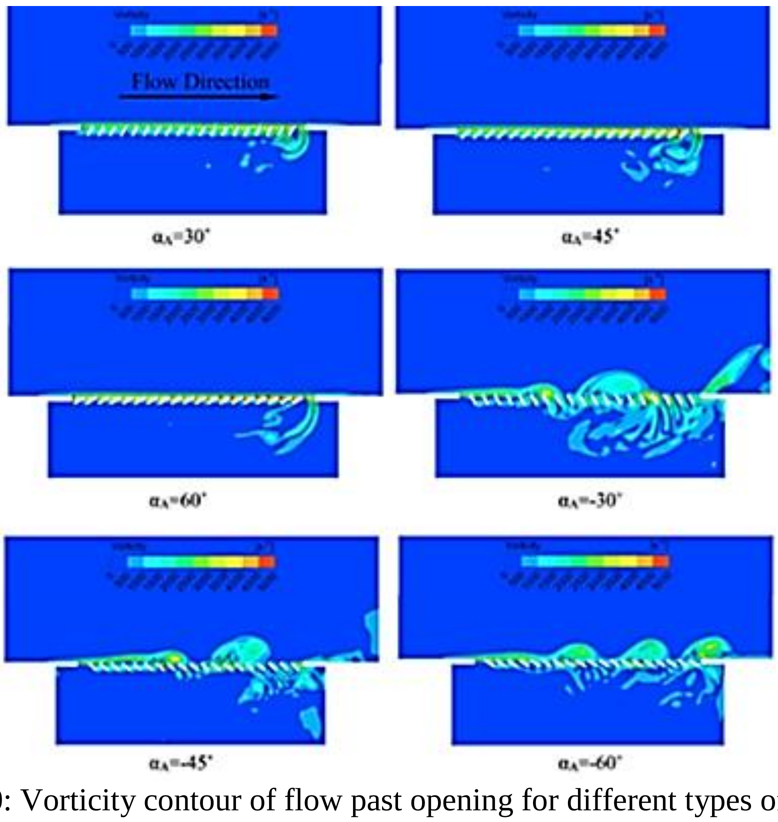

Figure 2.10: Vorticity contour of flow past opening for different types of trash rack (Zhang et al. 2014)

Based on a study by Nelke in 2012, the wind noise is normally occurred at low frequencies below 500Hz (Communications 2012). The wind noise occurs mainly at low frequencies with the main distribution at low frequencies and rapidly descending towards higher frequencies. Basically, the range of transmitted signal by two ways radio is between 300Hz to 3000Hz, thus only small range of wind noise is overlapping with the transmitted signal range. The major problem is most of the speech consist of lower frequency which has high tendency to the overlapping wind noise.

2.3 Wind tunnel testing of wind induced noise

In this study, wind tunnel test is conducted to measure the performance of radio under wind noise. The experimental setup is based on a study by Beranek and Z. Gu (Beranek et al. 1971) and (Gu et al. 2015). Beranek carried out an experiment to obtain data on the fluctuating pressure within and near the cavity. Figure 2.11 shows the experimental setup for this study. Fluctuating pressures are measured by piezoelectric microphones, which are located at one upstream of the cavity under the approaching boundary layer, three along the center line of the cavity floor, two in opposite corners of the floor, one in the rear bulkhead, and one in each glass side wall. A pressure probe is mounted within a 0.75 in (19.05 mm) diameter movable rod spanning the length of the cavity. Recirculating velocities in the cavity is measured by a Pitot-probe. From the study, idea of positioning microphone and wind velocity measurement gauge are used in designing experimental setup.

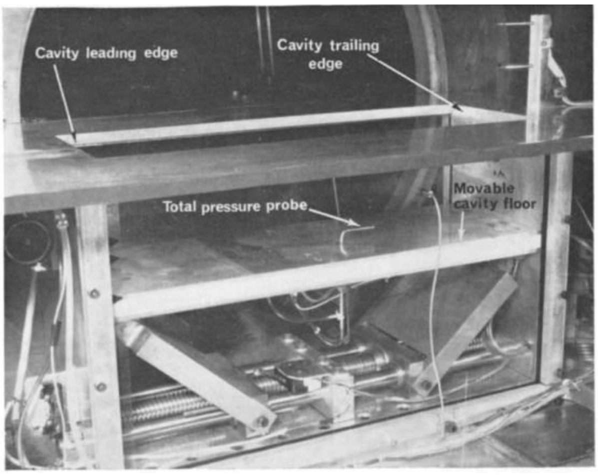

Figure 2.11 Experimental cavities in Massachusetts Institute of Technology Naval supersonic wind tunnel (Beranek et al. 1971).

Gu (2015) has researched on numerical simulation of automobile side-window buffeting noise based on fluid–structure interaction. An experiment was run to validate acoustical result of the simulation for his study. Experiment is carried out in subsonic wind tunnel and the measurement is done by using Scadas mobile equipment as show in Figure 2.12 (a) and (b) respectively. Subsonic wind tunnel is used due to the range of wind speed parameter to be tested is low. Based on the experiment, measurement equipment (LMS SCADAS mobile) and subsonic wind tunnel are the suitable idea for experimental setup in the research.

(a)

Figure 2.12 Experimental setup for (a) installation of cavity in the wind tunnel and (b) LMS SCADAS mobile (Gu et al. 2015).

(b)

Figure 2.12 Experimental setup for (a) installation of cavity in the wind tunnel and (b) LMS SCADAS mobile (Gu et al. 2015). (cont.)

2.4 Sound quality

In the modern world, people are not only interested in new invention, but also in quality of merchandise. The sound quality is one factor highlighted in the production of new technology especially involving user comfort. Normally, sound quality is closely related to an assessment of the accuracy or intelligibility of audio quality of an electronic device. A single-value descriptor for sound quality in a sufficient way becomes the frequent issue in the acoustic world (Genuit 2001).

Definition of sound quality by Blauert in 1994 is "adequacy of a sound in the context of a specific technical goal and/or task" (Blauert 1994). Another definition of sound quality is defined by Blauert and Jekosch in their study in 1997 is a judgements upon the totality of auditory characteristics of sound of product by users in their actual cognitive, factional and emotional situation (Blauert, J., Jekosch 1997). A simple definition of sound quality is percept related to both subjective and objective parts. The percept is product specific of a sound in a certain situation for a certain product, which listeners make judgements of sound quality base on a scale or/and a physical scale is used to the component sounds for that product (Lyon 2000) and (Sköld 2005).

Assessment of sound quality is carried out using either objective or subjective evaluation or both of assessment in a single evaluation. Objective evaluation is done by using a tool to gauge the accuracy of a production sound for a device; while subjective evaluation is based on human listeners respond to the sound or gauge its perceived similarity to another sound.

Objective evaluation is widely used to evaluate a product. One of the product evaluations is carried out by Teik C. Lim for power window systems (Lim 2001). In his study, psychoacoustics parameter is used to evaluate the system. Loudness level shown that noise from the power window system is impede speech communication severely.

There are a few studies focus on subjective evaluation such as the study performed by Waye and Oghrstrogm in 2002 (Medicine 2002). The study focus on evaluation of wind induced noise from wind turbine. In their study, there are 25 students consists of 13 women and 12 men form Gotëborg University with a normal hearing <20 dB HL are recruited. Quality of generated noise are scaled with the score 0 to 5 which is 0 for the worst and 5 for the best.

Complexity of sound perception is the main reason to find the general method to evaluate sound quality (Bodden 1997). There are a few factors contribute to sound perception likes sound source, operating situation of product and the person feeling using the product. Therefore, sound quality of a product does not depending on product's properties (Blauert, J., Jekosch 1997) but SQ is more related to listener perception which is exposed to the product.

2.5 Psychoacoustic

Psychoacoustics analysis is one type of objectives evaluation of sound quality. In acoustics, psychoacoustics is one of scientific study of acoustics waves related to auditory events. The psychoacoustics study focuses on understanding people's reactions to physical change of the sound such as pressure fluctuations in the air. Based on of literatures, psychoacoustics is related to the perception of an objective internal scale illustrated at external objective physical metrics of sound (Bodden 1999, Lyon 2000, Blauert 2003). Parameters of acoustical waves and attributes of auditory events also related to psychoacoustics (Jekosch 1997). The measurement methods of psychoacoustics are related to how humans actually hear sounds, which is doubted by the industry in general because engineers are not fully confident with research related to psychological study (Bodden 1999) .

Application of sound quality analysis is a common method in quality evaluation of a product. Most of studies focus on subjective evaluation compared to objective evaluation due to requirement of complicated and sophisticated technology in objective evaluation (U , 1997) . One of example is a study by Persson which is related to psychoacoustic characters of relevance for annoyance of wind turbine noise (Medicine 2002). The study was carried out based on 25 subjects exposed to five different wind turbine noises at the level of 40 dB. Subjective ratings of annoyance, relative annoyance and awareness duration of the noises were carried out after 10 minutes exposure. The limitation of subjective evaluation is not applicable to small changing in sound properties due to limitation of human ear to capture the changing (Bodden 1999).

Objectives evaluation is getting popular among of the manufacturer of ….. because its measurable indicator (Zwicker 2007). There a few studied based on psychoacoustics objective evaluation. In 2009, Arne Nykänen carried out a study about sound quality of automobile power windows (Nykänen & Sirkka 2009). The study was focused on three psychoacoustics parameters which are loudness, sharpness and fluctuation strength. The results show low loudness, sharpness and motor speed fluctuations led to perceived high product quality. Other study was carried out by Catarina Mendonça on noise perception, psychoacoustic indicators, and traffic noise (Mendonça 2012). Several sound measures, weightings and psychoacoustic parameters were discussed and compared. The author proposed loudness measurement according to Zwicker (2012) as a standard for environmental noise assessment, in detriment of the widely accepted A-weighted Leq. From the study, other sound measures might correlate with annoyance, but not as robustly across all pavement types. A similar effect is found for vehicle detection. Crucially, each pavement is differently predicted by the psychoacoustic values, revealing different timbre characteristics which are still not well represented in common psychoacoustic algorithms.

Combination objectives and subjective evaluations in evaluation of product was carried out by Silke in psychoacoustics analysis of HVAC noise with equal loudness (Hohls et al. 2014). The sound field developed by the heating, ventilation and air conditioning system (HVAC) affects the perceptible sound field inside the car cabin. For identifying the relevant psychoacoustic parameters for assessing the sound quality of HVAC noise, a listening test, using the preference paired-comparison technique, was performed on seven sound samples of different vehicles in the defrost mode. The sounds were equalized in their loudness on an average level. Thus, the aim of this study was to analyze the correlation between the listeners' preference and additional parameters beside the dominant parameter loudness. It was found that the sharpness, the articulation index and the roughness determine a preference decision when the loudness is eliminated from the sound samples compare to listing test.

Based on the previous findings, psychoacoustics objective evaluation is used to carry out the study of speech quality analysis for two-way radio subjected to induced wind noise. There are three psychoacoustic parameters used in the evaluation which are roughness, sharpness and loudness. Psychoacoustics annoyance is calculated based on the three psychoacoustics parameters.

2.5.1 Roughness

Roughness is a parameter to measure sound quality. It describes the subjective judgment for a sound design of sound impressions (Head acoustics 2006). As the roughness increases, noise emissions also increase. Roughness is suitable to be perceived at faster variations. It is related to the modulation frequency, modulation ratio, central frequency and sound pressure level. Roughness occurs whenever a time-variant envelope exists within critical band. The unit of roughness is asper. One asper unit comes from a tone with physical characteristics 1kHz, 60 dB and 100% modulated at 70 Hz (Karjalainen n.d.). Roughness is decreasing towards lower and higher modulation frequency. An application of roughness in the case of slow envelope variations (below 15 Hz), where the fluctuation of loudness changes resulting in capable to be detected by the human ears but the ears are no longer capable to detect the increasing modulation rate (other sound impressions are perceived, such as “R-roughness” (for rates around 20 Hz), which then changes into the actual roughness impression) (Head acoustics 2006).

When the modulation frequency reaches below 15 Hz the perceived loudness fluctuations start to overtake sensation of roughness. At low modulation frequencies between 1 to 20 Hz, any changes in loudness intensity will cause loudness fluctuation